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Abstract

Continuously increasing consumption of material goods drives current resource and environmental crises, including climate change and loss of biodiversity. Although technology offers solutions, their development and adoption is not at the speed required to address these crises. Therefore, demand side responses have to be triggered using policies, with economists suggesting mainly the use of price signals. However, both the effectiveness and the political acceptability of taxation have been questioned, especially since increases in fuel prices during the last decade in both Europe and North America have not yielded the expected reductions in the fuel economy and after the vigorous opposition to the ambitious increases in fuel taxes, for example in France. The present paper offers an explanation for the reduced effectiveness of environmental taxation by focusing on relatively high-income individuals whose consumption of highly polluting material goods is driven by motivations to improve their social status. Furthermore, the paper shows that complementing the tax with information provision aiming at moderating status seeking overconsumption improves social welfare. Decoupling consumption of highly polluting material goods from social status in individuals' well-being, through informative advertisement campaigns, could have a substantial environmental effect directly and also indirectly by improving the effectiveness of taxation.

JEL codes: Q53, Q58, D62, D82

Keywords: status-seaking, replicator dynamics, information provision, environmental taxation

Declarations of interest: none

1 Introduction

A number of influential studies in the seventies have sounded loud warnings regarding overexploitation of natural resources and environmental degradation.[1] Although the continuously increasing consumption of resources that followed did not yield the predicted devastating shortages in raw material, it indisputably placed huge pressure on specific resources and environmental services. During the twentieth century, as reported in Arrow et al. (2004), world population grew by a factor of four, industrial output increased by a factor of forty, energy use has increased by a factor of sixteen, annual fish harvesting by a multiple of thirty five and carbon and sulfur dioxide emissions by a factor of ten. There is mounting evidence showing that increased global consumption of material goods contributes significantly to environmental crises, including climate change and loss of biodiversity, as well as to local problems related to flow pollution, such as atmospheric pollution and pollution of local water bodies.

Tackling these problems cannot be delegated solely to technological innovation, especially due to the urgency of the situation, and thus, it is particularly important to examine consumers' contribution, induced both by incentives-based policies and increased awareness. The vast literature on environmental policy examines the effectiveness of market-based instruments, standard setting and more recently environmental awareness raising campaigns. With few exceptions,[2] the literature does not consider environmental policies that attempt to affect the social aspects of individuals' consumption.

In this paper we incorporate in consumer's objective function (well-being) her response to other individuals' level of consumption. In particular, we consider the case in which consumers increase their level of consumption in response to an increase in average consumption, so as to attain a higher social status. We allow the social component in consumer's well-being to vary among individuals and we further assume that each one can change the social aspect of her behavior by adopting that of a more "successful" individual, through a replicator dynamic process. Therefore, total consumption, and thus, pollution depends on each individual's level of consumption and

[1] Meadows et al. (1972) and Ehrlich and Ehrlich (1976).

[2] See, for example, Nyborg (2003) and Brekke et al. (2003).

the share of differently behaving individuals in the population. Within this framework we examine the effectiveness of environmental policy. We show that environmental taxation creates perverse effects by increasing the share of the highly consuming group of individuals, limiting thus its effectiveness. This lead us to examine the use of information provision aiming at reducing the importance of the social component in consumer's well-being as a complementary policy instrument. We show that a combination of these two policy instruments maximizes social welfare.

Motivation

To coin any increase in consumption as overconsumption is simplistic since consumption levels differ widely across different parts of the world and groups of people, depending on wealth, income and preferences. Furthermore, the type and magnitude of consumption's environmental impact differs substantially among different types of goods. In particular we are interested in relatively affluent consumers whose income allows purchases that go beyond the satisfaction of their basic needs to what it has been defined in the literature as positional (Frank, 1985), or status goods (Bisin and Verdier, 1998). This literature recognizes that the value some individuals derive from the consumption of certain goods depends strongly on how their own consumption compares with other peoples' level of consumption.[3] That is, their consumption decisions are heavily motivated by consumption's expected effect on their social environment. These consumers are not confined only to rich countries anymore but are also located in developing and in transition countries and according to various studies account for a large and increasing share of global population and consumption.[4] In the

[3] The literature on status-seeking consumption originates with Veblen's work on conspicuous consumption (Veblen, 1994) and Duesenberry's 'relative income hypothesis' (Duesenberry, 1949). According to Harsanyi (1980) ".. apart from economic payoffs, social status (social rank) seems to be the most important incentive and motivating force of social behavior." A very good presentation of the main ideas from sociology and their economic applications is given in Weiss and Fershtman's (1998) survey. The role of preferences for social status has been studied, relative to their effect on the allocation of resources by Fersthman and Weiss (1993), on savings and the accumulation of human capital by Cole et al. (1992), and relatively to their effect on endogenous growth models by Corneo and Jeanne (1996). Bernheim (1994) examines a model of social interaction, while Bisin and Verdier (1998) study the formation of preferences for 'social status' as the result of intergenerational transmission of cultural traits.

[4] The new consumers emerged in significant numbers in the early eighties, and their major increase occurred largely during the nineties. Myers and Kent (2002) report 1.1 billion of "new consumers" in 17 developing and three transition countries on top of the 850 million long-established consumers in rich countries. A widely cited Coldman Sachs (2008)

present paper we are concerned about the old and new affluent consumers' excessive consumption of material goods for the purpose of improving their social status.[5]

Although the disproportionate impact of the global population's wealthiest part on environment is well documented,[6] we do not claim that affluence or status seeking necessarily leads to unsustainable consumption: High incomes are likely to allow people to purchase higher quality, more durable material goods with an overall lower environmental impact. Furthermore, people may choose to channel their increased income on less polluting material goods (such as cleaner cars) or nonmaterial services (education, cultural services), or even donations to environmental groups. Also, we do not claim that lower income people ignore social status.[7] However, the adoption of more environmentally friendly preferences still remains restricted primarily to developed countries and has yet to register a significant effect on pollution reduction.[8] On the contrary, it is clear that a large and continuously growing part of global population possesses the means and seeks social recognition through the consumption of highly polluting material goods.

In attempting to improve their relative position in society, status seekers increase their own consumption which in turn raises the average level of

study estimates that this group of consumers (income bracket equivalent to US$6,000-$30,000 in PPT terms) increases by 70 million people each year a trent that if it continues will result in over 2 billion of new consumers by 2030. For more recent information on the growing importance of middle income new consumers see Kharas (2017) and WEF (2020).

[5]The importance of conspicuous consumption has also been shown empirically by, for example, relating such consumption to excessive spending on weddings and other events in developing countries (Banerjee and Duflo 2008), the wealth gap between blacks and whites in the United States (Charles et al., 2009) and to personal bankruptcy decisions (Agarwal et al., 2016). More recently Bursztyn et al. (2018) provide field-experimental evidence of the existence of status goods using a sample of upper-middle-class bank customers in Indonesia, one of the home-countries of what we called above "new consumers".

[6]For example, Oxfam (2020) reports that, in 2015, the world's wealthiest 10% were responsible for around half of global carbon dioxide emissions, while the top 1% were responsible for 15% of emissions, nearly twice as much as the world's poorest 50%, who were responsible for just 7%.

[7]See the discussion in Brekke (1998) as to whether status seeking is primarily to be found in rich societies.

[8]Despite the fact that many studies find that consumers have a positive attitude towards environmental protection (Ellen et al., 2006), the market share of green products remains very low, not exceeding 3% of the total market (Bray, Johns and Killburn, 2011). A large body of literature attempts to explain the gap between intention and actual purchasing behavior (Vermeir and Verbeke, 2008). And even though the share of green products has increased substantially during the last decade in certain developed countries, its effect remains still relatively small.

consumption, lowering thus the relative position of similar thinking agents. Thus, the existence of status desire implies that each individual's action has negative external effect on other agents' utility, adding an additional externality to the environmental one. This leads to continuously increasing consumption, or to what has been termed as a "positional treadmill" or consumption "rat race" (Frank 1985).

The basket of status or positional goods includes those supporting diets of highly processed foods and meat; big housing; high fuel consuming vehicles; personal computers and other consumer electronics produced under the strategy of planned or programmed obsolescence; fashionable apparel and accessories such as jewelry.[9,10] Intertemporally, status seeking is also related to high turnover of the consumer's stock of goods in this basket. A strong indication of the importance of purchasing goods even purely for their positional impact, is the fact that the market for fake designer products is worth tens of billions of dollars globally: consumers are willing to purchase goods that they know are of low quality just to imitate higher status. Although, as noted above, we recognize the gradual development of green consumerism, the evidence indicates that the great majority of new affluent consumers globally adopt the old, environmentally harmful, overconsuming behavior of which the social component is a major driver. Thus, at least for the immediate future, the main environmental pressure is expected to come from individuals eager to make their new income visible by purchasing environmentally harmful material goods.

Contribution

In the present paper we incorporate social status into our model by assuming that individuals' well-being has two components: a private and a social, each weighing differently across consumers. For simplicity we assume that there are only two groups of consumers: those that assign a positive weight on the social component of utility and those that care only about

[9]For example, Charles et al. (2009), based on a survey they conducted, consider the following categories as status goods: apparel, personal care, and vehicles. They also recognize the importance of housing, but they exclude it from their study for reasons of racial differential treatment in the housing market. Alpizar et al. (2005) find, using experimental and survey-based methods, that apart from houses and car ownership, relative consumption is also considerably important for vacation and insurance.

[10]A number of studies broadly specify the sectors of housing, food and beverages, mobility and tourism as the primary sources of environmental pressure coming from consumption (for example, for the EU see EEA, 2010 and EEA, 2013).

their own private utility. We assume that both groups possess the same level of income. Furthermore, we group consumption goods and services in two broadly defined baskets: The first comprises of material goods that provide intrinsic private utility up to a certain level, but their abundance is considered by the first group of consumers to signal higher social status. The second basket includes goods that provide self-centered utility and are necessary to support a basic standard of living, education, health care, entertainment and other services which increase the standard of living, and goods that generate lower environmental damage, like eco-friendly substitutes of plastic, such as glass, platinum silicone, natural fibber cloth, wood, pottery and other ceramics.[11] Goods in the latter basket have lower environmental impact relative to the former, and, for simplicity, we assume that only goods that can be used to project status generate pollution. Both groups of consumers purchase goods from both baskets, with the status seeking group consuming higher quantities of the first, more polluting, basket.

