ABSTRACT

Title of Dissertation:	FIFTY SHADES OF GREEN: ESSAYS ON ECO-FRIENDLY CONSUMPTION, PUBLIC POLICY, AND INCOME INEQUALITY
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Dissertation directed by:	Professor Neslihan Uler Department of Agricultural and Resource Economics

This dissertation offers a thorough examination of the impact of income inequality on environmental quality, with particular attention to the obstacles encountered by low-income individuals and families in adopting sustainable and environmentally friendly consumption practices. Through the development of a general theoretical model, I provide a novel approach on understanding the dynamics of this relationship. By examining various income inequality scenarios, I assess their effects on environmental quality. Based on these findings, I propose a policy recommendation that addresses both income inequality and environmental concerns. Additionally, I propose an innovative laboratory experiment to empirically validate the theoretical predictions of the general model.

In Chapter 1 I present a brief introduction emphasizing the significance of examining the impact of income inequality on the environment. he importance of exploring the individual

trade-offs associated with consuming environmentally friendly goods (referred to as 'green goods'), which are more expensive, compared to their environmentally harmful counterparts (referred to as 'brown goods'), which are cheaper to buy. Building upon this framework of green and brown goods, I introduce a general model in Chapter 2 to comprehend individual behavior and investigate the impact of income inequality on environmental quality. This theoretical model offers insights into why income inequality can lead to improved, worsened, or neutral outcomes for the environment, which provides an explanation for the mixed empirical evidence found in previous studies.

In Chapter 3, I propose a solution to address the issues of income inequality and the externality generated by the consumption of brown goods simultaneously. I propose the implementation of a permit market in which a regulatory agency issues a limited number of permits to cap the total demand for brown goods, thereby preventing environmental quality from falling below a predetermined threshold. Consumers have the opportunity to trade these permits, enabling income transfers from buyers to sellers and ultimately reducing income inequality.

Finally, in Chapter 4 I present the design and analysis of a novel laboratory experiment aimed at empirically testing the theoretical predictions derived from the model introduced in Chapter 2. The experimental results reveal a positive effect of income inequality on environmental quality across all treatments, contradicting the predicted negative effect in specific scenarios. To account for these deviations, I augment the theoretical model by integrating two behavioral motivations, which effectively elucidate the observed behavior. These extensions not only contribute to a deeper understanding of the empirical findings but also offer promising prospects for further research exploration.

FIFTY SHADES OF GREEN: ESSAYS ON ECO-FRIENDLY CONSUMPTION, PUBLIC POLICY, AND INCOME INEQUALITY

by

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Dedication

A Mónica y Rafael por siempre estar ahí.

A Pina, Mely y Maru porque, aunque ya no están, continúan aquí.

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Chapter 1 : Introduction

The pressing global challenges of environmental protection, climate change mitigation, and income inequality reduction are at the forefront of today's agenda (IPCC 2007, UN 2022, World Bank 2022). The climate crisis disproportionately affects vulnerable populations, leading to environmental degradation and extreme weather events, posing a threat to poverty eradication efforts worldwide. To address these challenges, sustainable consumption and production patterns have been proposed as a potential solution. By transitioning to greener technologies and products, it is possible to meet energy and consumption demands while simultaneously providing environmental and health benefits to all members of society. The adoption of environmentally friendly goods, commonly known as 'green goods', holds promise for decoupling economic progress from environmental degradation while maintaining existing living standards. However, the affordability of green goods is a critical concern, particularly for low-income individuals and families, as high costs may hinder their access and adoption.

In light of these concerns, the feasibility of transitioning to a green economy is questioned, as it may be more accessible for developed and advanced economies given their resources and financial capabilities. Furthermore, it is crucial to recognize the potential disparities in the distribution of benefits within countries, particularly in regions characterized by high levels of income inequality. The distribution of income has garnered considerable attention in socioeconomic research, with income inequality emerging as a prominent issue since the 1990s (Banerjee and Piketty 2005; Piketty 2015; Rey and Sastré Gutiérrez 2015; Saez and Zucman 2016; Goda, Onaran and Stockhammer 2017; Dong and Hao 2018; Piketty, Yang and Zucman 2019). However, the relationship between income inequality and environmental quality remains a subject of debate. Some studies argue that income and power inequalities contribute to environmental problems (Boyce 1994; Torras and Boyce 1998; Downey 2015; Uzar and Eyuboglu 2019), while others find no clear relationship or even suggest a positive effect on environmental quality as income inequality increases (Scruggs 1998; Heerink, Mulatu, and Bulte 2001; Grunewald, Klasen and Martínez-Zarzoso 2017). As a result of this conflicting evidence, further research is required to gain a better understanding of the complex relationship between environmental issues with socioeconomic inequalities.

In this dissertation, I aim to contribute to this understanding by analyzing consumer decision-making processes in the context of purchasing green goods that are more expensive than their environmentally harmful counterparts, also known as 'brown goods'. While consumers may have various motivations for buying green goods, such as signaling environmental concern or displaying a luxurious lifestyle, these motivations may not always translate into actual pro-environmental behavior. Furthermore, some green goods may not deliver the intended environmental benefits or may simply be the result of marketing strategies lacking genuine environmental impact.

To address these issues, my research focuses on situations where consumers seek to increase their overall consumption without considering external factors that may influence their purchasing decisions. Specifically, I investigate the impact of changes in individual income on the consumption of green and brown goods, exploring whether higher individual income levels lead to the adoption of green goods and/or the abandonment of brown goods. Given that the consumption of brown goods contributes to environmental degradation in this setup, exploring the latter effect is of particular importance.

To examine the impact of income inequality on the environment, I analyze aggregate consumption choices under varying levels of income inequality while keeping total income constant. The primary objective is to determine whether inequality has detrimental effects on the environment by causing an increase in the aggregate demand for brown goods, or vice versa. Overall, my research aims to provide valuable insights into the effect that income inequality has over the environment, with the goal of informing policy decisions to address these two critical societal challenges.

To the best of my knowledge, my dissertation represents the first attempt to analyze the impact of income inequality on environmental quality in the presence of green and brown goods. My main contribution is twofold. First, I employ a neoclassical framework to develop a general model capable of explaining the varying effects of income inequality on the environment, depending on the circumstances. In this model, consumers have the option to buy both green goods and brown goods, distinguished by the fact that brown goods can be acquired at a lower cost but generate negative externalities on the environment. Based on the results of this model, I provide a policy recommendation that can simultaneously reduce income inequality and improve environmental quality. Furthermore, I identify conditions under which this policy can optimize environmental quality.

Second, I design a novel laboratory experiment to empirically assess the outcomes predicted by the neoclassical model. My experimental design incorporates both between-subjects and within-subjects analyses to account for individual characteristics and potential confounding effects related to income redistribution. Drawing from the results, I propose two behavioral motivations to explain deviations from the standard predictions. Integrating these two extensions into a combined model offers a valuable framework for effectively explaining the observed results, thereby providing further insight into the underlying data.

The rest of the dissertation is structured as follows. In Chapter 2, I present the theoretical model in which individual preferences are based only on total consumption and environmental quality, which I model as a pure public good. I find that the individual consumption of brown goods follows a pattern similar to an Environmental Kuznets Curve. Initially, as low-income individuals receive more income, their consumption of brown goods increases until a turning point is reached. Beyond this point, additional income incentivizes consumers to reduce their brown goods consumption until it can be completely substituted by green goods. Additionally, my model explains why income inequality can have both positive and negative effects on the environment, depending on the circumstances.

In Chapter 3, I introduce a solution to address income inequality and environmental quality simultaneously by proposing the implementation of a permit market. I assume that a regulatory agency possesses the authority to issue a limited number of permits to cap the total demand for brown goods, thereby preventing a decline in environmental quality below a predetermined threshold. Consumers have the ability to trade these permits amongst themselves, which would allow income to be transferred from buyers to sellers, and consequently reducing income inequality.

I investigate the conditions under which the regulatory agency can determine the optimal initial distribution of permits that induces all consumers to participate in the market as either buyers or sellers. Through my analysis, I discover that if all consumers behave as price-takers, the regulatory agency can use the initial distribution of permits as a policy tool in its own right to achieve an optimal trading price capable of equalizing the marginal rates of substitution for all consumers. This equilibrium would ensure a socially efficient level of environmental quality while contributing to a reduction in income inequality.

In Chapter 4 I present the design and analysis of a novel laboratory experiment aimed at empirically testing the theoretical predictions derived from the model in Chapter 2. Specifically, I investigate the prediction that income inequality may result in environmental quality that is equivalent to, better than, or worse than the quality achieved when all consumers in the economy receive the same initial income.

The experimental results reveal a weak, positive effect of income inequality on environmental quality across all treatments, particularly in the scenario where the theoretical model predicted that this effect would be negative. I introduce two behavioral motivations to account for these deviations. The first extension involves a “warm glow” preference towards the consumption of green goods (Andreoni, 1990), while the second includes a theory of conformity (Bernheim 1994) where consumers experience disutility when their consumption of brown goods deviates from a social norm. These theories help to explain the observed behavior in the experiment and suggest avenues for future research.

Chapter 2 : A Tale of Two Goods

2.1 Introduction

The impact of income inequality on environmental quality remains uncertain, as conflicting evidence exists. Some studies suggest that inequality reduces social capital and cooperation, leading to worse environmental outcomes. However, others argue that unequal societies are more effective in protecting the environment due to the greater incentives for innovation and adoption of greener technologies among higher-income individuals. This discrepancy raises the question of why different studies yield conflicting results. In my research, I aim to explore the underlying factors contributing to these differing arguments and assess whether public policy can effectively address both problems of income inequality and environmental degradation. To address this research question, I examine the interplay between the consumption of green and brown goods and individual income.

In this chapter, I introduce a theoretical model, based on the model of environmentally friendly consumption (Kotchen 2005, 2006), that examines the decision-making process when individuals choose between purchasing green goods, which have no negative impact on the environment, and cheaper brown goods that possess identical characteristics to green goods but contribute to a decline in environmental quality. I consider a general class of utility functions that considers that consumers have well-defined preferences for two objects: total private consumption and environmental quality, which I conceptualize as a pure public good. Drawing from the outcomes of the model, I classify consumers into three categories based on their income allocation: Brown Consumers, who solely consume brown goods; Mixed Consumers, who purchase both brown and green goods; and Green Consumers, who exclusively opt for consuming green goods.

The findings of this model provide support for the existence of two critical income levels for every consumer. The first level determines the shift from being a Brown Consumer to a Mixed Consumer, while the second level signifies the transition from being a Mixed Consumer to a Green Consumer. Specifically, the model indicates that the demand for brown goods increases as income rises when income is low. However, there comes a turning point at which consumers begin substituting their consumption of brown goods with green goods until they are fully committed to green consumption. Consequently, this model establishes the presence of an individual-level Environmental Kuznets Curve.

As a result, the implications of income inequality on the environment can vary significantly based on the relative advantages or disadvantages experienced by different consumer groups. If income inequality disproportionately harms Mixed or Green Consumers compared to Brown Consumers, it may lead to environmental degradation. Conversely, if it benefits Mixed Consumers, it could result in a more positive environmental outcome. Therefore, this model provides an explanation for the ambiguous findings regarding the impact of inequality on environmental quality.

The rest of this chapter is structured as follows. In Section 2.2, I conduct a review of the existing literature, examining the effects of inequality on the environment as well as the research on public goods provision and the consumption of green goods. Section 2.3 presents the baseline model and outlines the outcomes derived from the market equilibrium. Section 2.4 discusses the impacts of inequality on the environment and individual well-being. Finally, the chapter concludes with Section 2.5.5.

2.2 Literature Review

This chapter is situated within two relevant strands of literature. First, it aligns with a substantial body of research investigating the impact of income inequality on various indicators of environmental quality. The findings from these studies present a mixed picture, with positive, negative, and neutral effects of inequality observed. The conflicting findings motivate my research, as I seek to understand the underlying factors contributing to these disparities. Second, this chapter is closely connected to prior studies examining the provision of public goods by private agents. As I argue that environmental quality exemplifies a pure public good, the study of these models is crucial in comprehending the factors influencing consumption decisions between green goods and brown goods.