Degradation of environmental quality, generated by pollution, affects both types of agents. However, given that each consumer acts individually, we assume, following the literature, that each takes the pollution level as given. Thus, although their utility is decreasing in pollution, their consumption is not responsive to pollution. This assumption simplifies the analysis considerably while it does not affect the results, since individual responses, without "warm glow" effects or other type of altruistic motives, do not affect greatly total pollution.

Given the interdependency of individual consumers' choices through average consumption, we consider the choice of seeking status through increased consumption as a choice of strategy, which can be changed through time as a result of a learning process akin to a replicator dynamics. Since the share of each group of agents in the total population determines the extent of overconsumption, we examine the evolution of consumers' choice of strategy. Each agent's choice of assigning a positive or zero weight on the social component of her utility is a strategic choice and separate from her preferences, which remain stable even if the agent changes her choice of seek-

[11] As noted above, some of the goods included in this basket could be used to attain social status within groups that place high value on environmental protection. We reiterate that the data do not support that such groups are numerous enough yet to have an important global effect. Future research could examine the case in which status provision shifts from the environmentally harmful to friendly goods.

ing to improve her social status through material consumption. We assume that the agent's decision to change social strategy depends on the difference between her own and the average payoff. Furthermore, we assume that the importance individuals place on status can be influenced by public policies, including public information campaigns on the detrimental environmental effects of overconsumption. This informative advertisement is provided by the government in an attempt to decrease the pollution externality, along with a tax on consumption.

As expected, we confirm that status seekers consume higher quantities of the goods that signal status. However, the well-being of the consumers that care about status could be lower for a wide range of parameter values. In the absence of any type of environmental regulation, in the steady state, either all consumers will be status seekers or there will be a polymorphic steady state in which both types of consumers co-exist. Employing particular functions for consumers' well-being, we are able to define analytically the steady states and perform comparative analysis for the most important parameters. Furthermore, given that status seekers' overconsumption exacerbates the environmental problems, we discuss the effectiveness of two types of policy instruments: incentives-based, and behavior-changing which aim at reducing the importance of the status-seeking component in consumers' well-being. In particular, we use a per-unit standard Pigouvian tax, while we denote the behavior-changing instrument as public information provision, briefly discussed in the next paragraphs. We find that the effectiveness of environmental taxation can be compromised under certain conditions leading to an increase in the relative well-being of status seekers, which, in turn, increases their share in the population. Public information campaigns that effectively convince status seekers to change their social strategy could be an important policy instrument to complement taxation. The problem of defining the optimal choice of policy instruments is highly non linear and deriving analytical solution is not possible. Resorting to numerical simulations, we are able to show that indeed a combination of the two policy instruments yields an improvement in social welfare.

Behavioral change policy instruments

The society described above faces two types of externalities: the environmental externality related to the pollution from C, and the overconsumption externality. Apart from market incentives, the regulator can use a range of policy instruments to correct these externalities, including, public information campaigns, command and control measures and bans, and nudges.[12] The policy instrument which, for brevity, we denote as information provision throughout the paper incorporates all forms of policy instruments that stimulate behavioral change. These policy instruments have been used to tackle a broad range of social issues, such as excessive drinking, physical activity, obesity, organ donation, crime, energy savings, climate change, and smoking.

We provide examples, focusing on the case of tobacco control, since for the solution of this problem all types of policies have been used for a long period of time. Information campaigns include messages aired or printed, paid by the government, which shared evidence from medical research and appealed to social responsibility, as well as mandated messages on products, such as printed messages on cigarette boxes, like, "Smoking causes lung cancer". Smoking bans in public places, banning visual displays, including graphic warnings and forcing plain packaging, are methods that have been used to nudge people away from smoking.[13] Nyborg (2003) summarizes the results of a number of papers related to a research project at Statistics Norway, and presents examples of how public policy did change individual behavior related to smoking in private homes, recycling of household waste, and voluntary community work, by affecting social or moral norms. Nyborg (2003) also points out to the difficulties of exploiting the subtle ways in which public policy affects individual behavior.

Given the complexity of the working of behavior changing policy instruments, we do not model in detail the mechanism through which information provision affects individuals' attitudes towards status seeking. It is also beyond the scope of the current paper to suggest specific examples of behavior changing policy instruments to reduce the importance of status seeking in consumers' well-being. Instead, we assume that a combination of interventions such as those described above, revised appropriately, can affect individuals' attitudes towards status seeking. The goal of this paper is to initiate the discussion of the important, despite being unintended,

[12] The groundbreaking work of Thaler and Sunstein (2008) introduced the word "nudge" in policymakers' vocabulary, describing how nudges can be used in designing public policy, and the revised edition (2021) provides examples of applications on a variety of issues. Howlett (2018) discuses all types of behavioral policy instruments in detail.

[13] Alemanno (2012) provides a review of behavior changing policies for tobacco control.

environmental consequences of status seeking behavior, and contribute to the growing literature of integrating social aspects of human behavior into economic theory and policy design.

Literature review

Our work is based on the literature on conspicuous consumption, briefly reviewed in footnote 2. A number of important contributions examine the effects of taking into account social aspects of individuals' behavior, on taxation, discounting, optimal growth and environmental policy. Aronsson and Johansson-Stenman (2021), find that the incentive to reduce overconsumption resulting from status seeking is reduced substantially if involuntary unemployment is taken into account. They identify cases in which positional externalities could even lead to lower marginal taxation. Aronsson and Johansson-Stenman (2008), in a model with two productivity types of individuals, examine the effect of status seeking on the optimal tax structure and public good provision. The main result is that when overconsumption externalities are considered, the marginal income tax rates increase. In a similar model, Aronsson and Johansson-Stenman (2018) find that the optimal income tax that a paternalist and a welferist government choose are very similar. This is because the overconsumption externality, which concerns the welferist government, is similar to the individual's own behavioral failure, as perceived by the paternalist government. Using a similar model, Aronsson and Johansson-Stenman (2017), introduce the notion of genuine savings and develop a measurement of welfare change. They show that, if consumption increases along the general equilibrium path, overconsumption externalities imply that genuine savings overestimates the change in social welfare. Within a similar framework, in which individuals care about relative consumption, Johansson-Stenman and Sterner (2015) find that the social exceeds the private discount rate, and it is lower than the Ramsey rate. Despite the fact that the above papers do not consider pollution externalities from consumption, their results are in the same direction as the ones in our paper, emphasizing the importance of incorporating the social dimension of consumers' behavior into policy design.

The early contribution of Howarth (1996) incorporates social status concerns into individuals' utility and finds that the efficient pollution tax exceeds the standard Pigouvian tax in order to reduce overconsumption. More recently, Dasgupta et al. (2016) examine the effectiveness of environmental policies when socially embedded preferences are taken into account. They consider the case that consumption is competitive, as in the present paper, when is used for conformity and they also examine the case of socially directed preferences, i.e. taking into account altruistic behavior. Although the latter work is more closely related to ours, the research questions are different. While they are concerned with defining optimal taxes in a broad range of socially embedded preferences in a static framework with identical agents, we focus on status seeking behavior by a segment of the population and we examine the effect of environmental policies on the evolution of the share of status seekers through time.

There are a few other papers that examine the effect of social norms on environmental quality. Nyborg et al. (2006) model green consumers by including moral motivations which create interdependencies between the demand of different individuals. Chander P. and S. Muthukrishnan (2015) show that collective action by green consumers,who derive benefits from consuming environmentally cleaner products, can reduce pollution and improve social welfare in the same manner as pollution taxes or subsidies for reducing pollution can. The effect of status concerns on common pool renewable resource has also been examined (Long and McWhinnie, 2012; Benchekroun and Long, 2016).

The paper also relates to the literature on the role of information provision to induce more environmentally friendly behavior. The role of information provision as a policy instrument to supplement environmental taxation has been examined in a static framework in Petrakis et al. (2005) and in a dynamic framework in Sartzetakis et al. (2012). The information provided by the government, shifts consumers towards less polluting alternatives, reducing the rate of the tax and improving welfare. More recently Hong and Zhao (2014) examine the role of information provided by environmental groups in inducing International Environmental Agreements. More closely related to the present paper is Kallbekken et al. (2010), which considers appeals to social norms as a policy instrument to address consumption externalities. They find that when the existing norm helps to shift consumption towards the socially optimal level of consumption, taxation welfare dominates appeals to social norms as a policy tool, while when the norm shifts behavior away from the socially optimal the opposite is true.

The rest of the paper is organized as follows. The next Section lays out the general framework of our analysis. Section 3 presents the optimal choices of the representative agents and Section 4 the replicator dynamics. Section 5 presents a particular specification of the model which allows the derivation of analytical solutions, first in the absence of policy intervention and subsequently for selective, exogenously determined, policy intervention, allowing us to discuss the effectiveness of policy instruments. Section 6 defines the optimal choice of policy instruments and Section 7 concludes the paper.

2 The model

For the purposes of our analysis we group all goods and services into two bundles: one containing less-polluting goods and services which we denote by m[14] and another bundle comprising of highly polluting goods whose consumption indicates status, denoted by C[15]. For simplicity we treat the two bundles as composite goods. We further normalize their impact on pollution, by assuming that the composite good m generates zero pollution.

We examine a population of individuals of size n, whose consumption decisions are interdependent. We model this interdependency by assuming that agents' well-being depends not only on their personal enjoyment from consuming m and C, but also on the population's average consumption of C. Furthermore, their well-being is affected by the damages aggregate pollution inflicts on them. For simplicity we assume that there are only two types of consumers defined, given the focus of the paper, according to the choice of their strategy: Type 2 agents, hereafter called green agents, consume C only for the sake of their own satisfaction, enjoyment, or personal meaning. Type 1 agents, hereafter called status seekers, apart from personal satisfaction from consuming C they are motivated by the desire to earn social recognition (status). We will formalize this by assuming that status agents' well-being depends not only on their own consumption but also on the average consumption of C. Acting in this manner, status seekers consume beyond their personal needs, generating relatively more pollution.

[14] This bundle includes goods covering basic needs and other low polluting goods and services.

[15] This bundle includes products purchased for their symbolic and social value rather than only for their "intrinsic utility", that is, goods associated with choice of life-style rather than covering basic needs.

Our working assumption is that agents can change their strategy through a "learning process" which comprises of comparing the utility they derive from their current strategy to that derived by the alternative strategy; if the alternative strategy offers higher payoff, they will switch strategy. Furthermore, we assume that agents may also change strategy as a result of policies implemented by the government.

We assume that the total population of agents n remains constant over time, and we denote by $n_1(t)$ and $n_2(t)$ the population of type 1 and type 2 agents at time t respectively. We also define $x(t) = \frac{n_1(t)}{n}$ the fraction of type 1 agents and thus, $1 - x(t)$ is the fraction of type 2 agents. We normalize assuming $n = 1$, which implies $x(t) = n_1(t)$.

We denote by $P(t)$ the pollution level at time t. For simplicity, we assume flow pollutants which are proportional to total consumption of C at each time period, $TC = n_1C_1 + n_2C_2$, which under the normalization $n = 1$, is equal to average consumption $\bar{C} = xC_1 + (1-x)C_2$.[16] Thus, the pollution path is, $P(t) = \bar{C}\,(t)$, assuming for simplicity that emissions per unit of output is unity. Pollution inflicts damages on individuals assumed non-decreasing and convex in P,

$$D(t) = \gamma P^2\,(t)\,, \tag{1}$$

where, $\gamma/2$, is the slope of marginal damage.

The well-being of consumers consists of the utility, the personal enjoyment, they derive from the consumption of C and m, the disutility they experience due to environmental damage D and, in the case of status seeking agents, the enjoyment they derive from social status, which is assumed to depend on the difference between own and average consumption of C. We use the following formulation of such type of well-being functions,[17]

$$w_i = u_i(m_i, C_i; P) + v_i(C_i - \bar{C}), \tag{2}$$

where $i = 1, 2$ indicates the type of consumer and v is concave in the differ-

[16]It should be noted that the assumption of flow pollutants affects the results regarding the structure and the efficiency of the policies chosen by the regulator. However, it simplifies considerably the analysis relative to the case of stock pollutants which should be examined in future research. Appendix 2 provides a suggestion for future work on how to incorporate stock pollutants into the model.

[17]Similar kind of functions have been used for exapmle by Bisin and Verdier (1998), without environmental damages, and Dasgupta et al. (2016), with environmental damages.

ence, $C_i - \bar{C}$. The utility function u is a standard utility function, increasing in both m, $\frac{\partial u_i}{\partial m_i} > 0$ and C, $\frac{\partial u_i}{\partial C_i} > 0$, and decreasing in P, $\frac{\partial u_i}{\partial P} < 0$. Without loss of generality we may assume $v(0) = 0$. Given the definition of green consumers, $v_2 = 0$, for any C_2. Furthermore, we assume that if average consumption $\bar{C}$ increases, the status seeking consumers' well-being decreases, $\frac{\partial w_1}{\partial \bar{C}} < 0$, and that the marginal well-being of average consumption is increasing in C_1, $\frac{\partial^2 w_1}{\partial \bar{C} \partial C_1} > 0$. These assumptions imply that the optimal choice of C_1 is increasing in $\bar{C}$, thus modelling a catching up with the Joneses effect. Finally, we assume that marginal utility of consumption is more sensitive to C_1 than to $\bar{C}$, that is, $\left|\frac{\partial^2 w_1}{\partial C_1 \partial \bar{C}}\right| < \left|\frac{\partial^2 w_1}{\partial C_1 \partial C_1}\right|$.

3 Optimal choices for the representative agent

In order to focus our attention on the polluting composite good C, we assume that the utility function of both types of consumers is quasilinear in m. Neutralizing income effects is a reasonable assumption given that we focus on a consumers' group with specific income and we do not examine changes in income. For simplicity, we assume that both types of agents have the same income. We also assume that all goods are produced in perfectly competitive markets under constant returns to scale. Thus, before-tax prices are equal to the constant marginal and average cost of production. To simplify further, we normalize setting the price of m equal to 1, so that p denotes the relative price. Recalling the assumption of zero pollution from m, there is no need for corrective taxation on m and thus, m's after tax price is unity.

Given these assumptions, the constrained maximization problem of type 1 representative agent's well-being at time t is,

$$\max_{(m_1, C_1)} w_1 = u_1(C_1; P) + \mu_1 m_1 + v_1(C_1 - \bar{C}),$$
$$\text{subject to: } \bar{p}C_1 + m_1 \leq Y,$$

where μ_1 indicates type 1's agent's constant marginal utility of m; Y presents the sum of agent's income, y, plus any lump-sum redistribution of the tax revenues, s, that is, $Y = y + s$; $\bar{p}$ is the after tax price of C, that is, $\bar{p} = p + \tau$, where p is the price and τ is a per unit tax imposed on C by the government in an attempt to regulate pollution and overconsumption due to status seeking.[18] Given that we set m as the numeraire good, μ_i is equal to the marginal utility of income. The intention is to allow differences between the two types of agents' marginal rate of substitution $MRS_{C,m}$, so as to examine both effects of environmental taxation on C's consumption: the usual direct reduction and the indirect effect through changing the share of status seeking agents by affecting the relative well-being at the equilibrium.

We further assume that both types of consumers take $\bar{C}$, and thus, P, as given when they make their choices. The individual agent realizes the minimal effect her consumption has on aggregate/average consumption, and thus, on P, and ignores it: Assuming that status seekers take $\bar{C}$ as given when choosing C_1, implies that they do not choose strategically in order to manipulate $\bar{C}$. Assuming that both status and green agents take P as given, implies that each agent, regardless of her type, ignores the damage her own consumption inflicts on her, which is a reasonable assumption given that the own effect is very small relative to the externality created.

The first order conditions of the Lagrange function corresponding to the above problem yield,

$$u_{C_1} + v_{C_1} = \lambda_1 \bar{p}$$
$$\mu_1 = \lambda_1$$

where $u_{C_1} = \frac{\partial u_1}{\partial C_1}$, $v_{C_1} = \frac{\partial v_1}{\partial C_1}$ and λ_1 denotes the Lagrange multiplier. The above system yields type 1 agent's demand for C, as a function of the exogenous parameters $\bar{p}$, $\bar{C}$ and P at t. Assuming that interior solutions exist for this problem, we may implicitly determine status agent's demand as,

$$C_1^*(t) = c_1^*\left(\bar{C}(t), \bar{p}(t); \mathbf{z}_1\right). \tag{3}$$

where, $\mathbf{z}_1$ denotes the vector of preference parameters including μ_1.

The representative green agent solves a similar to the above maximization problem, with the only difference that $v_2(.) = 0$. In a similar manner

[18] The different nature of the two externalities require different treatment: the environmental externality a per unit tax while the overconsumption externality an ad valorem tax (see Dasgupta et al., 2016). Since the imposition of two separate taxes seems not very realistic and the emphasis of the present paper is on the evolution of status seeking behavior, we assume only one type of tax is levied.

as above, green agent's demand for C is,

$$C_2^*(t) = c_2^*\left(\bar{C}(t), \bar{p}(t); \mathbf{z}_2\right). \tag{4}$$

Both (3) and (4) are assumed to hold at any time period t.

Notice that C_i^* depends on the equilibrium average consumption,

$$\bar{C}^*(t) = x(t)C_1^*(t) + (1 - x(t))C_2^*(t). \tag{5}$$

Therefore, it is evident that the system of equations (3), (4) and (5) can be solved for status and green agents' consumption and the average consumption $\bar{C}(t)$, as functions of the price p, the tax rate τ, the fraction of status agents x and time t. That is, we can define, $C_i^*(t) = c_i^*(\bar{p}(t), x(t))$ and $\bar{C}^*(t) = \bar{c}^*(\bar{p}(t), x(t))$. Substituting these expressions into each type of agent's well-being, given in (2), we obtain,

$$W_i(t) := f_i^*(\bar{p}(t), x(t), Y; \mathbf{z}_i), \tag{6}$$

the indirect well-being at time t of type $i = 1, 2$ agent.

4 Replicator dynamics

We assume that agents change their strategy regarding status seeking as a result of a learning process, akin to a replicator dynamics, defined in evolutionary biology (Taylor and Jonker, 1978 and Schuster and Sigmund, 1983) and used in evolutionary game theory. The replicator dynamics based on imitation, asserts that a strategy's share in the population is increasing linearly with the net payoff that this strategy yields relative to the alternative strategy (see Xepapadeas, 2005, and Schlag, 1998 and 1999). In terms of our framework, agents choose whether to adopt a status seeking strategy or not, based on the relative utility they derive at equilibrium. More precisely, we assume that the incentive of each agent to change strategy depends on the difference between her own and the average well-being defined as, $\overline{W}(t) := x(t)W_1(t) + (1 - x(t))W_2(t)$.

We assume that, at each time period, each agent of either type learns the average payoff. She then compares her own payoff, that is, her indirect well-being $W_i(t)$, $i = 1, 2$, to $\overline{W}(t)$. For the status agent, for example, the incentive to change strategy is proportional to the difference $W_1(t) - \overline{W}(t)$. The greater the difference between her own and the average payoff is, the larger is the incentive to retain her strategy and for a green agent to change her strategy, thus, increasing the share of status agents in the population. Accordingly, the replicator equation is,

$$\dot{x}(t) = dx(t)/dt = x(t)\,\beta\left(W_1(t) - \overline{W}(t)\right),$$

where β is a positive parameter.