2.2.1 Income Inequality and Environmental Quality

Traditionally, the economics literature has primarily focused on examining the impact of national income on environmental outcomes. Many studies have centered around the Environmental Kuznets Curve (EKC), which tests the hypothesis that there exists an income turning point where pollution begins to decline rather than increase (i.e., Grossman and Krueger, 1995). However, it has been found that an exclusive focus on economic growth in environmental analysis may yield biased results if measures of income dispersion are not included (Heerink, Mulatu, and Bulte, 2001).

Various theories have been proposed to explain how income inequality can affect the environment. One argument suggests that inequality influences social norms, such as consumerism, individualism, and short-termism, which may create divergent environmental interests among different social groups (Berthe and Elie, 2015). Income inequality can also impact individual economic behavior, for instance, when there is competition for social status (Wilkinson and Pickett, 2010) or when low-income individuals prioritize increasing their living standards at the expense of negative environmental impacts (Uzar 2020).

Empirical studies examining the relationship between income inequality and environmental conditions have yielded mixed findings. Some studies have shown that reductions in income inequality are associated with improved environmental outcomes in a range of countries, including 19-58 nations (Torras and Boyce 1998). Notably, China experienced enhanced environmental conditions as a result of redistribution policies targeted at the low-income population (Golley and Meng 2012), while the United States witnessed a reduction in CO_2 emissions (Baek and Gweisah 2013). Similarly, in Turkey, income inequality was linked to improved environmental quality (Uzar and Eyuboglu 2019). Equivalently, other studies find that increasing income inequality leads to higher levels of carbon intensity in both OECD and non-OECD countries since the 1990s (Jorgenson 2015). This trend has been observed in the United States, with rising income inequality associated with increased CO2 emissions (Liu, Kiang and Xie 2019), as well as in China (Hao, Chen, and Zhang 2016).

Nonetheless, it is important to acknowledge that certain studies have failed to establish a significant relationship between income inequality and various environmental indicators (Scruggs, 1998; Borghesi, 2006). Furthermore, certain studies have even suggested that higher levels of inequality some studies have even proposed that higher levels of inequality, both between and within countries, are associated with lower carbon emissions at given average incomes (Ravaillion, Heil, and Jalan, 2000) or may even act to prevent environmental degradation within specific timeframes (Liu, Wang, Zhang, Li and King 2018).

2.2.2 Public goods and green goods

Building upon this discussion, the study of environmental quality is intrinsically linked to the literature on public goods as it helps to examine the non-excludable and non-rival nature of environmental quality within a particular geographical region. In traditional economic theory, the supply of the public good is calculated simply as the sum of individual inputs. Examples of this approach include the analysis of contributions destined to fund public radio (Kingma 1989), rural health care (Smith, Kehoe and Cremer 1995), green electricity programs (Kotchen and Moore 2007), environmental organizations (Grant and Langpap 2018), or charitable giving broadly defined (i.e., Andreoni 1989; Payne 1998; Okten and Weisbrod 2000; Fiala amd Noussair 1997; Andreoni and Payne 2013; Filiz-Ozbay and Uler 2018). This approach is based on the assumption that each consumer benefits from the provision of public goods by all other consumers.

Previous studies have found that redistributing income among contributing consumers does not impact the total contributions, as the increase in contributions by recipients is exactly offset by the decrease in contributions by those who lose income (Warr 1983; Bergstrom Blume and Varian 1986). This result holds for a general class of utility functions. However, it has been shown that redistributive policies can enhance social welfare by creating sufficient income inequality between contributors and non-contributors (Bardham, Ghatak and Karaivanov 2007). Specifically, when only the rich contribute to public goods or when there are productivity differences among agents, such inequality can lead to improved outcomes. On the contrary, in cases where inequality is reduced through the combination of redistributive taxation and tax-deductible charitable contributions, increasing the tax rate to promote greater egalitarianism can result in the efficient provision of public goods, irrespective of the pre-existing income inequality (Uler 2009).

These previous studies primarily focus on the issue of inequality and contributions to public goods within the context of pure public goods, which exclusively generate benefits for the entire community. However, when considering the consumption of green and brown goods, it is important to extend this analysis to also consider impure public goods, which not only have community-wide impacts but also provide private benefits to individual consumers (Cornes and Sandler 1984, 1994). Impure public goods encompass a wide range of examples, including military alliances (Murdoch and Sandler 1984) to the warm-glow-of-giving phenomenon (Andreoni 1989, 1990; Long 2020). Furthermore, various real-world applications such as climate change and biodiversity loss (Rübbelke 2003; Chan 2019), refugee protection (Betts 2003), environmentally friendly consumption goods (Kotchen 2005, 2006), green electricity programs (Kotchen and Moore 2007; Mitra and Moore 2018), and ancillary benefits of climate policy (Brumme, Buchholz and Rübbelke 2020, Brumme 2022) emphasize the significance of studying impure public goods.

To analyze the consumption patterns of green and brown goods, I adapt the environmentally friendly consumption model introduced by Kotchen (2005, 2006). This model integrates key elements from the impure public goods model and the characteristics approach to consumer behavior (Lancaster 1971; Gorman 1980) The characteristics approach suggests that consumers derive utility from various attributes associated with the goods they consume, which aligns with the nature of both green and brown goods. Previous research has extensively employed the impure public goods framework to model green goods (i.e., Kotchen 2005, 2006; Kim 2009; Wichman, 2016; Chan and Kotchen 2014; Chan, 2015; Chan and Dinelli 2020; Montoya-Villalobos 2023). This is because green goods offer a private benefit to individual consumers, enabling an increase in their private consumption, while simultaneously contributing to the preservation of environmental quality, which is a public good.

Similarly, the impure public goods framework has also been utilized to model the consumption of brown goods. Unlike green goods, brown goods generate an externality by diminishing the level of the public good through pollution or increased emissions. Studies focusing on brown goods primarily focus on understanding whether individuals would willingly contribute funds to offset the environmental damage caused by consuming these goods. In this context, studies have revealed several key findings. In large economies, donations tend to converge to a value that compensates for the individual damage caused by each consumer (Vicary 2000). The level of individual income plays a significant role in determining whether consumers choose to donate an amount surpassing the pollution they generate from consuming brown goods (Kotchen 2009). While donations can mitigate net damages, they do not result in a decrease in the consumption of brown goods (Lange and Ziegler 2017; Lange, Schwirplies, and Ziegler 2017). Furthermore, although donations may improve individual welfare by addressing damages after they occur, they do not enhance economic efficiency within competitive markets (Kuhn and Uler 2019).

In my study, I examine the environmental impact of brown goods while considering green goods to be environmentally neutral. Instead of investigating the effect of donations to offset the damage caused by brown goods, my analysis centers on the tradeoff between consuming a more expensive good that does not generate pollution. The work that most closely aligns with my research is Kotchen (2005), which explores the comparative statics of individual consumption of green and brown goods. However, it does not analyze equilibrium outcomes or the influence of income inequality. To the best of my knowledge, this chapter represents the first attempt to explore the implications of inequality on the environment within the framework of impure public goods, providing the foundation for this research.

2.3 The Baseline Model

To answer my research questions, I first build a baseline model where there is a small economy with $n > 1$ consumers. Each consumer has an initial endowment w_i that is exogenously given. Preferences are defined over two objects: total private consumption (x_i) and environmental quality (Y). The object x_i shares the same characteristics as a private good, but Y is affected by the actions of all the consumers. As such, it is possible to think of Y as a public good (in the sense that it is non-rival and non-excludable). There are no markets for either x_i or Y. Instead, consumers can use their endowment to buy green goods (g_i) and/or brown goods (b_i). I assume that there are constant returns to scale in the production of these two goods and that they are sold in perfectly competitive markets. The price per unit of g_i is greater than the price per unit of b_i ($P_g > P_b$). The consumption of one unit of g_i has a proportional effect on X_i and no effect over Y. Similarly, the consumption of one unit of b_i has the same effect on x_i as g_i, but with the difference that it has a negative effect over Y. Let $\sum_{i=1}^{n} b_i$ denote the total consumption of the brown good in the economy. The level at which the public good is provided is $Y = Y^0 - \sum_{i=1}^{n} b_i$, where Y^0 is a positive and exogenous constant. The utility maximization problem that an individual consumer faces is:

$$max \quad U_i = U_i(x_i, Y) \quad \text{s.t.} \quad w_i = P_g g_i + P_b b_i$$

$$x_i = g_i + b_i \qquad (2.1)$$

$$Y = Y^0 - \sum_{i=1}^{n} b_i \qquad (2.2)$$

$$g_i \geq 0, \; b_i \geq 0$$

I assume that the utility function U_i is strictly increasing in each of its arguments and strictly quasiconcave. Therefore, the solution to this problem is unique and consumers will optimize their individual consumption of x_i and Y. However, these assumptions do not affect the total amount of g_i and b_i that each individual will buy. As a result, this model allows for the possibility to have some consumers allocating all their income to consume only one of the goods. With this outcome in mind, it is possible to identify three different categories of consumers:

- Green Consumers: They only consume green goods ($g_i^* > 0$, $b_i^* = 0$).
- Brown Consumers: They only consume brown goods ($g_i^* = 0$, $b_i^* > 0$).
- Mixed Consumers: They consume both goods ($g_i^* > 0$, $b_i^* > 0$).

To identify under which category each consumer falls, it is useful to compare the Marginal Rate of Substitution (MRS) to the following price ratio:

$$\frac{U_Y}{U_{x_i}} \gtrless \frac{P_g - P_b}{P_g} \qquad (2.3)$$

If the LHS is greater (less) than the RHS of (2.3), then these consumers are willing to pay more (less) than the price difference between g_i and b_i to preserve one unit of Y. Therefore, they will only consume g_i (b_i) and they will be considered Green (Brown) Consumers. If the LHS of (2.3) is equal to the RHS, then the price difference between g_i and b_i exactly identifies the willingness to pay to preserve one unit of Y and these consumers will choose a mixture of g_i and b_i to maximize their utility. Since they acquire both types of goods, they will be considered as Mixed Consumers.

2.3.1 Consumer Demands

To characterize the consumer demands for g_i and b_i, it is convenient to first express the utility maximization problem in terms of x_i and Y. Substituting (2.1) and (2.2) into the budget constraint and the non-negativity constraints we obtain:

$$max_{X_i,Y} \;\; U_i = U_i(x_i, Y) \quad \text{s.t.} \quad m_i = P_x x_i + P_Y Y \tag{2.4}$$

$$Y \leq Y_{-i} \tag{2.5}$$

$$X_i \geq Y_{-i} - Y \tag{2.6}$$

where:

$$Y_{-i} = Y^0 - \sum_{j \neq i} b_j \quad (2.7)$$

$$m_i = w_i + P_Y Y_{-i} \quad (2.8)$$

$$P_x = P_g \quad (2.9)$$

$$P_Y = P_g - P_b \quad (2.10)$$

The budget constraint in (2.4) considers that the "full income" of a consumer depends not only on the original endowment w_i , but also on the value of the exogenous Environmental Quality received (Y_{-i}) after everybody else has made their own consumption decisions. Each unit of these spill-ins and, overall, of each unit of Y is valued at P_Y. This virtual price P_Y is the difference of prices between goods g_i and b_i. The virtual price P_x is the unitary cost that every individual must pay to get one unit of characteristic x_i, and it is equal to price of g_i. Intuitively, the full-income constraint works as follows. Whenever consumers substitute away one unit of g_i for one of b_i, they effectively pay for one fewer unit of Y. This substitution allows them to have P_Y additional units of income, which they can use to increase their consumption of x_i.

Constraint (2.5) states that the level of Y cannot be greater than the exogenous level Y_{-i} provided by others, which comes from the non-negativity constraint on b_i. This situation happens because this model does not allow consumers to increase the provision of Y, they can just affect it in a negative manner through their consumption of b_i. Constraint (2.6) reflects the fact that the consumption of x_i must be at least the same as the difference between the level of Y_{-i} and Y or, in other words, the consumption of b_i. As such, it is a different way to interpret the non-negativity constraint on g_i. Figure 2.1

represents graphically this utility maximization problem in the (x_i, Y) plane. The line *bc* represents the full income constraint, while the lines *ab* and *ac* represent the non-negativity constraints on g_i and b_i. Hence, the triangle *abc* represents the consumption set.