Furthermore, we assume that the government in an attempt to decrease pollution damages could employ two policy instruments: an environmental tax τ, already incorporated into the price $\bar{p}$, and informative advertising θ, which is financed by the government in order to communicate the message that overconsumption is a major pollution driver, providing thus, incentives to move away from the status strategy. Consumers tend, on the one hand, to observe others' behavior and mimic the "privately successful" one, while on the other hand, ignore the effect of their consumption on the environment. Thus, public advertisement has the important role of revealing to consumers information regarding the contribution of status-seeking overconsumption to environmental damages. Information is effective only if there exists a positive number of green agents, so that status agents can associate the information to existing consumption behavior. The higher is the share of green agents, the more effective is informative advertisement.

According to the above discussion we assume that informative advertisement decreases the utility status agents derive from using C to attain status. That is, we assume that $\frac{\partial v_i(C_i - \bar{C})}{\partial \theta} < 0$, and thus, $\frac{\partial W_1(t)}{\partial \theta} < 0$. Given that, $W_1(t) - \overline{W}(t) = (1 - x(t))\,(W_1(t) - W_2(t))$, $\dot{x}(t)$ is written as,

$$\dot{x}(t) = x(t)(1 - x(t))\left[\beta\left(W_1(t) - W_2(t)\right)\right]. \tag{7}$$

If the share of green agents in the population is not zero, $x(t) < 1$, then a positive flow of information could reduce the share of status agents in the population, where $\frac{\partial v_i(C_i - \bar{C})}{\partial \theta}$ represents the incentive that informative advertisement provides to status agents to change their strategy. If everybody is a status seeker then informative advertising will have no impact.

Note that (7) is deceptively simple, since the term $W_1(t) - W_2(t)$ depends on $x(t)$, as shown in (6). Substituting (6), for $i = 1, 2$, into (7) and setting, without loss of generality, $\beta = 1$, the replicator dynamics equation is,

$$\dot{x} = x(1-x)\left[f_1^*\left(\bar{p}(t), x(t), Y, \theta(t); \mathbf{z}_1\right) - f_2^*\left(\bar{p}(t), x(t), Y; \mathbf{z}_2\right)\right]. \tag{8}$$

Thus, the replicator dynamics equation is a function of the policy instruments τ and θ and the price p. As mentioned above, we do not model production explicitly and we assume that the price p is exogenously given, determined in competitive markets.

From (8) is evident that if each strategy's payoff is independent of its share, the evolutionary outcome will be a population completely dominated by one of the two strategies depending on the relative payoff. When individual payoffs depend on the share of each strategy, as (6) indicates, we could have polymorphic evolutionary stable strategy equilibrium. That is, the replicator dynamics equation (8) has two steady states at the boundaries $x_0^* = 0$ and $x_1^* = 1$, and possibly interior steady states $0 < x_i^* < 1$ such that $x_i^* = \arg\{f_1^*\left(\bar{p}(t), x(t), Y, \theta(t); \mathbf{z}_1\right) - f_2^*\left(\bar{p}(t), x(t), Y; \mathbf{z}_2\right) = 0\}$. In order to derive analytical results, we introduce specific functional forms for each type of agents' well-being. In the following Section we characterize analytically the possible steady states in the absence of policy intervention and discuss the effectiveness of the two policy instruments τ and θ.

5 Analytical solution with particular utility functions

We assume the following specific functional form for each of the two types of agents' well-being,

$$w_1 = a_1 C_1 - \frac{1}{2}C_1^2 + b\left[(C_1 - \bar{C}) - \frac{1}{2}(C_1 - \bar{C})^2\right] + \mu_1 m_1 - \frac{1}{2}d_1\gamma P^2, \tag{9}$$

$$w_2 = a_2 C_2 - \frac{1}{2}C_2^2 + \mu_2 m_2 - \frac{1}{2}d_2\gamma P^2, \tag{10}$$

where, $a_i,\ i = 1, 2$ indicates the maximum intrinsic utility each type of agent receives from consuming C, with $a_1 \geq a_2$; $b > 0$ is a parameter indicating the relative importance of status in type 1 agent's well-being, μ_i indicates the constant marginal utility of m, and $d_i > 0$ indicates each type of agent's perception of pollution damage, with $d_2 \geq d_1$.[19] In this Section we assume that the two types of agents have different preferences, that is, $a_1 > a_2$, $\mu_1 < \mu_2$ and $d_1 < d_2$. That is, status agents, apart from using C to signal status, they derive higher utility from C relative to green agents and downplay environmental damages. These assumptions are made to assist us in discussing the effectiveness of policy instruments and they are dropped in order to perform welfare analysis in the next Section. The above specification satisfies the conditions set following (2). It should be noted that the condition $\frac{\partial w_1}{\partial \bar{C}} = -b + b(C_1 - \bar{C}) < 0$, implies (given $b > 0$) that $C_1 - \bar{C} < 1$ or $C_1 - C_2 < \frac{1}{1-x}$.

Using the above specification of individuals' well-being we derive the optimal consumption choice for each type of agents, the average consumption and the difference between the two types of agents' consumption,

$$C_2^* = a_2 - \mu_2 \bar{p}, \tag{11}$$

$$C_1^* = a_1 - \mu_1 \bar{p} + \frac{b - b(1-x)\left(\Delta a - \Delta\mu\bar{p}\right)}{1 + b(1-x)} = a_2 - \mu_2 \bar{p} + B, \tag{12}$$

$$\bar{C}^* = a_2 - \mu_2 \bar{p} + xB, \tag{13}$$

$$\Delta C^* = C_1^* - C_2^* = B. \tag{14}$$

where, $B = A_1 + A_2 = \frac{b + \Delta a - \Delta\mu\bar{p}}{1+b(1-x)}$ with $A_1 = \frac{b}{1+b(1-x)}$, $A_2 = \frac{\Delta a - \Delta\mu\bar{p}}{1+b(1-x)}$, $\Delta a = a_1 - a_2 \geqslant 0$ and $\Delta\mu = \mu_1 - \mu_2 \leqslant 0$. Consumption of status agents consists of two parts: one that provides intrinsic utility, and another that increases well-being by improving social status, which is positive, assuming $b > 0$ and $0 < \Delta a - \Delta\mu\bar{p} < \frac{1}{1-x}$.[20] Both types of agents' consumption of C is decreasing in the after tax price, that is, an increase in the tax will decrease average/aggregate consumption of C. However, an increase in the tax will increase the difference between the two types of agent's consumption:[21] an increase in the tax reduces the consumption of green agents relatively more, and thus, it affects the replicator dynamic process. Furthermore, the differ-

[19] We assume agents in the two groups evaluate differently the damage inflicted on them by aggregate pollution. Their perceptions of environmental damage are not equal to actual damages. In performing welfare analysis, in Section 6, we will assume that both groups of agents have the same evaluation of environmental damage which is equal to the actual environmental damage the regulator is using in making decisions.

[20] The latter holds since it is a necessary and sufficient condition for $\frac{\partial w_1}{\partial \bar{C}} < 0$

[21] $\frac{\partial B}{\partial \bar{p}} = -\frac{\Delta\mu}{1+b(1-x)} > 0$, given that we assumed $\Delta\mu < 0$.

ence in consumption ΔC^* is increasing in b and in x, with $\frac{\partial B}{\partial x} > \frac{\partial B}{\partial b} > 0$, $\forall$ $x < 1$.[22,23]

Substituting (11), (12), (13) and (14) into (9) and (10) we derive the difference between the two types of agents' indirect well-being. For presentation purposes we divide the difference of agents' indirect well-being into three components: the difference between the two groups' intrinsic indirect well-being, $\Delta W_{\text{intrinsic}}$, the well-being status seekers derive from using the consumption of C as status indicator, ΔW_{status}, and the difference in the perception of environmental damages ΔW_{env}. The difference in agents' well-being, $\Delta W = W_1 - W_2$, is,[24]

$$\Delta W = \underbrace{\Delta a C_1^* + \Delta \mu m_1^* - \frac{B^2}{2}}_{\Delta W_{\text{intrinsic}}} + \underbrace{b\,(1-x)\left(1 - \frac{(1-x)\,B}{2}\right)B}_{\Delta W_{\text{status}}} - \underbrace{\frac{1}{2}\Delta d\gamma\left(\bar{C}^*\right)^2}_{\Delta W_{\text{env}}}, \tag{15}$$

where, $\Delta d = d_1 - d_2$.

We start our analysis focusing on agents' perception of social status, assuming homogeneous preferences, that is, $\Delta a = \Delta\mu = \Delta d = 0$. Then, (15) reduces to, $\Delta W = -\frac{B^2}{2} + b\,(1-x)\left(1 - \frac{(1-x)B}{2}\right)B$, with $B = A_1$. Therefore, for $b > 0$, the difference between the two types of agents' well-being could be either positive or negative, $\Delta W \gtrless 0$ if $x^{\min} \lesseqgtr \frac{1+b-\sqrt{1+b}}{b}$, which, for $0 < b < 1$, is in the range $\frac{1}{2} < x^{\min} < 2 - \sqrt{2}$. That is, for any given b, there is a limit in the status agents' share in the population beyond which their indirect well-being is smaller relative to that of green agents. The competitive nature of status seeking imposes a limit on the share of status seekers beyond which status seeking becomes less appealing. Assuming homogeneous preferences, this limit depends only on the importance of social status in agents' well-being, which implies that the after tax price has no effect on ΔW.

We now turn to the case of heterogeneous preferences and we examine each term in (15) separately. As expected, $\Delta W_{\text{status}} > 0$ in (15), since the term in parenthesis is positive as we have already assumed $B < \frac{1}{1-x}$. An

[22] We derive, $\frac{\partial B}{\partial b} = \frac{1-(\Delta a - \Delta\mu\bar{p})(1-x)}{(1+b(1-x))^2} > 0$, given that $B < \frac{1}{1-x}$, and $\frac{\partial B}{\partial x} = \frac{b[b+(\Delta a - \Delta\mu\bar{p})]}{(1+b(1-x))^2} > 0$.

[23] Note that ΔC^* gets its highest value for $x = 1$, $\Delta C^*_{\max}(x=1) = b + (\Delta a - \Delta\mu\bar{p})$, and its lowest for $x = 0$, $\Delta C^*_{\min}(x=0) = [b + (\Delta a - \Delta\mu\bar{p})]/(1+b)$.

[24] Appendix 1 provides the basic steps of the calculations.

increase in the after tax price increases ΔW_{status}, that is, $\frac{\partial W_{\text{status}}}{\partial \bar{p}} > 0$.[25] An increase in the tax will increase the spread between the status agent's and the average consumption, $C_1^* - \bar{C}^*$,[26] and therefore the satisfaction she enjoys from her increased social status.

The difference between status and green agent's intrinsic utility is negative, $\Delta W_{\text{intrinsic}} < 0$, under the assumption that green agents have a relatively higher preference for m, that is $\Delta\mu < 0$, except for relatively large differences Δa. If $\Delta a = 0$, status agents consume more C relative to green agents both because of their higher $MRS_{C,m}$ and of their strive to improve their status. Since the benefits from improving their status are counted in W_{status}, green agents' intrinsic utility is clearly higher. The effect of the after tax price $\bar{p}$ on $\Delta W_{\text{intrinsic}}$ depends on the relative size of the differences Δa and $\Delta\mu$. For $\Delta a = 0$ and $\Delta\mu < 0$, an increase in the tax reduces the gap between green and status agents' indirect intrinsic well-being. The intuition is as follows: The tax addresses both the environmental and the rat race externality. With respect to the intrinsic utility, the effect of the tax is to decrease status agents' consumption of C aligning thus their relative consumption of C and m to their intrinsic preferences and for this reason it reduces at a lower rate their intrinsic utility relative to the green agents' utility.

The sign of the last component ΔW_{env} in (15) is evidently determined by the sign of Δd. It seems reasonable to assume that green agents would be more sensitive to environmental damages, that is, $d_2 > d_1$. This is a very common representation of the differences among consumers' environmental awareness in the literature.[27] Under this assumption, $\Delta d < 0$ and thus, the environmental component in (15) is positive. This implies that the range of parameters for which $\Delta W < 0$, becomes smaller the larger is Δd. As it will be explained in what follows, within the mimicking framework employed in the present paper, this effect leads to some counterintuitive results. An increase in the tax reduces the size of ΔW_{env} since it reduces the average consumption.

The above discussion is summarized in the following Proposition.

[25] Note that, $\frac{\partial W_{\text{status}}}{\partial \bar{p}} = \frac{\partial W_{\text{status}}}{\partial B} \frac{\partial B}{\partial \bar{p}}$ with $\frac{\partial W_{\text{status}}}{\partial B} = b\,(1-x)\,[1-(1-x)B] > 0$ and $\frac{\partial B}{\partial \bar{p}} > 0$.

[26] From (12) and (13) we have $C_1^* - \bar{C}^* = (1-x)\,B$.

[27] See for example Constantatos et al (2021).

Proposition 1. *(i) Status seeking agents always consume more of C than green agents at the equilibrium, $C_1^* > C_2^*$.*
(ii) Assuming homogeneous preferences, $\Delta a = \Delta\mu = \Delta d = 0$, the share of status seekers x increases above one halve up to a limit imposed by the competitive nature of status seeking. In this case, a tax has no effect on x.
(iii) Assuming heterogeneous preferences, $\Delta a = \Delta d = 0$ and $\Delta\mu < 0$, the share of status seekers is smaller in the absence of taxation. In this case, an increase in the tax makes the status strategy relatively more attractive.
(iv) Assuming heterogeneous preferences, $\Delta a = \Delta\mu = 0$ and $\Delta d < 0$, the share of status seekers is larger in the absence of taxation. In this case, an increase in the tax makes the status strategy relatively less attractive.

As expected, the effect of an environmental tax τ on ΔW depends on the difference between the two types of agents' intrinsic preferences. If both types of agents have the same intrinsic preferences, that is, $\Delta a = \Delta\mu = \Delta d = 0$, the environmental tax has no effect on ΔW since it does not affect the difference between the two types of agents' consumption at the equilibrium. In such case, the tax will have the primary effect of decreasing both types of agents' consumption of C, but will not have any multiplier effects by affecting ΔW. For $\Delta a = 0$ and $\Delta\mu < 0$, that is, when green agents' relative evaluation of m is higher than that of the status agents, the environmental tax –in addition to the primary effect of decreasing aggregate consumption of C– will make the status strategy relatively more attractive. We turn now to examine the evolution of strategies described by the replicator dynamics equation (8).

5.1 Steady state in the absence of policy interventions

Before determining the optimally chosen values of the two policy instruments, environmental tax τ and informative advertisement θ, we define the steady state in the absence of policy intervention and we also examine combinations of policy instruments that can steer the economy to a desired, exogenously determined, steady state.

The replicator dynamics equation (8) has two steady states at the boundaries $x_0^* = 0$ and $x_1^* = 1$, and possibly interior steady states if, in the absence of policy intervention, or for a given choice of τ and θ, there exist,

$$x_i^* \in (0,1) : W_1(p, x^*, \tau, \theta; \mathbf{z}_1) - W_2(p, x^*, \tau; \mathbf{z}_2) = 0.$$

The local stability properties of a steady state depend on the sign of the derivative,

$$\left.\frac{d\dot{x}}{dx}\right|_{x=x_i^*,\ i=0,1} \begin{matrix} < 0 & \text{Local stability} \\ > 0 & \text{Local instability} \end{matrix}$$

We examine first the case with no policy intervention, that is, we set $\tau = \theta = 0$. With respect to preferences we focus on the difference in $MRS_{C,m}$, that is, we assume $\Delta a = \Delta d = 0$ and $\Delta\mu < 0$. Under these assumptions, (15) becomes,

$$\Delta W = \Delta\mu m_1^* - \frac{B^2}{2} + b\,(1-x)\left(1 - \frac{(1-x)\,B}{2}\right)B. \tag{16}$$

Given that $\Delta\mu < 0$, it is clear that green agents' indirect well-being could be higher even when the share of status agents is smaller relative to the case that $\Delta\mu = 0$. That is, if the relative evaluation of status goods in green agents' preferences is lower relative to status agents, then it is more likely that green consumers attain higher well-being at the equilibrium.

From the replicator dynamics equation (8) and (16) it is clear that apart from the two trivial fixed points, $x_0^* = 0$ and $x_1^* = 1$, $\dot{x}$ may have additional interior fixed points x^*, defined by the solution of (16). Given that (16) is quadratic in x, there are two possible interior fixed points $x^*(\Delta\mu, b, p)$,[28] of which only one is admissible, that is, $x^* < 1$. For admissible values of the parameters yielding an interior x^*, an increase in the price increases x^*. That is, a price increase has the expected direct effect of reducing both types of agents 'consumption of C, but it also has the indirect effect of increasing total consumption since it increases the share of the overconsuming segment of the population.

In particular, for homogeneous preferences, according to Proposition 1 and the preceding discussion, the higher is the importance of status in type 1 agents' well-being, that is the higher b is, the larger x^* will be.[29] As the value of b increases, under homogeneous preferences, status agents' share in the population increases up to $x^* = \frac{1+b-\sqrt{1+b}}{b}$, with $\lim_{b\to\infty} x^* = 1$. For $\Delta\mu < 0$, the price affects x^*. For given price, as $\Delta\mu$ increases, naturally

[28] The roots of are $x^*(\Delta\mu, b, p) = \frac{\Phi \pm \sqrt{\Psi}}{\Omega}$, where $\Omega = b\left(b^2 - \Delta\mu^2 p^2 + 2b\Delta\mu m_2^*\right)$, $\Phi = b\,(1+b)\,[b + \Delta\mu\,(2m_2^* - p)]$ and $\Psi = b\,(1+b)\,(b - \Delta\mu p)^2\,[b + \Delta\mu\,(m_1^* + m_2^*)]$. Only the negative root can give values less than unity under certain restrictions regarding the size of $\Delta\mu$ relative to the rest of the parameters.

[29] If in addition $b = 0$, that is, when both types of agents are the same, naturally $x = 1/2$.

x^* decreases. For given value of $\Delta\mu$, as the price increases, x^* increases. For values of $\Delta\mu$, b, and p for which $\Delta W|_{\tau=\theta=0} \gtreqless 0$, for $x \lesseqgtr x^*$, only the polymorphic steady state is stable, since the slope of $\dot{x}$ will be negative at x^*.

The following Proposition summarizes the above discussion.

Proposition 2. *In the absence of policy intervention, $\tau = \theta = 0$, and assuming (i) homogeneous preferences, the share of status agents is $x^* > 1/2$ and increasing in the importance status seekers place on status, $\frac{\partial x^*(0,b,p)}{\partial b} > 0$. In this case, a tax cannot affect the share of status agents in equilibrium, (ii) heterogeneous preferences, $\Delta a = \Delta d = 0$ and $\Delta\mu < 0$, the share of status agents in the steady state is decreasing in the preferences' difference for given price, $\frac{\partial x^*(\Delta\mu,b,p)}{\partial \Delta\mu} < 0$ and is increasing in the price for given difference in preferences, $\frac{\partial x^*(\Delta\mu,b,p)}{\partial p} > 0$.*

We can briefly discuss now the effect of different environmental preferences between the two types of agents, which in the current framework implies different perceptions of environmental damages. Since the intuition of the results is straightforward we choose to avoid complicated analytical proofs, which though are available upon request. It is reasonable, although not necessarily always true, to associate status seeking behavior with dismissal of environmental damages, implying a relatively lower d, that is, we assume $\Delta d = d_1 - d_2 < 0$. In such case, the last term in (15) is positive and thus, the share of status seekers in the polymorphic steady state gets higher, for any values of $\Delta\mu$, b and p for which $x^*(\Delta\mu, \Delta d, b, p) < 1$, that is, $\frac{\partial x^*(\Delta\mu,\Delta d,b,p)}{\partial \Delta d} > 0$. Actually it can be shown that for high values of γ and $\Delta d < 0$, x_1^* is the only stable steady state. For $\Delta\mu = 0$, and given Δd and b, an increase in the price will decrease average/total consumption an thus, it will have a negative effect on x^*, that is, $\frac{\partial x^*(0,\Delta d,b,p)}{\partial p} < 0$, eroding the positive effect of Δd. The above discussion is summarized in the following Corollary.