Point *d* in Figure 2.1 represents an interior solution for the utility maximization problem and the first-order condition in (2.3) holds with equality. Since neither constraint (2.5) or constraint (2.6) binds in this situation, the individual demands of a Mixed Consumer can be fully characterized as:

$$x_i = x_i(P_x, P_Y, m_i) \tag{2.11}$$

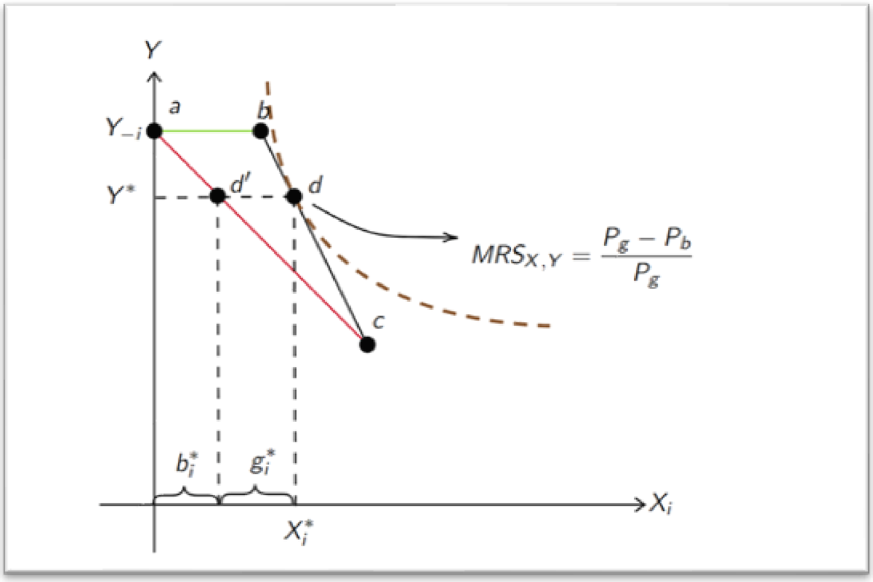
$$Y = y_i(P_x, P_Y, m_i) \tag{2.12}$$

Using the relationships in (2.1), (2.2), (2.5), (2.6), and (2.7) it is possible to recover the demands for both g_i and b_i from (2.11) and (2.12):

$$g_i = x_i(P_x, P_Y, m_i) - [Y_{-i} - y_i(P_x, P_Y, m_i)] \tag{2.13}$$

$$b_i = Y_{-i} - y_i(P_x, P_Y, m_i) \tag{2.14}$$

Figure 2.1. Consumption set in (x_i, Y) space



2.3.2 Nash Equilibrium

The individual demands in (2.11)-(2.14) depend on the term Y_{-i} (either through m_i or on its own), which implies that consumers optimize their decisions by considering the actions taken by others. Therefore, these individual demands can be considered as best response functions and the appropriate solution concept for this model is a Nash Equilibrium. To guarantee the existence of a unique Nash Equilibrium, it is convenient to impose the following assumption:

$$0 < \frac{\partial y_i}{\partial Y_{-i}} < 1 \qquad (2.15)$$

The assumption in (2.15) guarantees that both x_i and Y are normal with respect to income, and its use is standard in models of privately provided public goods (i.e., Bergstrom, Blume and Varian 1986; Kotchen 2006). Since Y is normal, there exists an inverse function $y_i^{-1}(\cdot)$ such that:

$$
\begin{aligned}
&y_i^{-1}(P_x, P_Y, Y) = m_i \\
&y_i^{-1}(P_x, P_Y, Y) = w_i + P_Y Y_{-i} \qquad (2.16)
\end{aligned}
$$

The interpretation of (2.16) is that the term $y_i^{-1}(P_x, P_Y, Y)$ represents the full-income a consumer must have to demand a given level of Y at prices P_x and P_Y. Using the identity $Y_{-i} = Y + b_i$,[1] it is possible to use (2.16) to express b_i as a conditional demand given the level of Y. Suppressing notation for prices, denote this conditional demand as $\hat{b}_i(Y)$:[2]

$$\hat{b}_i(Y) = \frac{y_i^{-1}(P_x, P_Y, Y) - w_i}{P_Y} - Y \qquad (2.17)$$

[1] This identity comes from substituting (2.7) into (2.2) and rearranging.
[2] Cornes and Hartley (2007) define it as a Replacement Function because it identifies the best response to keep Environmental Quality fixed at a level Y. If there is an exogenous variation in this level, then the individual demand would exactly *replace* it.

It is possible to follow a similar approach for g_i. The first-order condition in (2.3) implicitly defines a function $x_i = x_i(P_x, P_Y, Y)$. Substituting this function and (2.17) into (2.1) gives:

$$\hat{g}_i(Y) = x_i(P_x, P_Y, Y) - [\frac{y_i^{-1}(P_x, P_Y, Y) - w_i}{P_Y} - Y] \qquad (2.18)$$

The conditional demands in (2.17) and (2.18) are useful to state the following lemma:

Lemma 2.1: *Given a level of* Y, *there exists a critical income level* $w_i^G = w_i^G(P_x, P_Y, Y)$ *implicitly defined as:*

i) $0 = \frac{y_i^{-1}(P_x, P_Y, Y) - w_i^G}{P_Y} - Y$, *or*

ii) $\frac{w_i^G}{P_g} = x_i(P_x, P_Y, Y) - [\frac{y_i^{-1}(P_x, P_Y, Y) - w_i^G}{P_Y} - Y]$

above which consumer i *becomes a Green Consumer, and another critical income level* $w_i^B = w_i^B(P_x, P_Y, Y)$ *implicitly defined as:*

i) $\frac{w_i^B}{P_b} = \frac{y_i^{-1}(P_x, P_Y, Y) - w_i^B}{P_Y} - Y$, *or*

ii) $0 = x_i(P_x, P_Y, Y) - [\frac{y_i^{-1}(P_x, P_Y, Y) - w_i^B}{P_Y} - Y]$

below which consumer i becomes a Brown Consumer. Both $w_i^G(P_x, P_Y, Y)$ and $w_i^B(P_x, P_Y, Y)$ are continuous and increasing functions in Y. Furthermore, $w_i^G > w_i^B > 0$ and $\frac{w_i^B}{w_i^G} = \frac{P_x - P_Y}{P_x}$ $\forall\, Y \in \mathbb{R}$.

All proofs are included in Appendix A. Lemma 2.1 is helpful to understand the impact that income w_i has in this model. A sufficiently low income can induce consumers to allocate all their income to consume units of b_i regardless of their attitudes or preferences towards the level of Y. Conversely, a sufficiently high income can induce consumers to do the opposite and allocate all their income to consume units of g_i. It is important to note that these income levels need not be the same for every individual. Both $w_i^G = w_i^G(P_x, P_Y, Y)$ and $w_i^B = w_i^B(P_x, P_Y, Y)$ include the term $y_i^{-1}(P_x, P_Y, Y)$ within their definition, which implies that individual preferences have an impact in determining them. However, there always exists a range of income in which any given individual behaves as a Mixed Consumer.

The results in Lemma 2.1 are helpful to characterize the full schedule of the demands for g_i and b_i. Suppressing notation for prices, denote these full schedules as $g_i(w_i, Y)$ and $b_i(w_i, Y)$:

$$g_i(w_i, Y) = \begin{cases} w_i/P_g & if \quad w_i \geq w_i^G \\ \hat{g}_i(Y) & if \quad w_i \in [w_i^B, w_i^G] \\ 0 & if \quad w_i \leq w_i^B \end{cases}$$

$$b_i(w_i, Y) = \begin{cases} 0 & if \quad w_i \geq w_i^G \\ \hat{b}_i(Y) & if \quad w_i \in [w_i^B, w_i^G] \\ w_i/P_b & if \quad w_i \leq w_i^B \end{cases} \qquad (2.19)$$

where $\hat{g}_i(Y)$ and $\hat{b}_i(Y)$ are defined as in (2.18) and (2.17), respectively. The results from Lemma 2.1 help describe how different levels of income will have an impact on the demands for g_i and b_i. However, these results do not give an explanation about the impacts that the level of Y has in the demand schedules. Lemma 2.2 provides an answer to that question.

Lemma 2.2: *$b_i(w_i, Y)$ is a continuous and weakly increasing function in Y, and strictly increasing if $w_i \in [w_i^B, w_i^G]$.*

The implication of Lemma 2.2 is that an increase in the level of Y will not lead to a reduction in the consumption of b_i and, generally, it will increase it. This effect occurs because a higher level of Y reduces its marginal utility and consumers now have an incentive to increase their consumption of x_i. To fund this consumption pattern, consumers must decrease their consumption of g_i and increase it for b_i.

Using the results from Lemma 2.1 and Lemma 2.2, it is possible to state the following proposition:

Proposition 2.3: *There exists a unique Nash Equilibrium Y^* given by:*

$$Y^0 - \sum_{i=1}^{n} b_i(Y^*) = Y^* \tag{2.20}$$

Substituting the demand schedules (2.19) in (2.20) and rearranging gives:

$$\sum_{i \in M} y_i^{-1}(P_x, P_Y, Y^*) - P_Y(n_M - 1)Y^* = \sum_{i \in M} w_i + P_Y \left[K - \frac{\sum_{j \in B} w_j}{P_x - P_Y}\right] \tag{2.21}$$

where the subscripts M and B denote the set of Mixed and Brown Consumers, respectively, and n_M denotes the total number of Mixed Consumers. The interpretation of expression (2.21) is that, given the preferences of the Mixed Consumers, the wealth required to sustain Y^* as a Nash Equilibrium outcome must be equal to their aggregate full income. Additionally, expression (2.21) is also helpful to state the following proposition:

Proposition 2.4: *Let Y^* be a Nash Equilibrium. Then a marginal increase in w_i:*

i) *increases Y^* if i is a Mixed Consumer;*

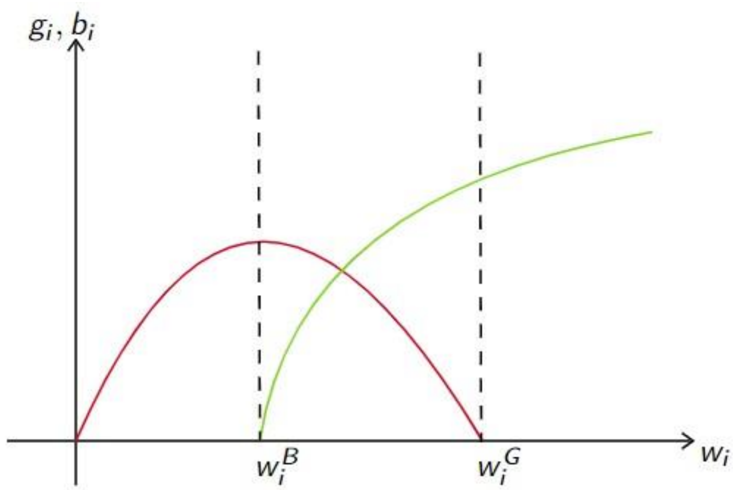
ii) *decreases Y^* if i is a Brown Consumer; and*

iii) *does not have an impact on Y^* if i is a Green Consumer.*

Given the results from Proposition 2.4, it is possible to state the following result:

Corollary 2.5: *In a Nash Equilibrium, the brown good is an inferior good for Mixed Consumers and a normal good for Brown Consumers. Similarly, the green good is a normal good for Mixed and Green consumers.*

Figure 2.2. Consumption of the green and brown good as income changes



As a consequence of Proposition 2.4, changes in income have different impacts on the level of Y^* along the income distribution. In particular, a redistribution of income can have ambiguous results on the level of Y^*, such that a more egalitarian distribution might cause Y^* to decrease in some situations, stay the same in others, or might even increase in some cases. Proposition 2.6 explains the different possible scenarios.

Proposition 2.6: *Let there be a transfer of income between two different consumers such that each of them remain in their same category of consumers pre- and post-transfer. Then in a Nash Equilibrium:*

i) *A transfer from a Green Consumer to:*

  a. *another Green Consumer does not affect the level of* Y^*;

  b. *a Mixed Consumer increases the level of* Y^*;

  c. *a Brown Consumer reduces the level of* Y^*.

ii) *A transfer from a Mixed Consumer to:*

  a. *A Green Consumer reduces the level of* Y^*;

  b. *Another Mixed Consumer does not affect the level of* Y^*;

  c. *A Brown Consumer reduces the level of* Y^*.

iii) *A transfer from a Brown Consumer to:*

  a. *a Green Consumer increases the level of* Y^*;

  b. *a Mixed Consumer increases the level of* Y^*;

  c. *a Brown Consumer does not affect the level of* Y^*.