Corollary 1. *In the absence of policy intervention, $\tau = \theta = 0$, an increase in the environmental sensitivity of green agents leads to the decrease in their share in the population. When agents' preferences differ in their environmental sensitivity only, an increase in the tax will decrease x^*.*

The intuition is straight forward: assuming that green agents' perception of environmental damages is higher relative to status agents, i.e., $d_2 > d_1$, an increase in the tax reduces their well-being faster relatively to status agents' well-being, at any level of pollution. Therefore, an increase in the tax augments the difference between status and green agents' well-being, reducing thus, green agents' share in the population.

5.2 Steady state at selective, exogenously determined, policy interventions

When taxes τ and informative advertisement θ are used as controls, the controlled replicator dynamics equation, substituting (15) into (8) yields,

$$\dot{x} = x(1-x)\left[W_1(p, x^*, \tau, \theta; \mathbf{z}_1) - W_2(p, x^*, \tau; \mathbf{z}_2)\right], \tag{17}$$

where, $\theta = \phi(\theta)$.

As discussed above, the replicator dynamics always has two fixed points, the $x_0^* = 0$ and $x_1^* = 1$ solutions, while there is the possibility of more fixed points x^*, defined by the solution of the algebraic equation,

$$W_1(p, x^*, \tau, \theta; \mathbf{z}_1) - W_2(p, x^*, \tau; \mathbf{z}_2) = 0. \tag{18}$$

Thus, the regulator may be able, by choosing τ and θ, to steer the system to a steady state monomorphic population $x_0^* = 0$ or $x_1^* = 1$, or to a steady state polymorphic population x^*, determined by (18). Given that $\bar{p} = p + \tau$, it is evident from Proposition 2 first that, for homogeneous preferences, taxation will have no effect on ΔW and thus on x^*. Second, that, for $\Delta\mu < 0$ and $\Delta d = 0$, an increase in the tax will increase the share of status seeking agents in the population, that is $\frac{\partial x^*(\Delta\mu, b, p)}{\partial \tau} > 0$. However, we also know, from Corollary 1, that if $\Delta\mu = 0$ and for given $\Delta d < 0$, an increase in taxation will have the opposite effect of decreasing the share of status seekers. The overall effect of taxation on x^* will obviously depend on the relative size of the difference in agents' environmental and intrinsic consumption preferences, that is the size of $\Delta\mu$ and Δd. Denote by $x^*(\Delta\mu, \Delta d, b, p, \gamma)$ the solution of $\Delta W = 0$ as defined in (15). Then, $\frac{\partial x^*(0,0,b,p,\gamma)}{\partial \tau} = 0$, $\frac{\partial x^*(\Delta\mu,0,b,p,\gamma)}{\partial \tau} > 0$, $\frac{\partial x^*(0,\Delta d,b,p,\gamma)}{\partial \tau} < 0$, and thus, $\frac{\partial x^*(\Delta\mu,\Delta d,b,p,\gamma)}{\partial \tau} \lesseqgtr 0$. Taxation definitely decreases aggregate/average consumption of C. However, its effectiveness could be compromised when consumers' preferences differ, in which case the tax could promote status seeking behavior among agents. The above discussion is summarized in the following Proposition.

Proposition 3. *Taxing material consumption that is used by a segment of the population to signal social status, has two effects: the usual direct reduction of aggregate consumption and an indirect effect that erodes the direct effect. The indirect effect results from the decrease in the share of green agents induced by the tax, when the difference between the two groups' preferences for the numeraire good is stronger than the difference between the two groups' perception of environmental damage.*

A tax levied on C will change the relative price, shifting consumption away from material goods indicating social status. However, for $0 < x^* < 1$, an increase in the tax could increase status seeker's relative well-being in equilibrium. Thus, status seeking behavior will become more attractive and its share will increase. Therefore, the overall effect of taxation is reduced: all individuals reduce their consumption of C, but a higher share of them overconsumes in order to improve their social status.

The regulator has also the option of investing in the provision of information to directly influence the social component of status agents' demand for C. When social motivations of consumption are ignored, information provision usually targets individual's perception of environmental damages resulting from consumption, which in our model is denoted by parameter d_i, or consumers' evaluation of the dirty relative to clean alternative, which in our model is denoted by parameter μ_i.[30] However, as discussed in the introduction, even if an environmental awareness campaign is very successful and convinces all individuals to take into account the negative effect that their consumption has on them, only a small part of the problem will be addressed, since the main problem is due to the externalities created.[31] Furthermore, if information provision increases d's at different rate resulting in larger Δd, this will increase the share of status seekers in the population.

Instead of targeting consumer's intrinsic and environmental preferences, in this paper we assume that information provision policies target the social element in consumers' well-being. That is, we assume that government's investment in information provision affects the parameter indicating the relative importance of status in type 1 agent's well-being, that is, $b(\theta)$, with $\frac{\partial b(\theta)}{\partial \theta} < 0$. Public informative advertisement, by decreasing the importance

[30] See for example Petrakis et al. (2005), Sartzetakis et al. (2012).

[31] Important effect could only be derived by promoting altrouistic behavior, creating "warm glow" effects.

of status in agents' well-being, decreases status-seeking overconsumption in two ways: If status agents are convinced to place less importance on social status, then both their excess consumption relative to green agents is reduced, since $\frac{\partial \Delta C^*}{\partial b} > 0$, and their share in the population decreases.

Proposition 4. *A public information provision campaign that is effective in reducing the importance of social status in individuals' well-being, is successful in reducing both overconsumption due to status seeking and the share of status seeking agents in the population.*

It is clear that information provision targeting b is successful at reducing overconsumption of status seekers. At the extreme, a completely successful campaign reducing substantially b, will eliminate the difference between the two types of agents. However, a tax is still needed to correct the environmental externality created by all, including the green, consumers. In addition, information provision is costly, and thus, the optimal combination of the two instruments is not obvious. In the next Section we define the optimal combination of the two policy instruments.

6 Optimal choice of policy instruments

In deriving the regulator's optimal choice of policy instruments we use a simple mechanism through which information provision affects agents' choice of strategy. We assume that it is the level of information provision θ at time t which affects the agents' choice at t by reducing the relative importance of status in type 1 agent's well-being, that is, $b(\theta) = b - \theta$. Obviously the process is far more complicated, but we resort to these simplifying assumptions in order to derive numerical solution to the optimal policy choice problem.[32] The cost of providing information at time t, $c(\theta(t))$, with $c(0(t)) = 0$, is assumed convex, as suggested in the relevant literature.

Within this framework, the regulator chooses paths for $\tau(t)$ and $\theta(t)$ which optimize discounted social welfare over an infinite time horizon subject

[32] For example, Sartzetakis et al. (2012) assume that agents' choice is affected by the stock of information accumulated at time t and use, instead of a linear, an S-shaped response function to information provision.

to replicator dynamics. The instantaneous social welfare is expressed as,

$$W(t) = x\,(t)\, f_1^*\,(\bar{p}\,(t)\,, x\,(t)\,, \theta(t), Y) + (1 - x\,(t))\, f_2^*\,(\bar{p}\,(t)\,, x\,(t)\,, Y) - c\,(\theta\,(t))\,, \tag{19}$$

where $f_i^*\,(\bar{p}\,(t)\,, x\,(t)\,, Y)$, $i = 1, 2$ are defined in (6). Therefore, the regulator's optimal policy choice problem is,

$$\max_{\tau(t),\theta(t)} \int_0^\infty \mathrm{e}^{-\rho t} W(t) dt$$

subject to

$$\dot{x}(t) = x(t)(1 - x(t))\left[f_1^*\,(\bar{p}\,(t)\,, x\,(t)\,, Y) - f_2^*\,(\bar{p}\,(t)\,, x\,(t)\,, Y) - \phi\,(\theta\,(t))\right]$$

$$x(0) = x_0$$

The current value Hamiltonian of the above problem is,

$$\mathcal{H}\,(x\,(t)\,, \lambda\,(t)\,, \tau\,(t)\,, \theta\,(t)) = W\,(t) + \lambda\,(t)\,\dot{x}\,(t)\,,$$

where, $\lambda\,(t)$ is the shadow value of the proportion of status seekers indicating the change in maximized welfare from a small change in $x\,(t)$. Pontryagin's maximum principle implies the following conditions:

$$\tau^*\,(t) = h^\tau\,(x\,(t)\,, \lambda\,(t)) \;\;,\;\; \theta^*\,(t) = h^\theta\,(x\,(t)\,, \lambda\,(t))\,. \tag{20}$$

which are obtained as the solution of:

$$\frac{\partial \mathcal{H}\,(x\,(t)\,, \lambda\,(t)\,, \tau\,(t)\,, \theta\,(t))}{\partial \tau} = 0 \;,\; \frac{\partial \mathcal{H}\,(x\,(t)\,, \lambda\,(t)\,, \tau\,(t)\,, \theta\,(t))}{\partial \theta} = 0,$$

assuming interior solutions, and the Hamiltonian system

$$\dot{x}\,(t) = \frac{\partial \mathcal{H}\,(x\,(t)\,, \lambda\,(t)\,, \tau^*\,(t)\,, \theta^*\,(t))}{\partial \lambda} \;,\; x\,(0) = x_0 \tag{21}$$

$$\dot{\lambda}((t) = \rho\lambda\,(t) - \frac{\partial \mathcal{H}\,(x\,(t)\,, \lambda\,(t)\,, \tau^*\,(t)\,, \theta^*\,(t))}{\partial x}. \tag{22}$$

The steady state of the Hamiltonian system is defined as

$$(x^*, \lambda^*) : \dot{x}\,(t) = 0,\; \dot{\lambda}((t) = 0.$$

The structure of (21) implies that the Hamiltonian system will have for x the steady states $x^* = 1$, $x^* = 0$ and potentially additional interior steady states $x^* \in (0,1)$. An optimal solution $(x^*(t), \lambda^*(t))$ of the Hamiltonian system, if it exists, will provide, after substitutions into (20), the optimal paths for the controls $\tau(t)$ and $\theta(t)$.