I summarize the results from Proposition 2.6 in Table 2.1. These findings contrast with the typical outcomes from studies examining the provision of public goods by private individuals (i.e., Bergstrom, Blume, and Varian 1986; Boadway and Hayashi 1999; Cornes and Sandler 2000; Olszewski and Rosenthal 2004; Uler 2009) which usually only consider two types of consumers: contributors to the public good and non-contributors. In such cases, redistributing income from contributors to non-contributors unambiguously decreases the level of Y^*, provided that this new distribution does not alter the category of any consumer. As a result, there exists a tradeoff between reducing income inequality and public good provision. Furthermore, it has been shown that an optimal degree of inequality exists between these two groups (Bardhan, Ghatak, and Karaivanov 2007).

Table 2.1. Effect of income transfers on Y^*

To / From	Green consumer	Mixed consumer	Brown consumer
Green consumer	=	+	-
Mixed consumer	-	=	-
Brown consumer	+	+	=

In contrast, my baseline model distinguishes between three types of consumers: Green, Mixed, and Brown Consumers. Green and Mixed Consumers contribute to the environment by purchasing green goods or avoiding brown goods, which can be considered as a positive action towards environmental sustainability and akin to contributing to the public good. On the other hand, Brown Consumers allocate all their income towards consuming brown goods and are therefore equivalent to non-contributors in previous studies.

In the context of three distinct groups, where two of them play a significant role as contributors, the impact on Y^* resulting from changes in the income distribution is contingent upon the specific types involved in the process. Proposition 2.6 demonstrates that income transfers from Brown to Green or Mixed Consumers, as well as from Green to Mixed Consumers, lead to an increase in Y^*. Conversely, income transfers from Green or Mixed to Brown, or from Mixed to Green Consumers, result in a decrease in Y^*. Consequently, certain scenarios offer the opportunity to achieve higher levels of both equality and improved environmental quality simultaneously. Policymakers should take into account these varying impacts when creating strategies that successfully promote both goals.

2.4 Effect of income inequality on welfare and environmental quality

The possibility of increasing public good provision through income transfers presents the opportunity to examine whether redistributive policies can not only have positive welfare effects, but also achieve Pareto-improving outcomes. To do so, it is necessary for environmental quality to improve sufficiently to compensate for the negative impact imposed on those consumers who lose income. Proposition 1.3 suggests that Mixed Consumers are the ideal recipients of income transfers because they have the incentive to reduce their consumption of brown goods and potentially improve environmental quality. Additionally, Green or Brown Consumers might benefit from transferring a portion of their income, as their welfare loss caused by the decrease in their consumption possibilities may be offset by the overall increase in environmental quality.

To illustrate this claim more clearly, consider a small economy where all consumers have the same preferences (i.e., $U_i = U(x_i, Y)$) and the only source of heterogeneity being the initial income that each consumer has. In this case, the critical income levels for all consumers are the same, denoted as w^G and w^B, respectively. Therefore, Green Consumers will have the highest income, followed by Mixed Consumers, and Brown Consumers will have the lowest income. Let Y^* be the Nash Equilibrium level of environmental quality. By suppressing the price notation for ($\mathbf{1.16}$) and using the identity $m_i = y^{-1}(Y^*)$, it is possible to write the utility functions of each consumer in equilibrium as follows:

$$U_i = \begin{cases} U\left(\frac{w_i}{P_x}, Y^*\right) & if \quad w_i \geq w^G \\ U(x(y^{-1}(Y^*)), Y^*) & if \quad w_i \in [w^B, w^G] \\ U\left(\frac{w_i}{P_x - P_Y}, Y^*\right) & if \quad w_i \leq w^B \end{cases}$$

Suppose that income is redistributed among some individuals such that $\sum_{i=1}^{n} dw_i = 0$ The change in welfare (dU_i) for each consumer can then be expressed as:

$$dU_i = \begin{cases} \dfrac{U_x}{P_x} dw_1 + U_Y d_{Y^*} & if \quad w_i \geq w^G \\ \left(U_x \dfrac{X_m}{y_m} + U_Y\right) d_{Y^*} & if \quad w_i \in [w^B, w^G] \\ \dfrac{U_{x_3}}{P_x - P_Y} dw_3 + U_Y d_{Y^*} & if \quad w_i \leq w^B \end{cases}$$

where:

$$d_{Y^*} = \sum_{i \in M} \frac{\partial Y^*}{\partial w_i} dw_i + \sum_{j \in B} \frac{\partial Y^*}{\partial w_j} dw_j + \sum_{k \in G} \frac{\partial Y^*}{\partial w_k} dw_k$$

and X_{2m} and y_{2m} are the derivatives of (2.11) and (2.12) with respect to income. These two terms are positive as a consequence of (2.15). By assumption, U_{x_i}, U_Y, P_x and $P_x - P_Y$ are also positive terms. Additionally, the subindices M, B, and G represent the sets of Mixed, Brown, and Mixed consumers. The expression d_{Y^*} describes how Y^* changes when there is a redistribution of income. From Proposition 2, the sign of $\frac{\partial Y^*}{\partial w_i}$ is positive if i is a Mixed Consumer, negative if i is a Brown Consumer, and equal to zero if i is a Green Consumer.

First, consider the case when a Green Consumer transfers one unit of income to a Mixed Consumer ($\sum dw_G = -1$, $\sum dw_M = 1$, $\sum dw_B = 0$). This transfer increases the provision level of Y^*, decreases inequality between the Green and Mixed Consumers, and results in an unambiguous. Increase in the welfare of everyone except the Green Consumer who lost the income unit. However, the welfare of the Green Consumer can also increase if $d_{Y^*} > \frac{U_{x_1}}{P_x U_Y}$. The appendix to this chapter includes an example using a Cobb-Douglas utility function where this situation occurs. This result shows that reducing inequality between Green and Mixed Consumers not only increases the provision level of Y^* but it can also make everyone better off. Thus, reducing income inequality can be beneficial both to environmental quality and social welfare.

Unfortunately, this result is not generalizable to all types of transfers and, in fact, could lead to a complete opposite outcome. For instance, if a Green Consumer transfers a unit of income to multiple Brown Consumers (i.e., $\sum dw_G = -2, \sum dw_M = 0, \sum dw_B = 2$), it will decrease the provision level of Y^* and unambiguously reduce the welfare of everyone, except for the recipients of the income transfer. However, the welfare of the transfer recipients can be negatively affected if $-d_{Y^*} > \frac{U_{x_3}}{(P_X - P_Y) U_Y}$. The Appendix to this chapter also includes an example using a quasilinear utility function where this situation occurs. This result shows that income transfers from Green to Brown Consumers decrease the provision level of Y^* and can also generate a Pareto-diminishing outcome. Therefore, reducing income inequality can be detrimental both to environmental quality and social welfare. The contrast between the two previous results highlights the importance of distinguishing situations where income-equalizing transfers can be beneficial and those that leave everyone worse off.

It is important to note that the income redistribution examples discussed in this section assume that the sets of Green, Mixed, and Brown Consumers remain the same.

With a larger redistribution, Pareto-improving outcomes may become unfeasible, but it can still help to improve social welfare. Furthermore, there can be some circumstances where it could be possible to achieve the socially efficient level of Y. I analyze this last situation in the following chapter by proposing a public policy to address the market failures that are present in the model.

2.5 Conclusion

Throughout this chapter, my aim has been to explore the impact of income inequality on environmental quality. While the topic has been widely debated in the literature, my research provides some clarity on this issue and helps to understand, from a theoretical point of view, why conflicting results have been reported. To investigate this relationship, I adapted the model of impure public goods consumption, which examines how consumers make their consumption decisions when they can choose between environmentally harmful goods that are cheap (brown goods) and environmentally friendly goods that are more expensive (green goods).

My model classifies consumers into three groups: Green Consumers, Mixed Consumers, and Brown Consumers. While the decision about which group to belong to depends on both income and individual preferences, the model predicts that each consumer will always have two critical income levels. Below the first one, consumers are better off being Brown Consumers and consuming only brown goods, as the cost of substituting brown goods for green goods is greater than the benefit of protecting one unit of environmental quality. This implies that for consumers below this income level, promoting environmentally sustainable consumption behavior requires addressing their financial constraints.

Between the two critical income levels, consumers will choose to be Mixed Consumers, as the individual cost of paying the price difference to substitute some brown goods for green goods is now beneficial to preserve environmental quality. Above the second critical level, consumers are better off being Green Consumers, as they can fully satisfy their consumption needs by purchasing only green goods while minimizing the damage to environmental quality. However, it is important to note that the critical income levels are dependent on individual preferences. As a result, it is possible for a consumer with lower income to become a Mixed or Green Consumer, while a wealthier one may remain a Brown Consumer.

This relationship between income and individual consumption results from the assumption that both total private consumption and environmental quality are normal goods, implying that consumers have a higher demand for both when financial constraints are absent. However, consumers prioritize their private consumption at the expense of environmental quality when income levels are low. Consequently, as consumers transition from Brown to Mixed Consumers, they increase their consumption of brown goods, negatively impacting environmental quality. However, as consumers become Mixed Consumers and transition to Green Consumers, they decrease their consumption of brown goods, leading to a reduction in pollution and an improvement in environmental quality. This pattern is reminiscent of the Environmental Kuznets Curve at the individual level.

This finding has important implications for policymakers and businesses aiming to promote sustainable consumption behavior, particularly for consumers with low and middle incomes who may wish to engage in pro-environmental behavior. To promote sustainable consumption behavior among low-income consumers, policymakers need to focus on providing affordable green goods and services. They may also need to provide financial incentives such as subsidies, tax credits, and other forms of support to encourage green consumption.

Finally, by examining how individuals make consumption decisions as their income changes, the baseline model offers valuable insights into how income inequality impacts the environment. Consistent with the findings of models dealing with pure public goods, changes in the income distribution will have no impact on environmental, provided that the total income of Green, Brown, and Mixed consumers remains constant. However, if income redistribution increases the total income of Mixed Consumers or decreases the total income of Brown Consumers, there will be a positive effect on environmental quality. Conversely, if the total income of Brown Consumers increases at the expense of Green or Mixed Consumers, environmental quality will decrease.

It is also important to consider that income transfers between different types of consumers can have different effects on environmental quality and social welfare, depending on the set of consumers involved and the magnitude of the income transfer. My analysis reveals that income-equalizing transfers can be beneficial in some situations, but detrimental in others. Thus, policymakers should distinguish between situations to avoid income transfers that negatively impact social welfare. Additionally, I identify scenarios where reducing income inequality can improve environmental quality, emphasizing the need to develop policies that address both issues simultaneously. In the following chapter, I analyze a policy that can achieve these two objectives, by addressing the market failures that prevent the attainment of the socially efficient level of environmental quality.

Chapter 3 : Double trouble – The impact of tradable permits in green markets

3.1 Introduction

In the previous chapter of this dissertation, I analyzed how consumers make choices in competitive markets regarding the consumption of green and brown goods, and their impact over environmental quality under different types of income inequality. However, these individual choices neglect to consider the harm caused by the consumption of brown goods to the wider population, resulting in an externality problem. This problem leads to suboptimal resource allocation and negative welfare consequences for society as a whole.

While addressing the externality problem is crucial for achieving socially optimal outcomes, it is equally important to tackle the problem of income inequality. Low-income consumers face significant constraints in their consumption choices, and their consumption of brown goods may be driven by these constraints rather than their preferences. Addressing income inequality is important in its own right and, based on the results from the previous chapter, it can also have a positive effect on environmental quality under certain circumstances. Therefore, it is important to design policies that can effectively tackle both problems at the same time.

In this regard, I propose the implementation of a permit market that limits individual consumption of brown goods and facilitates permit trading among consumers. This market concept draws inspiration from the literature on individual-transferable quotas (ITQs) which has demonstrated their potential for efficient outcomes with minimal information requirements (Arnason 1990, Heaps 2003, Arnason 2009). Under this policy, a regulatory agency would allocate permits to consumers, limiting their consumption of brown goods. Once consumers exhaust their permits, they would be unable to purchase additional units of the brown good. However, they could acquire extra permits from other consumers who haven't fully utilized theirs, enabling an increase in their brown goods consumption. This system creates an opportunity for individuals with lower brown goods consumption to generate additional income by selling their unused permits to those with higher demand. The revenue generated from permit sales could be used to increase their consumption of either green or brown goods.

The primary objective of this proposed policy is to address the externality problem associated with brown goods consumption by internalizing the costs of their environmental damage. It accomplishes this by increasing the effective price of brown goods and implementing a cap on their aggregate consumption. Consequently, the policy ensures a minimum level of environmental quality that surpasses what would be attained in a competitive market. Additionally, the policy facilitates market-based income transfers among consumers. Low-income individuals who consume fewer brown goods can earn supplementary income by selling their unused permits, thus mitigating their income constraints. By simultaneously addressing the externality problem and income inequality, the proposed policy has the potential to achieve socially optimal outcomes that benefit all members of society.

Based on my analysis, I find that if all consumers act as price-takers and willingly participate in the market as buyers or sellers, the regulatory agency can use the initial distribution of permits as a policy tool to achieve an optimal trading price. This price would equalize the marginal rates of substitution for all consumers, resulting in a socially efficient level of environmental quality and a reduction in income inequality.

This chapter contributes to the existing literature on impure public goods provision (Cornes and Sandler 1984, 1994) by proposing an optimal policy framework for green and brown goods consumption. Previous approaches, such as Pigouvian taxes and direct transfers, face challenges when consumers have heterogeneous preferences, necessitating individualized tax schemes (Atkinson and Stern 1974; Boadway and Keen 1993; Itaya, de Meza, and Myles 1997). To overcome this issue, alternative methods have been explored, including compensatory taxation (McMahon 2015), incentive-compatible mechanisms (Wichman 2016), and cost-sharing mechanisms (Chan and Dinelli 2020). However, these approaches assume access to detailed preference information or the ability to implement personalized pricing. In contrast, my proposed policy avoids these challenges by incentivizing permit trading among consumers to establish an equilibrium market price.

However, it is important to acknowledge that the optimality of this policy is contingent upon complete market participation, which may not be realized in practice. Consequently, consumers who choose not to participate may experience varying marginal rates of substitution, potentially impeding the ability to achieve the socially efficient level of environmental quality. Despite this limitation, the permit market remains a valuable second-best policy approach as it effectively addresses income inequality and promotes environmental quality improvements.

The rest of this chapter is organized as follows. In section 3.2 I provide a review of the literature on Individual Transferable Quotas (ITQs), tradable permits, and their application as a policy instrument. In Section 3.3, I introduce the social choice model and highlight its distinctions from the baseline model discussed in Chapter 2. In Section 3.4 I present the permit market model, explaining the different decision-making processes that buyers and sellers have to make. I show the outcomes resulting from the market equilibrium in section 3.5. Finally, in Section 3.6, I offer concluding remarks on the chapter's findings.

3.2 Literature Review

The concept of using tradable permits to address pollution and manage common-pool resources emerged from the economic discussions of the 1960s and 1970s, focused on the theory of externalities (Dales, 1968; Baumol and Oates, 1988). It is based on the recognition that environmental issues arise due to the absence of well-functioning markets (Gordon, 1954; Coase, 1960; Hardin, 1968). By implementing tradeable permits, the aim is to establish a market that enforces property rights related to environmental usage, fostering a competitive market with minimal transaction costs. This enables individuals to negotiate and trade these rights efficiently.

Tradable permit schemes have the potential to effectively address challenges such as overfishing and pollution without relying on direct regulatory measures like taxes or technical standards, while maximizing economic rents (Arnason, 1990; Shotton, 2000). Essential characteristics of these permits include permanence, security, exclusivity, and tradability (Scott 1989; Grafton 1996; Squires, Kirkley, and Tisdell 1995; Arnason, 2007; Libecap 2007). Ultimately, the objective is to minimize the costs associated with achieving predetermined environmental targets.

Examples of this approach include the implementation of individual transferable quotas (ITQ) in fisheries, which have been studied extensively (McCay, Creed, Finlayson, Apostle and Mikalsen 1995; Hermann 2000; Arnason 2002, 2005; Hilbron, Orensanz and Parma 2005; Stewart, Walshe, & Moodie 2006; Chu, 2009; Brinson and Thunberg 2016), and the adoption of emission trading schemes (ETS) to mitigate pollutant discharge into the environment (Demailly and Quirion 2008; Cullenward and Coghlan 2016; Martin, Muûls, and Wagner 2016; Narassimhan, Gallagher, Koester and Alejo 2018). In practice, specifically for ETS, a central regulator assigns or sells a limited number of emission permits based on an emission reduction target. Polluters are obligated to hold permits equivalent to or exceeding their emitted quantity. This system resembles a cap-and-trade mechanism that employs quantity as a planning instrument to achieve a desired output level, such as clean air, while motivating producers to minimize production costs (Weitzman, 1974).

Although permit schemes have been effective in enhancing the efficiency of environmental resource management, particularly in U.S. fisheries (Wang, 1995; Annala 1996; Weninger, 1998; Arnason 2012; Brinson and Thunberg, 2016), they have faced criticism for their insensitivity to social needs, inequitable distributional consequences, and disproportionate impact on small stakeholders (Copes and Charles 2004; Olson 2011; Knapp 2011; Carothers and Chambers 2012; Soliman 2014). Therefore, it is crucial to consider the distributional effects of initial permit allocation to ensure access for income-constrained individuals while balancing equity and efficiency concerns (Laffont and Robert 1996; Che, Gale and Kim 2013; Holzer and McConnell 2023). This chapter contributes to the existing literature by proposing permit allocation as a policy tool that favors income-constrained consumers who can derive greater monetary gains from reselling permits, while also ensuring that their polluting consumption remains restrained due to their economic disadvantage.

3.3 Social planner model

Suppose that there is a regulatory agency that wishes to maximize social welfare. To that extent, this agency will try to find the optimal level of environmental quality (Y) given the total income in the economy $(\sum_{i=1}^{n} w_i)$ and the market prices of the green (g_i) and brown goods (b_i). The overall social budget is: $\sum_{i=1}^{n} w_i = P_g \sum_{i=1}^{n} g_i + P_b \sum_{i=1}^{n} b_i$. Considering the identities from the baseline model $x_i = g_i + b_i$ and $Y = Y^0 - \sum_{i=1}^{n} b_i$, then it is possible to write the social budget in terms of x_i and Y.

$$M = P_x \sum_{i=1}^{n} x_i + P_Y Y$$

where $M = \sum_{i=1}^{n} w_i + P_Y Y^0$, $P_x = P_g$, $P_Y = P_g - P_b$, and $Y^0 > 0$ is the initial, exogenous value of environmental quality. The regulatory agency evaluates a social welfare function $S(\cdot)$ that includes the utility of every consumer as one of its arguments. Since each consumer has their own unique utility function, the social welfare function includes a separate argument for each of these functions. This $S(\cdot)$ function shares the same properties as the individual utility functions: it is quasiconcave, continuous, and strictly increasing in each of its arguments. The agency's problem is therefore to choose the level of total consumption for every consumer and the overall level of environmental quality:

$$\max_{x_1, x_2, \dots, x_n, Y} \left\{ S\big(U_1(x_1, Y), U_2(x_2, Y), \dots, U_n(x_n, Y)\big) \,\middle|\, M = P_x \sum_{i=1}^{n} x_i + P_Y Y \right\}$$

Assuming that the optimal level of Y is located somewhere in the interior,[3] then the socially optimal allocation is the unique solution to the following $n+1$ first-order conditions:

$$\frac{\partial S}{\partial U_i} \cdot \frac{\partial U_i}{\partial x_i} - \lambda P_x = 0, \qquad i = 1, 2, \dots, n$$

$$\sum_{i=1}^{n} \frac{\partial S}{\partial U_i} \cdot \frac{\partial U_i}{\partial Y} - \lambda P_Y = 0$$

[3] The maximum value that Y can have is Y^0, and it occurs if there is no consumption of b_i in the economy. The minimum value would be $Y^0 - \frac{\sum_{i=1}^{n} w_i}{P_b}$ and it occurs if there is no consumption of g_i in the economy. Therefore, the previous statement refers to the scenario where the regulatory agency will look to have a positive consumption of both g_i and b_i.

where λ is the Lagrange multiplier associated with the social budget constraint. From the previous set of equations, the optimal marginal rate of substitution for each consumer i must be equal to:

$$\frac{\partial U_i / \partial x_i}{\partial U_i / \partial Y} = \frac{P_x}{P_Y}\left[1 + \frac{S_{Y_{-i}}}{\frac{\partial S}{\partial U_i}\frac{\partial U_i}{\partial Y}}\right], \qquad i = 1,2, \dots, n \tag{3.1}$$

where $S_{Y_{-i}} = \sum_{j \neq i} \frac{\partial S}{\partial U_j} \cdot \frac{\partial U_j}{\partial x_j} > 0$. The result in (3.1) highlights two important ways in which the social optimum differs from the competitive equilibrium. First, achieving the social optimum requires all consumers to have an equal marginal rate of substitution. This is satisfied by Mixed consumers, but not by Green and Brown consumers who have different marginal rates of substitution from the price ratio between P_x and P_Y. Second, to account for the externality created by Brown goods, the social optimum requires a higher marginal rate of substitution than this price ratio. As a result, a policy to achieve the social optimum would require two separate instruments to address each one of these issues.

To mitigate the negative impacts of brown goods consumption, I suggest implementing a market for permits based on the individual-transferable quotas (ITQs) model. The proposed model involves a regulatory agency issuing permits to consumers to limit their consumption of brown goods. Once consumers use up their allotted permits, they cannot purchase any additional units of the brown good. However, they can purchase additional permits from other consumers who have not exhausted theirs. This system provides an opportunity for those who consume fewer brown goods to earn extra income by selling their unused permits to those who require more. The proceeds obtained from selling permits can then be used to increase their consumption of either green or brown goods.

The cost of acquiring a permit would be equivalent to an increase in the price of the brown good. The market would determine the price of the permits, and all consumers would adjust their consumption decisions based on the publicly available information. The revenue from selling the permits would go directly to the sellers, without the need for the regulatory agency to redistribute it. As such, the market for permits would have two policy instruments: the equilibrium price for permits and the total number of permits set by the regulator. By setting a maximum number of permits, the market would solve the externality problem caused by brown goods consumption. The equilibrium price would establish the optimal transfer that certain consumers should receive, leading to a more efficient allocation of resources or higher overall welfare.

3.4 The market for permits

Following the baseline model outlined in Chapter 1, I consider an economy with $i = 1,2, \ldots, n$ consumers who derive utility $U_i(x_i, Y)$ from total private consumption (x_i) and environmental quality (Y), which I model as a pure public good. Consumers can choose to buy either green (g_i) or brown (b_i) goods, such that $x_i = g_i + b_i$. Initially, the level of environmental quality is set at an exogenous level Y^0. However, the consumption of b_i generates a negative externality over environmental quality. Specifically, if anyone in the economy consumes one unit of b_i, then the level of environmental quality will decrease by one unit (i.e., $Y = Y^0 - \sum_{i=1}^{n} b_i$).

I assume that the price of the green good (P_g) is higher than the price of the brown good (P_b), and that the individual income (w_i) is exogenously determined. The utility function is strictly increasing in both x_i and Y, continuously differentiable, and quasiconcave. The individual demand for environmental quality has the following property:

$$\frac{\partial Y}{\partial Y_{-i}} \in (0,1) \tag{3.2}$$

where $Y_{-i} = Y^0 - \sum_{j \neq i} b_j$ is the exogenous value of environmental quality that consumer i receives at the moment of making the individual consumption decisions. The property in (3.2) is called the normality assumption and guarantees that both x_i and Y are strictly normal goods.

The regulatory agency seeks to establish a minimum environmental quality for the economy, which it achieves by setting a cap on the total consumption of brown goods. To implement this cap, the agency first distributes an initial endowment of permits to every consumer i. Each permit entitles the consumer to purchase one unit of b_i at the market price P_b. Therefore, the maximum number of units of the brown good that consumers can buy is equal to the number of permits they initially receive. Let $\bar{q}_i$

denote the initial permits received by consumer i and $\overline{\boldsymbol{Q}} = (\bar{q}_1, \bar{q}_2, \dots, \bar{q}_n)$ the vector of all permits assigned by the regulator.

Consumers will have the option to buy a permit from someone else if they wish to consume additional units of b_i than initially allowed. The regulator allows potential buyers and sellers to negotiate the price of each permit (P_q) freely. I assume that all individuals behave as price takers, there is perfect information about all trades, negligible transaction costs, and that P_q settles at the market-clearing level of a perfectly competitive market. The sellers of permits can use the revenue they earn to increase their total private consumption. In the following section, I will analyze the buyers' and the sellers' problems separately.