The Hamiltonian system (21)-(22) is highly nonlinear and, because of this, closed form solutions are not possible. In order to provide some insight into the choice of optimal controls we resort to numerical simulations. Since we are interested in exploring the impact of optimal policy relative to the case in which no policy is applied, we consider steady states when $x(t)$ is evolving according to the replicator dynamics and no policy is applied, that is $\tau = 0$, $\theta = 0$ and then we compare them with steady states resulting from optimal policies determined by (21)-(22).

To construct the instantaneous social welfare in (19), we derive $f_1^*(\bar{p}(t), x(t), \theta(t), Y)$ and $f_2^*(\bar{p}(t), x(t), Y)$, using the specific functional forms given in (9) and (10), and a quadratic cost of providing information $c(\theta) = \frac{1}{2}c\theta^2$. For the numerical analysis the following values for the parameters: $a = 1.5$; $\mu_1 = \mu_2 = 0.4$; $b = 0.6$; $d_1 = d_2 = 1$; $\gamma = 1$; $p = 2$; $c = 1$; and $y = 10$. These parameter values were chosen so that, in the absence of policy intervention, there is convergence to a stable polymorphic steady state with roughly similar shares of status and green agents. In this way, we facilitate clear comparison between the steady states attained under no intervention and under optimal policy. In Section 5.1 we stated that setting ΔW, given in (16), equal to zero yields, the interior solutions $x^* \in (0,1)$ of the static model in the absence of policy intervention. Assuming no difference in preferences between the two groups of consumers, that is, when $\Delta\mu = \Delta d = 0$, the admissible no-policy interior steady state is $x^* = \frac{1+b-\sqrt{1+b}}{b}$, which for $b = 0.6$ becomes $x_{NP}^* = 0.558482$. Figure 1, plotting the replicator dynamic equation in (8) as function of x, illustrates the result in Section 5.1 that for the specific parametrization only the polymorphic steady state is stable, since the slope of $\dot{x}$ is negative at x_{NP}^*, while the steady states at the boundaries $(0,1)$ are unstable.

Given the highly nonlinear structure of the optimal policy problem and the associated Hamiltonian system, we consider a first order expansion of the Hamiltonian function around the no-policy stable polymorphic steady state, $x_{NP}^* = 0.5585$. Although the resulting Hamiltonian is still nonlinear, this allows the numerical analysis of the regulator's optimal policy problem in a tractable context. We consider this approximation as reasonable, 1

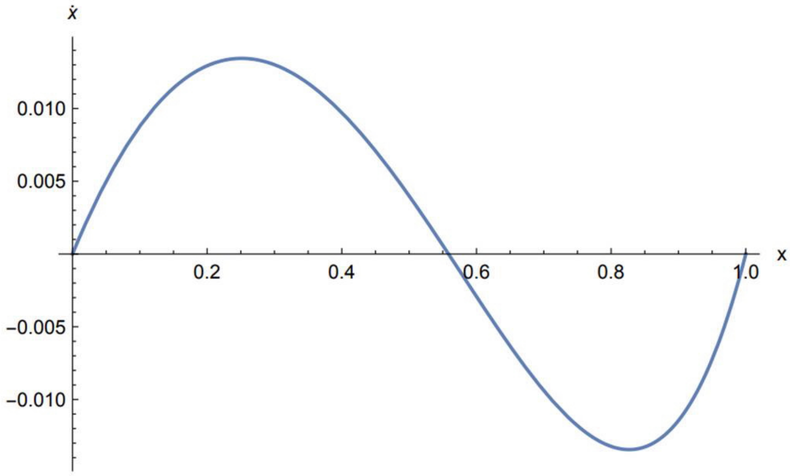

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Figure 1: The no-policy steady states with $x^*_{NP} = 0.5585$

since it allows comparisons between the no-policy and the optimal policy outcomes. The results of the solution under this approximation are summarized in Table 1. The first two columns in Table 1 present the steady states for (x^*, λ^*) obtained from the maximization of the Hamiltonian function.[33] Columns three and four report the optimal controls $\tau(x^*, \lambda^*)$, $\theta(x^*, \lambda^*)$ that correspond to each steady state while the last column presents the values of the steady state welfare. The first two rows present the results of the two admissible steady states with the respective welfare defined as $W^*_{SS} = \frac{1}{\rho} W(x^*, \tau(x^*, \lambda^*), \theta(x^*, \lambda^*))$. To facilitate comparison, the last row presents the values of x^* and the welfare W^*_{NP} at the steady state in the absence of policy intervention.

	x^*	λ^*	$\tau(x^*, \lambda^*)$	$\theta(x^*, \lambda^*)$	W^*
	0	-3.710	1.421	0.379	392.8
Optimal policy	0.036	-3.551	$1,566$	0.323	394.822
No policy	0.558	–	0	0	377.947

Table 1. Numerical results at the steady states and the no-policy case

[33] The Hamiltonian system produced two more steady states: one boundary at $x^* = 1$, that is, a steady state where only status agents exist, and one interior with $x^* > x^*_{NP}$. However, the solutions corresponding to both these steady states require very high levels of taxation and information provision, the first leading to negative consumption by green agents. Furthermore, the welfare, in both these steady states, is lower relative to the global maximum welfare. For these reasons we choose not to report these two steady states in Table 1.

In brief, Table 1 illustrates the social welfare improvements the regulator can attain using combinations of tax and information. For example, levying on C a tax, $\tau = 1.421$, and providing a level of information, $\theta = 0.379$, that reduces the importance of status seeking from, $b = 0.6$, to, 0.221, eliminates status seeking, $x^* = 0$. However, this is not optimal, as a policy mix of a higher tax and lower level of information, $\tau = 1.421$ and $\theta = 0.379$, although it allows a small share of status seekers, $x^* = 3.6\%$, yields the highest welfare, $W^* = 394.822$. Clearly, the optimal policy mix depends on the specific functional forms we used to present agents' well-being, the effect of information on status seeking and the cost of providing information, and also on the values of the parameters used for the simulations.

The stability properties of a steady state are determined by the Jacobian determinant evaluated at the steady state:

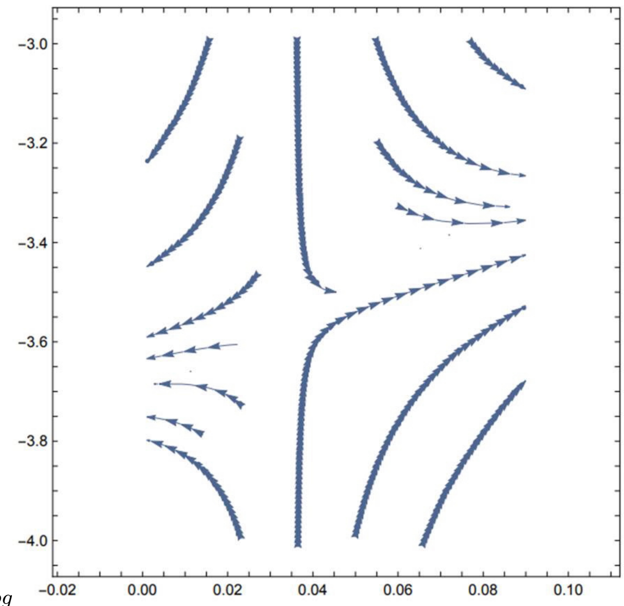
$$J = \begin{pmatrix} \frac{\partial \dot{x}}{\partial x} & \frac{\partial \dot{x}}{\partial \lambda} \\ \frac{\partial \dot{\lambda}}{\partial x} & \frac{\partial \dot{\lambda}}{\partial \lambda} \end{pmatrix}$$

Calculation of the eigenvalues of the Jacobian matrix at the two local/global optimal steady states $x^* = 0$, and $x^* = 0.036$, respectively indicates that both of them are saddle points. Figure 2, in which the horizontal axis measures values of x and the vertical values of λ, presents the phase plot of the steady state $x^* = 0.036$, which corresponds to the global optimum.

At the globally optimal steady state $x^* = 0.036$, the regulator chooses a level of information provision $\theta^* = 0.323$ and levies a tax $\tau^* = 1,566$ on C, a policy combination that reduces the share of status seeking agents from 55.8% without policy intervention, to 3.6%. This policy intervention reduces aggregate consumption of C from $TC^*_{NP} = 0.9649$ to $TC^* = 0.0813$, yielding, the reported in Table 1, social welfare improvement over the case without policy intervention. Notice that eliminating completely the status agents, although it presents an improvement over the no-policy case, it is not the best choice. At the globally optimal steady state, a small fraction of status agents still exists.