3.4.1 The Buyers' Problem

Consider a scenario where the regulator assigns an initial endowment of $\bar{q}_i$ permits to consumer i ($\bar{q}_i \geq 0$), but the individual demand for b_i is greater than this amount. As a result, this consumer will have the incentive to buy additional permits from the market. Let q_i^d denote the number of permits demanded by consumer i. It is important to note that a portion of the individual income must be allocated to this new expenditure. However, it provides an opportunity to increase the consumption of b_i beyond the cap set by $\bar{q}_i$ (i.e., $b_i \leq \bar{q}_i + q_i^d$). Given this context, the consumer solves a utility maximization problem by considering the trade-off between purchasing additional permits and the other consumption goods, subject to the budget and brown consumption constraints.

$$\max_{x_i, Y, g_i, b_i, q_i^d} \left\{ U_i(x_i, Y) \middle| \begin{array}{ll} w_i = P_g g_i + P_b b_i + P_q q_i^d, & b_i \leq \bar{q}_i + q_i^d, \\ x_i = g_i + b_i, & Y = Y_{-i} - b_i - \dfrac{P_q q_i^d}{P_b}, \\ & g_i, b_i, q_i^d \geq 0 \end{array} \right\} \quad (3.3)$$

where $Y_{-i} = K - \sum_{j \neq i} b_j$ refers to the exogenous environmental quality that consumer i faces after all other consumers have made their own consumption decisions. This utility-maximization problem differs from the baseline model in three aspects. The first one is that the income constraint now considers that consumers may destine a portion of their income to trade for permits (q_i^d) to increase their brown consumption. The second condition is that the individual consumption of the brown good is now limited by the number of permits that consumer i obtains, either through the initial assignation or by trading in the market. The third is that buyers must consider that their purchase of permits will have an adverse impact on environmental quality since all sellers utilize the proceeds from permit sales to increase their consumption of brown goods.[4]

In this setup, consumers need to consider if it is optimal to acquire additional permits in the market and, if so, determine how many they require. From (3.3), the term

[4] In the following section, I explain why sellers allocate the revenue from selling permits towards increasing their consumption of brown goods.

q_i^d appears only in the budget and brown consumption constraints. As such. the individual demand for permits can be characterized by its first-order condition:

$$\lambda_w P_q = \lambda_b + \mu_q$$

where λ_w and λ_b are the Lagrange multipliers associated to each of the constraints and μ_q is the multiplier related with the non-negativity constraint on q_i^d. Note that if $b_i \leq \bar{q}_i + q_i^d$ is not binding, then $\lambda_b = 0$. As a consequence, the first-order condition over q_i^s requires that $\mu_q > 0$ and $q_i^{d^*} = 0$.[5] This situation implies that acquiring additional permits in the market is not optimal, as these consumers can fulfill their demand for b_i with their initial allocation $\bar{q}_i$.[6] By not participating in the market, the utility maximization problem reverts to the baseline model and consumers would follow the same behavior outlined in it.

For the case in which $q_i^{d^*} > 0$, it follows that $b_i = \bar{q}_i + q_i^d$. This implies that the individual demand for permits must fully offset the demand for the brown good, considering the initial allocation $\bar{q}_i$. By substituting this equality into the budget constraint, we can derive the following condition:

[5] The previous condition will not hold in the special case where $P_q = 0$. In this situation, there would be free disposal of permits and consumers would get any amount of them without impacting their optimal choice of g_i^* and b_i^*.

[6] In this situation, consumers may have unused permits that they could simply discard. I present an overview of the incentives required to motivate consumers to sell their surplus permits in the following section.

$$w_i - P_b \bar{q}_i = P_g g_i + \left(P_b + P_q\right) q_i^d$$

When consumers act as buyers in the market, they exhaust their initial permits to acquire as many units of b_i as possible at the prevailing price P_b. Once this is achieved, they allocate their remaining income towards the purchase of additional units of the green good, or towards the acquisition of more permits, which would enable them to consume more units of the brown good. As it is optimal to obtain one additional permit for every unit of the brown good consumed, the cost of purchasing one permit is implicitly given by the sum $P_b + P_q$. By representing the income constraint in this manner, it is possible to employ the identities stated in (3.3) to reformulate the utility-maximizing problem as:

$$\max_{x_i, Y} \left\{ \left. U_i(x_i, Y) \right| \, m_i^d = P_x^d x_i + P_Y^d Y, \quad Y_{-i} - x_i \leq Y \leq Y_{-i} - \bar{q}_i \quad \right\} \qquad (3.4)$$

where $m_i^d = w_i + \frac{P_g P_q}{P_b + P_q} \bar{q}_i + P_Y^d Y_{-i}$, $P_x^d = P_g$, $P_Y^d = \frac{P_b}{P_b + P_q}\left(P_g - P_b - P_q\right)$, and the superscript d refers to the scenario where consumer i has a positive demand for permits. As in the baseline model, it is possible to express the problem only in terms of the full-income (m_i^d) and the implicit prices (P_x^d and P_Y^d). The differences are that the full-income additionally takes into account the monetary value of the initial allocation of permits, while the implicit price of Y is lower because it considers the extra cost of buying a permit to consume the brown good. Therefore, the consumption of one additional unit of environmental quality becomes implicitly cheaper. The inequality $Y \leq Y_{-i} - \bar{q}_i$ comes from the non-negativity constraint on q_i^d and captures the fact that consumer i will use all the initial permits to consume b_i . The inequality $Y \geq Y_{-i} - x_i$ comes from the non-negativity constraint on g_i and captures the situation where all the income is used to consume b_i (via the acquisition on permits). Alternatively, this inequality also states that environmental quality cannot be lower than the impact caused by the private consumption of consumer i.

Figure 3.1 Budget Set and Consumption Bundle (Permits Buyer)

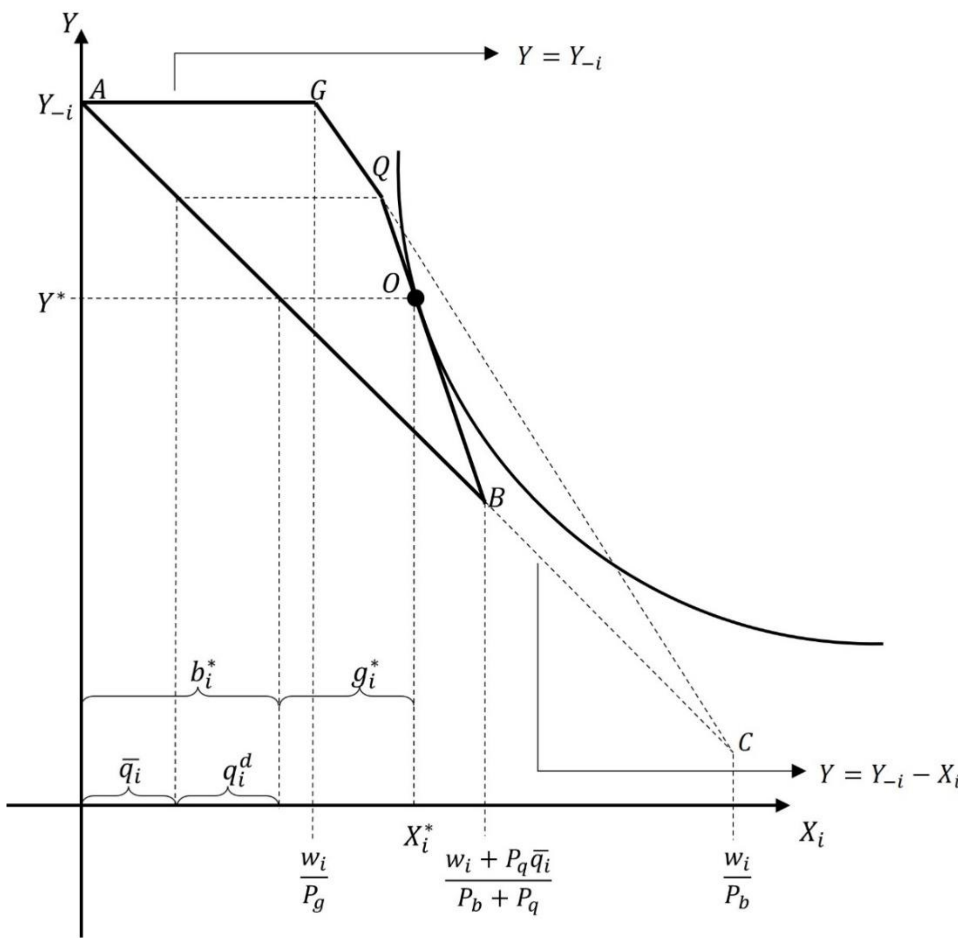


Figure 3.1 illustrates the budget set and the consumption bundle in terms of (x_i, Y). The feasible set is convex and is denoted by the trapezoid AGQB. The segment AC has a slope of -1 and captures the impact of the consumption of the brown good on environmental quality. The segment GQB represents the budget constraint and is divided in two parts by the kink point Q. The line GQ represents the situation when consumer i can satisfy the consumption of the brown good with the initial allocation of permits. The line QB considers that the consumer must buy a permit for every additional unit of the brown good. The triangle BQC shows the set that would have been feasible if the consumption of the brown good was not restricted by the permits.

Assuming that the segment QB includes the solution to (3.4), then it is possible to express the demand for environmental quality as a function of the full income and the vector of implicit prices $\mathbf{P^d} = \left(P_x^d, P_Y^d\right)$:

$$Y = y_i\left(m_i^d, \mathbf{P^d}\right) \tag{3.5}$$

Expression (3.5) is useful to recover the demand for permits by using the identity $Y_{-i} = Y + \bar{q}_i + q_i^d$.[7] By assumption, environmental quality is a normal good, which implies that (3.5) is an increasing function with respect to m_i^d. As such, there exists an inverse function ${y_i^d}^{-1}\left(Y, \mathbf{P^d}\right)$ with respect to the full income that is equal to:

[7] This identity comes from rearranging $Y = Y_{-i} - b_i$ and by assuming that the constraint $b_i \leq \bar{q}_i + q_i^d$ holds with equality.

$$y_i^{d^{-1}}\left(Y,\mathbf{P^d}\right)=m_i^d$$

$$=w_i+P_q\bar{q}_i+P_Y^dY_{-i}$$

The interpretation of $y_i^{d^{-1}}\left(Y,\mathbf{P^d}\right)$ is that it gives the full income required to sustain a demand of Y units of environmental quality when facing the price vector $\mathbf{P^d}$. From this previous expression, it is possible to obtain an identity that sets q_i^d as function that depends on the other parameters of the model.

$$q_i^d=\frac{y_i^{-1}\left(Y,\mathbf{P^d}\right)-w_i}{P_Y^d}-Y-\left(\frac{P_g-P_b}{P_Y^d}\right)\bar{q}_i \tag{3.6}$$

The right-hand side of expression (3.6) includes Y as one of its arguments. Thus, it is possible to interpret q_i^d as a value that is conditional on a given level of Y.[8] Since the optimal value of Y is restricted to a compact set by (3.4), the range of expression (3.6) must also be bounded. Let the function $q_i^d(Y,\bar{q}_i)$ represent the conditional demand for permits of consumer i, suppressing notation for income and prices. The following proposition summarizes the main properties of $q_i^d(Y,\bar{q}_i)$:

[8] Cornes and Hartley (2007) give expression (3.6) the interpretation of a replacement function. The reasoning for this name is that if there exists an exogenous change that increases Y in $\hat{Y}$ units, then the demand of consumer i would change in the same amount to keep the level of Y fixed at its target value.

Proposition 3.1: *If environmental quality is a normal good and* q_i^d *has a representation as in* (3.6)*, then consumer* i *has a conditional demand for permits* $q_i^d(Y, \bar{q}_i)$ *with the following properties:*

i) $q_i^d(Y, \bar{q}_i)$ *is a weakly increasing function in Y.*

ii) $q_i^d(Y, \bar{q}_i)$ *is a weakly decreasing function in* $\bar{q}_i$*.*

iii) For all $w_i > 0$*, there exists a value* $P_{q_i}^{d-max} < P_g - P_b$ *such that* $q_i^d(Y, \bar{q}_i) = 0$ *if* $P_q \geq P_{q_i}^{d-max}$*.*

iv) There exists an income level $w_i^{CB}(Y, \bar{q}_i)$ *such that* $q_i^d(Y, \bar{q}_i) = \frac{w_i - P_b \bar{q}_i}{P_b + P_q}$ *if* $w_i \leq w_i^{CB}(Y, \bar{q}_i)$

The result in part i) follows from assumption (3.2) that guarantees that both x_i and Y are normal. An exogenous increase in Y implies that the full-income of the consumer also increased. Since income, prices, and the allocation of permits are fixed, then the only remaining variable that can account for the increase in the full-income is Y_{-i}. Therefore, the consumer will have an incentive to consume more brown goods but not enough to offset the initial increase in Y. As a result, the demand for permits must increase in this situation.

Part ii) is a direct consequence of the functional form in (3.6). Consumers who have already been allocated sufficient permits during their initial allocation will have less need to purchase additional permits. Part iii) establishes that consumers who have used up their initial allocation $\bar{q}_i$ have incentives to purchase extra permits if the price is sufficiently low to enable an increase in their consumption of b_i. However, if the permit price surpasses a certain threshold, they will withdraw from the market and allocate all their remaining income towards the consumption of g_i. Finally, part iv) explains that when the individual income is too low, consumers may choose to prioritize the acquisition of as many permits as possible, while foregoing any consumption of g_i.

To distinguish between consumers in terms of their demand for permits, I will use two categories: regular buyers (RB) and constrained buyers (CB). Regular buyers are those whose demand for permits can be modeled by equation (3.6). On the other hand, while constrained buyers are those who have a demand constrained by their low income and can be represented by the equation $q_i^d(Y, \bar{q}_i) = \frac{w_i - P_b \bar{q}_i}{P_b + P_q}$.

3.4.2 The Sellers' Problem

From a seller's perspective, receiving an initial allocation of permits $\bar{q}_i$ is valuable not only for consumption purposes but because it provides trade value that can be used to increase the individual budget. Consumers who choose to sell some of their permits will receive a payment equal to P_q for each one of them. However, sellers need to carefully weigh the trade-off between selling their permits and their own consumption needs. They should not sell more permits than the ones they need to use, and they need to be aware that buyers will acquire permits to increase their own brown consumption. Consequently, sellers must take into account the negative environmental impact resulting from the use of each permit, whether it is for consumption or trading purposes. With these considerations, the utility maximization problem that each seller solves is:

$$\max_{x_i, Y, g_i, b_i, q_i^s} \left\{ U_i(x_i, Y) \middle| \begin{array}{ll} w_i + P_q q_i^s = P_g g_i + P_b b_i, & \bar{q}_i \geq b_i + q_i^s, \\ x_i = g_i + b_i, & Y = Y_{-i} - b_i - q_i^s, \\ & g_i, b_i, q_i^s \geq 0 \end{array} \right\} \tag{3.7}$$

where q_i^s denotes the number of permits that consumer i is offering in the market and $Y_{-i} = Y^0 - \sum_{j \neq i} b_j$ is the exogenous environmental quality that consumer i by taking the brown consumption of others as given. If a seller finds that $q_i^{s^*} = 0$ is optimal, then the solution to (3.7) is the same as in the baseline model. For the interesting case where $q_i^{s^*} > 0$, sellers must still decide how many units of g_i and b_i to consume with the total income they receive. Assuming that $\bar{q}_i > b_i + q_i^s$, the individual demands for g_i and b_i and offer of q_i^s can be characterized by equating the marginal utility per unit of money spent on each good:[9]

$$\frac{U_x + \mu_g}{P_g} = \frac{U_x - U_Y + \mu_b}{P_b} = \frac{U_Y}{P_q}$$

[9] To simplify the maximization problem, it possible to substitute the identities $x_i = g_i + b_i$ and $Y = Y_{-i} - b_i - q_i^s$ into the utility function and use the following Lagrangian function:

$$\mathrm{L} = U_i(g_i + b_i, Y_{-i} - b_i - q_i^s) + \lambda_w\left[w_i + P_q q_i^s - P_g g_i - P_b b_i\right] + \mu_g g_i + \mu_b b_i$$

Note that the previous expressions include the Lagrange multipliers μ_g and μ_b to account for the possibility of having an optimal consumption of $g_i^* = 0$ or $b_i^* = 0$. Solving for U_x gives a unique relationship involving the marginal utility of environmental quality and the three market prices P_g, P_b, and P_q:

$$\frac{P_g}{P_q}U_Y - \mu_g = \frac{P_b + P_q}{P_q}U_y - \mu_b$$

This expression is valuable in understanding the incentives that sellers have with respect to the consumption of both green and brown goods, given the market price for permits. If the seller consumes the green good, then $\mu_g = 0$,[10] but this situation is optimal only if $P_g - P_b \leq P_q$. Based on the buyer's problem, if the price of permits is greater than the price difference between the green and brown goods, then there will not be a positive demand for permits under this situation. For trade to occur, the price of each permit must be at least lower than the price difference (i.e., $P_q < P_g - P_b$). Therefore, it is never optimal for a seller to consume the green good.

Since $g_i^* = 0$, then total private consumption is completely satisfied by consuming the brown good (i.e., $x_i^* = b_i^*$) and the budget constraint reduces to the form $w_i + P_q q_i^s = P_b b_i^*$. With the income constraint expressed in this way, it is possible to use the identities in (3.7) to rewrite the seller's utility maximization problem as:

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[10] In this case, the consumption of the brown good is either positive of zero and $\mu_b \geq 0$. Therefore, the previous expression simplifies to:

$$0 \leq \mu_b = \frac{P_q - (P_g - P_b)}{P_q}U_Y$$

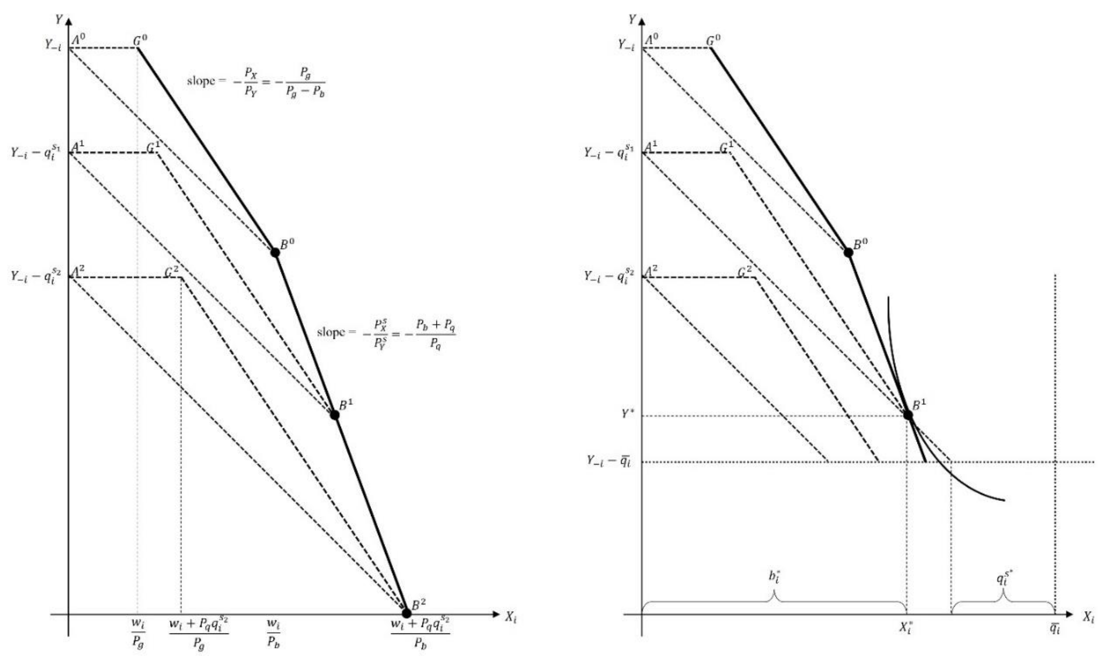
$$\max_{x_i,Y} \{\ U_i(x_i,Y)|\ m_i^s = P_x^s x_i + P_Y^s Y, \quad Y_{-i} - \bar{q}_i \leq Y \leq\ Y_{-i} - x_i\ \} \tag{3.8}$$

where $m_i^s = w_i + P_Y^s Y_{-i}$, $P_x^s = P_b + P_q$, $P_Y^s = P_q$, and the superscript s refers to the scenario where consumer i offers a positive amount of permits. Similar to the buyer's problem and the baseline model, it is possible to express the seller's problem in terms of the full-income (m_i^s) and the implicit prices (P_x^s and P_Y^s). In this scenario, the full-income incorporates the personal income and the monetary value of the exogenous environmental quality provided by others.

However, the implicit prices for both X_i and Y are different in this model. The implicit price of x_i is the sum $P_b + P_q$ because the consumer must consider the price of obtaining one unit of the brown good and the opportunity cost of using one permit instead of selling it. The implicit price of Y is P_q because that is the amount of money the consumer is willing to receive in exchange for receiving one fewer unit of environmental quality. The inequality $Y_{-i} - \bar{q}_i \leq Y$ comes from the brown consumption constraint $\bar{q}_i \geq b_i + q_i^s$. If individual sellers use all their permits either for consumption or for trading purposes, then the minimum environmental quality that can be attained is $Y = Y_{-i} - \bar{q}_i$. Finally, the inequality $Y \leq\ Y_{-i} - x_i$ comes from the non-negativity constraint on q_i^s and establishes that environmental quality will decrease at least as much as the private consumption of consumer i. This condition only holds when sellers choose not to trade away any permits.

Panel a) of Figure 3.2 illustrates how the budget set changes as consumer i sells permits. Initially, the consumer can choose any consumption bundle within the triangle $A^0G^0B^0$. When consumer i sells $q_i^{s_1}$ permits, the budget set shifts down to the larger triangle $A^1G^1B^1$. In this case, G^1 must be to the right of G^0, indicating that the consumer has received payment from selling the permits, but below the line G^0B^0 since the price of each permit is less than the price difference between the green and brown goods. If instead, consumer i sells $q_i^{s_2}$ permits, the budget set shifts further down to triangle $A^2G^2B^2$.

Figure 3.2: Budget Set and Consumption Bundle (Permits Seller)



a) Budget set without considering the initial allocation of permits.

b) Optimal consumption bundle considering the initial allocation of permits

The consumption bundles at B^0, B^1, and B^2 in the (x_i, Y) space represent the scenarios where consumer i uses all the available income to purchase b_i, subject to the number of permits sold. Therefore, the line starting at B^0, passing through points B^1 and B^2, represents the budget line, which has a slope equal to $-P_x^S/P_Y^S$. Furthermore, point B^0 corresponds to the situation where $Y = Y_{-i} - x_i$ as consumer i chooses to spend all the available income on b_i but not to sell any permits at all.

Panel b) shows how the initial allocation $\bar{q}_i$ affects the budget set and the optimal consumption bundle. The horizontal line at $Y = Y_{-i} - \bar{q}_i$ restricts all consumption bundles located below it as they are no longer feasible. Suppose the optimal consumption is located at point B^1. The optimal number of permits to sell is equal to the horizontal distance between the intersection of line A^1B^1 with the line at $Y = Y_i - \bar{q}_i$ and the vertical line at $x_i = \bar{q}_i$. This distance represents the permits that consumer i must sell to be able to consume at the optimal level. As a result, consumer i will retain a positive number of permits that will not be sold or used to buy b_i.