To check the robustness of our results we performed sensitivity analysis for the critical parameter b, indicating the relative importance of status in type 1 agent's well-being. Multiple runs with b in the range $[0.1, 1]$ indicate that an increase in b would increase, as expected, the proportion of status seekers at the no-policy equilibrium in the interval $[0.511, 0.586]$. The ap-

2



$_{2}.jpg$

Figure 2: The globally optimal steady state $x^{*} = 0.036$

proach based on the first-order expansion of the nonlinear Hamiltonian, for the different equilibrium values of the share of status agents in the absence of policy intervention, provided qualitatively similar results, with steady state values for x^{*} in the interval $[0.00165, 0.072]$. Thus, an increase in parameter b will increase the equilibrium proportion of status seekers, with and without policy intervention. Furthermore, as b increases in the interval $[0.1, 1]$, the regulator responds by increasing the level of advertisement at the steady state from 0.051 to 0.561, while decreasing slightly the optimal tax rate from 1.879 to 1.864. The intuition is that the regulator, when she observes status agents placing continuously increasing importance on status, responds by increasing information provision, which is the more efficient policy instrument to address overconsumption resulting from status seeking. Since, due to increased information provision, the importance of status is moderated, and thus, the increase in the share of status seekers is limited, overconsumption and thus environmental damage is controlled, allowing the regulator to slightly reduce the level of the environmental tax. This trade-off between information provision and environmental taxation is consistent with the results of the literature examining environmental information aiming at increasing agents' environmental awareness (see for example, Sartzetakis et al., 2012, and Petrakis et al., 2005).

Small changes of the discount rate from the central value of 1% did not provide any significant qualitative or quantitative changes in the results, while a reduction in the damage parameter d increased, as expected, the steady state share of status seekers and reduced advertisement and taxes. At the welfare maximizing steady state, when optimal policy is undertaken and positive consumption levels for both types of consumers are attained, an increase in the cost of information provision, i.e. the parameter c, reduces, as anticipated, the level of information provision and increases the level of the environmental tax. The rate at which the level of information provision decreases as the slope of its marginal cost increases, i.e., the derivative $d\theta/dc$, evaluated at x^*, is not constant. It is low for low x^* and high for high x^*, with x^* in $[0.00165, 0.072]$.

In general, the sensitivity analysis shows that the optimal control solution, restricting the admissible set of solutions to positive consumption for both types of agents, provided two types of admissible steady states: the boundary monomorphic steady state, $x^* = 0$, and the interior polymorphic steady states, x^*, in the interval $[0.00165, 0.072]$. As noted above, in all cases, the interior steady state solutions provided the highest welfare.

We acknowledge that these results hold for a first order expansion of the Hamiltonian around the no-policy point and that higher order expansions could provide better approximations to the solution corresponding to the original non linear Hamiltonian. However, our numerical simulations illustrate clearly that the adoption of optimal policy combination yields a considerable reduction in the share of status seekers and the an improvement in aggregate well-being relative to the no-policy case.

7 Epilogue

It is beyond dispute that the continuously increasing consumption of material goods is the primary driver of the resource and environmental crises, including climate change and loss of biodiversity, humanity is currently facing. Although technology continues to offer solutions, including for example renewable energy, the urgency of the crises requires much faster responses involving new and old technologies during transition, which could be achieved only with demand side adjustments. The common response of an economist would be to assign a levy through a tax or a permit scheme, on carbon emissions, in the case of climate change for example, in order to efficiently influence people's behavior towards internalizing the externalities they create. However, increases in fuel prices in the previous decade, both in North America and Europe, did not bring the required changes, as fuel markets continue to thrive. In addition, ambitious increases in fuel prices have met considerable political opposition, especially by low-income people, with the French experience over the last few years being the primary example.

In this paper we attempt to offer an explanation as to why an environmental tax might not be as effective as expected and also a potential remedy. In doing so we add to an expanding literature suggesting that a single carbon price might not be the appropriate solution (see for example Stiglitz, 2019). We focus our attention on relatively high-income individuals whose consumption of highly polluting material goods is driven by motivations to improve their social status. Since large numbers of individuals from developing countries are continuously joining this group, the proliferation of such behavioral trends could indeed be considered a primary driver of material goods overconsumption. We develop a framework that captures these basic characteristics and, taking into account the social dimension of demand motivations, we explain first, why a tax might not be as effective as expected; and second, we show that complementing the tax with information provision aiming at moderating status seeking overconsumption improves social welfare. Convincing people, through information campaigns and/or advertisement that should not use highly polluting material goods to improve their social status could have a substantial effect which perfectly complements taxation, improving actually its effectiveness.

The framework employed in this paper has been admittedly constrained by our intention to provide analytical solution in the first part of the paper and numerical examples in the far more complicated derivation of the optimal policy combination. For example, we were able to only sketch the way in which information provision affects the importance of status seeking in agents' well-being, resorting to a simple linear effect. Similarly, we did not discuss efficiency issues related to taxation, assuming zero administrative and distortive costs. Furthermore, by assuming equal income across agents we could not discuss distributional issues that decrease the acceptability of environmental taxation, as evidenced by, for example, the "yellow vests "movement in France (see for example Goulder et al., 2019). It is clear that both the efficiency and the cost of implementing the two policy instruments will affect the choice of the appropriate policy mix

The paper could be extended in numerous ways including the following. As already mentioned in the text, considering stock pollutants will be an important extension of the current work. Extending heterogeneity in the social aspect of the demand beyond the two groups examined in this paper could also enrich the results. Another important extension would be to relax the assumption of perfect competition and explicitly model the production side. A richer structure of how information provision affects the social component of the demand could provide intuition on how to design such policies. Needless to say, empirical work on how public information affects different aspects of consumers' behavior would be extremely helpful. Finally, another extension would be to consider policies targeting other problems that could also reduce the importance of status seeking. Given that carbon taxes are regressive and it has been shown that their regressivity could increase with the society's level of inequality (see Andersson and Atkinson, 2020, and Sterner 2012), it will be worth exploring whether policies that reduce income inequality also reduce the importance of status seeking. If such a relationship could be established, then such policies will attain a double dividend: on the one hand, according to our analysis, they will decrease directly overconsumption of polluting goods, and on the other hand, they will improve the effectiveness and also the acceptability of carbon taxes.[34]

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9 Appendices

9.1 Appendix 1.

First, from (12) and (13) the difference between status agent's and average consumption of C, is,

$$C_1^* - \bar{C}^* = (1 - x) B. \tag{23}$$

From (12) and (11) we also derive the sum of the two types of agents' consumption,

$$\sum C^* = C_1^* + C_2^* = 2 (a_2 - \bar{p}) + B. \tag{24}$$

We can now derive (15). First, we derive the difference in the intrinsic utility between the two groups of agents,

$$\begin{aligned}
\Delta W_{\text{intrinsic}} &= a_1 C_1^* - a_2 C_2^* - \frac{1}{2} \sum C^* \Delta C^* + \mu_1 m_1^* - \mu_2 m_2^* \\
&= (a_1 - \mu_1 \bar{p}) C_1^* - (a_2 - \mu_2 \bar{p}) C_2^* + \Delta\mu Y - \left[(a_2 - \mu_2 \bar{p}) + \frac{B}{2} \right] B \\
&= (a_1 - \mu_1 \bar{p}) C_1^* - (a_2 - \mu_2 \bar{p}) C_1^* + \Delta\mu Y - \frac{B^2}{2} \\
&= (\Delta a - \Delta\mu \bar{p}) C_1^* + \Delta\mu Y - \frac{B^2}{2} \\
&= \Delta a C_1^* + \Delta\mu (Y - \bar{p} C_1^*) - \frac{B^2}{2} \\
&= \Delta a C_1^* + \Delta\mu m_1^* - \frac{B^2}{2}
\end{aligned}$$

Using (23) we derive the well-being status seekers obtain, at the equilibrium, from the consumption of C as status indicator,

$$\begin{aligned}\Delta W_{\text{status}} &= b\left[(C_1-\bar{C})-\frac{1}{2}(C_1-\bar{C})^2\right]\\ &= b\,(1-x)\left(1-\frac{(1-x)\,\Delta C}{2}\right)\Delta C\\ &= b\,(1-x)\left(1-\frac{(1-x)\,B}{2}\right)B.\end{aligned}$$

9.1.1 Appendix 2: Stock Pollution.

The accumulation dynamics of a stock pollutant can be represented by,

$$\dot{P}(t)=\bar{C}\,(t)-\delta P\,(t)\ ,\ P\,(0)=P_0\ ,$$

where $\delta>0$ represents environment's cleaning capacity. We assume that consumers are myopic relative to pollution dynamics and maximize utility by considering that the current flow of pollution $\bar{C}\,(t)$ generates damages. Thus, after consumers make their optimal choice, pollution dynamics will be,

$$\dot{P}(t)=x(t)C_1^*(t)+(1-x(t))C_2^*(t)-\delta P\,(t)\ ,\ P\,(0)=P_0\ .$$

The instantaneous social welfare in this case is expressed as,

$$W(t)=x\,(t)\,W_1(t)+(1-x\,(t))\,W_2(t)-D^R(P(t))-c\,(\theta\,(t))\,,$$

where $W_i(t)$, $i=1,2$ are defined in (6), $c\,(\theta\,(t))$ is the cost of information provision and $D^R(P(t))$ is damage function indicating damages from the stock of pollution that consumers do not take into account. Then, the regulator solves the problem,

$$\max_{\tau(t),\theta(t)}\int_0^\infty \mathrm{e}^{-\rho t}W(t)dt$$

subject to,

$$\begin{aligned}&\dot{x}(t)=x(t)(1-x(t))\left[f_1^*\left(\bar{p}\,(t)\,,x\,(t)\,,Y\right)-f_2^*\left(\bar{p}\,(t)\,,x\,(t)\,,Y\right)-\phi\left(\theta\,(t)\right)\right]\\ &x(0)=x_0\\ &\dot{P}(t)=x(t)C_1^*(t)+(1-x(t))C_2^*(t)-\delta P\,(t)\ ,\ P\,(0)=P_0\ .\end{aligned}$$

This is a highly nonlinear optimal control problem with two state variables whose solution opens up an area of further research.