Assuming that point B^1 is the solution to (3.8), then it is possible to express the demand for environmental quality as a function of the full income and the vector of implicit prices $\mathbf{P}^s = (P_x^s, P_Y^s)$:

$$Y = y_i^s(m_i^s, \mathbf{P}^s) \tag{3.9}$$

By assumption, environmental quality is a normal good, meaning that (3.9) is an increasing function with respect to m_i^s. As such, there exists an inverse function ${y_i^d}^{-1}(Y, \mathbf{P^d})$ with respect to the full income that is equal to:

$$\begin{aligned} {y_i^s}^{-1}(Y, \mathbf{P^s}) &= m_i^s \\ &= w_i + P_Y^s Y_{-i} \end{aligned}$$

Similar to the buyer's problem, the expression ${y_i^s}^{-1}(Y, \mathbf{P^s})$ has the interpretation of being the full-income required to sustain a demand of Y units of environmental quality when facing the price vector $\mathbf{P^s}$. From the identity $Y = Y_{-i} - b_i - q_i^s$ and the budget constraint $w_i + P_q q_i^s = P_b b_i$, it is possible to use ${y_i^s}^{-1}(Y, \mathbf{P^s})$ to derive the supply of permits and state it as:

$$q_i^s = \frac{P_x^s - P_Y^s}{P_x^s}\left[\frac{{y_i^s}^{-1}(Y, \mathbf{P^s})}{P_Y^s} - Y\right] - \frac{w_i}{P_Y^s} \tag{3.10}$$

Since expression (3.10) includes Y as one of its arguments, it is possible to interpret q_i^s as the conditional supply of permits given level of Y. As the value of Y is restricted to a compact set by (3.8), the range of expression (3.10) must also be bounded.[11] Let the function $q_i^s(Y, \bar{q}_i)$ represent the conditional supply for permits of consumer i, suppressing notation for income and prices. The following proposition summarizes the main properties of $q_i^s(Y, \bar{q}_i)$:

[11] This situation is equivalent to what occurs in the buyer's problem.

Proposition 3.2: *If environmental quality is a normal good and q_i^s has a representation as in (3.10), then consumer i has a conditional supply for permits $q_i^d(Y, \bar{q}_i)$ with the following properties:*

i) *For all $w_i > 0$, there exists a value $P_{q_i}^{s-min} > 0$ such that $q_i^s(Y, \bar{q}_i) = 0$ if $P_q \leq P_{q_i}^{s-min}$.*

ii) *There exists a maximum number of permits that consumer i is willing to use, whether it is for consumption or for trading purposes. If consumer i receives fewer initial permits than this amount, then an income level $w_i^{CS}(Y, \bar{q}_i)$ exists such that $q_i^s(Y, \bar{q}_i) = \frac{w_i - P_b \bar{q}_i}{P_b + P_q}$ if $w_i \leq w_i^{CS}(Y, \bar{q}_i)$*

iii) *$q_i^s(Y, \bar{q}_i)$ is a weakly increasing function in Y.*

Consumers who have depleted their initial allocation $\bar{q}_i$ will have the incentives to purchase extra permits if the price is sufficiently low to enable an increase in their consumption of b_i. However, if the permit price surpasses a certain threshold, they will withdraw from the market and allocate all their remaining income towards the consumption of g_i. Conversely, when the individual income is too low, consumers may choose to prioritize the acquisition of as many permits as possible, while foregoing any consumption of g_i.

To distinguish between consumers in terms of their demand for permits, I will use two categories: regular buyers (RB) and constrained buyers (CB). Regular buyers are those whose demand for permits can be modeled by equation (3.6). On the other hand, while constrained buyers are those who have a demand constrained by their low income and can be represented by the equation $q_i^d(Y, \bar{q}_i) = \frac{w_i - P_b \bar{q}_i}{P_b + P_q}$.

3.5 Market Equilibrium

In the previous sections, I have established the conditions that must be met so that consumers have incentives to trade permits among each other. It is essential that there are consumers who are interested in increasing their consumption of the brown good but are constrained due to an insufficient initial allocation of permits. Similarly, there should be consumers who have received more permits than they can afford to use to purchase brown goods, creating a supply of permits. To achieve an optimal outcome through this market, the regulatory agency must ensure that low-income consumers receive enough permits to participate as sellers and benefit from a market-based income transfer.

If the regulatory agency selects an appropriate initial allocation of permits that incentivizes at least one consumer to sell permits and another to buy them, then I can show that a market equilibrium with tradable permits exists.

Definition 3.3*: A market equilibrium with tradable permits is a price P_q^*, an allocation $\left((g_1^*, b_1^*), (g_2^*, b_2^*), \dots, (g_n^*, b_n^*), Y^*\right)$, and an array of trades $\bar{\boldsymbol{Q}} = (q_1^*, q_2^*, \dots, q_n^*)$ such that:*

1. *for all $i = 1,2, \dots, n$: $U_i(g_i^* + b_i^*, Y^*) \geq U_i(g_i + b_i, Y)\ \forall (g_i + b_i, Y) \in \mathbb{R}_+ \times \mathbb{R}$ for which $w_i = P_g g_i + P_b b_i + P_q^* q_i^*$*

2. $Y^0 - \sum_{i=1}^{n} b_i^* = Y^*$

3. $Q^D(P_q^*, Y^*) = Q^S(P_q^*, Y^*) > 0$

where $Q^D(P_q^*, Y^*) = \sum_{i \in D} q_i^d(Y, \bar{q}_i)$ and $Q^S(P_q^*, Y^*) = \sum_{j \in S} q_j^s(Y, \bar{q}_j)$ denote the aggregate demand and aggregate supply of permits. The value q_i^* represents the net amount of permits that consumer i chooses to trade in the market and is calculated as $q_i^* = q_i^{d^*} - q_i^{s^*}$, which is positive if consumer i chooses to buy permits, negative if consumer i chooses to sell permits, and equal to zero if consumer i does not participate in the market.

The first condition ensured that all consumers are maximizing their utility and cannot be better off by choosing a different allocation. The second condition establishes that the aggregate demand of the brown good generates a Nash Equilibrium level on environmental quality. The following two Lemmas further demonstrate that there exists a unique Nash Equilibrium for any price P_q at which the permits are traded.

Lemma 3.4: *$b_i(Y, \bar{q}_i)$ is a continuous and weakly increasing function in Y $\forall\ i = 1, \ldots, n$.*

Lemma 3.5*: Let $P_q \in (0, P_g - P_b)$, then there exists a unique value Y^* that satisfies the following equation:*

$$Y^0 - \sum_{i=1}^{n} b_i(Y^*, \bar{q}_i) = Y^* \tag{3.11}$$

The first condition ensured that all consumers are maximizing their utility and cannot be better off by choosing a different allocation. The second condition establishes that the aggregate demand of the brown good generates a Nash Equilibrium level on environmental quality. The following two Lemmas further demonstrate that there exists a unique Nash Equilibrium for any price P_q at which the permits are traded.

Lemma ***3.4*** is a generalization of Lemma 2.2, holding true even for non-participants in the market, as they follow the behavior outlined in the baseline model. For buyers of permits, the identity $b_i = \bar{q}_i + q_i^d$ establishes that $b_i(Y, \bar{q}_i)$ shares all the properties from the function $q_i^d(Y, \bar{q}_i)$, which are described in Proposition 3.1. A similar situation occurs with sellers, as the identity $P_b b_i = w_i + P_q q_i^s$ guarantees that the function $b_i(Y, \bar{q}_i)$ shares all the properties from the function $q_i^s(Y, \bar{q}_i)$, which was described in Proposition 3.2. Therefore, since $b_i(Y, \bar{q}_i)$ is an increasing function in Y, then the same process used to prove Proposition 1.1 applies to establish the result from Lemma 3.5.

The third condition for a market equilibrium with tradable permits states that aggregate demand for permits must equal aggregate supply. Let $P_q^{d-max}(Y^*)$ be the minimum price among all potential buyers that ensures that the aggregate demand for permits is zero at an environmental quality level Y^*. Similarly, let $P_q^{s-min}(Y^*)$ be the maximum price among all potential sellers that ensures the aggregate supply of permits is zero at an environmental quality level Y^*. The following Lemma establishes that there exists a price P_q that guarantees that the market clears.

Lemma 3.6: *Let Y^* be defined as in* (3.11) *and $P_q^{d-max}(Y^*) > P_q^{s-min}(Y^*)$ so that trading occurs in the market. Then there exists a market-clearing price P_q^* such that:*

$$Q^D\left(P_q^*, Y^*\right) = Q^S(P_q^*, Y^*)$$

Therefore, I can use the results from Lemma 3.5 and Lemma 3.6 to prove that, as long as consumers have incentives to trade for permits, a market equilibrium with tradable permits must exist:

Proposition 3.7: *If $P_q^{d-max}(Y^*) > P_q^{s-min}(Y^*)$, then* a *market equilibrium with tradable permits exists*.

It is important to note that the result from Proposition 3.7 establishes only the existence of equilibrium, and it does not imply that any initial permit allocation chosen by the regulatory agency will necessarily lead to a socially efficient outcome. Therefore, the regulatory agency must consider among various possible allocations to determine the most efficient and welfare-maximizing one for the economy. To examine the impact of altering the initial permit allocation, I will assume the following market conditions:

A.2.1. *Law of Demand for permits:* There is an inverse relationship between the price and the quantity demanded of permits. $\left(\frac{\partial Q^D(P_q,Y)}{\partial P_q} < 0\right)$

A.2.2. *Law of Supply for permits:* There is a direct relationship between the price and the quantity supplied of permits. $\left(\frac{\partial Q^S(P_q,Y)}{\partial P_q} > 0\right)$

A.2.3. *Complementarity of permits and brown goods:* The aggregate demand of the brown good decreases when the price of the permits increases. $\left(\frac{\sum \partial b_i(Y,\overline{q_i})}{\partial P_q} < 0\right)$

A.2.4. *Relative strength of substitution effect:* The substitution effect of the ratio between the market clearing condition and the aggregate demand of the brown good is greater than the income effect generated by changes in environmental quality. $\left(\frac{\frac{\partial Q^D}{\partial P_q} - \frac{\partial Q^S}{\partial P_q}}{\frac{\sum \partial b_i}{\partial P_q}} > \frac{\frac{\partial Q^D}{\partial Y} - \frac{\partial Q^S}{\partial Y}}{\frac{\sum \partial b_i}{\partial Y}}\right)$

Assumptions A.2.1 and A.2.2 guarantee that the permits are not classified as Giffen Good. Assumption A.2.3 implies that permit buyers are more sensitive to changes in the permit price, which results in a reduction of their brown good consumption, compared to any positive effect it may have over permit sellers. Assumption A.2.4 limits the effect that a change on environmental quality can have on the market clearing conditions. These four assumptions are sufficient to show that there is an inverse relationship between the equilibrium price and the initial allocation assigned by the regulatory agency to permit buyers.

Proposition 3.8*: If assumptions A.2.1, A.2.2, A.2.3, and A.2.4 hold, then the equilibrium price of permits decreases if any given buyer receives an additional initial permit.*

The regulatory agency can utilize the result of Proposition 2.8 to shift the bargaining power between buyers and sellers. If buyers receive fewer initial permits, they may participate more actively in the market to fulfill their demand for the brown good. Conversely, if their initial allocation is larger, they may adopt a more passive approach and wait for better prices. However, the task for the regulatory agency is to find a rule that can generate a socially optimal outcome through the initial allocation of permits. Proposition 2.9 provides an answer to this question.

Proposition 3.9*: Let* $\overline{\boldsymbol{Q}}$ *be an allocation of permits such that it induces market trading, and all consumers are either regular buyers or regular sellers. The market equilibrium with tradable permits is Pareto-Optimal if, and only if,* $P_q^* = \frac{P_b}{P_g+P_b}(P_g - P_b)$.

From the social choice problem (3.1), the regulator must find a price that internalizes the negative effects of brown good consumption and equalizes the marginal rates of substitution of all consumers. In the case where all consumers are either regular sellers or regular buyers, the price that achieves this is $P_q^* = \frac{\mathrm{P_b}}{\mathrm{P_g}+\mathrm{P_b}}(\mathrm{P_g} - \mathrm{P_b})$ which equalizes the following price ratios for permit buyers and sellers:

$$\frac{P_x^d}{P_Y^d} = \frac{P_x^s}{P_Y^s}$$

If the market equilibrium with tradable permits fails to achieve the optimal price, the regulator can reallocate initial permits for buyers, depending on whether the equilibrium price is lower or greater than the optimal price. This will help to correct the market and achieve the optimal price.

Finally, in the more general case where there are non-participants, restricted buyers, and/or restricted sellers, the market equilibrium with tradable permits will not be able to equalize their marginal rates of substitution to the optimal price ratio. This implies that the market may not achieve the social optimum. However, this does not mean that the market is a failure or should not be implemented. This market can still control the externality problem and generate a different income distribution that can lead to an increased social welfare.

Overall, the market equilibrium with tradable permits provides a means for the regulator to solve the externality problem by internalizing the negative effects of brown good consumption. It also provides a means for income redistribution and to potentially increase social welfare. While the market may not always achieve the social optimum, it still provides a valuable tool for to achieve gains in efficiency and address the problem of income inequality. The existence of an optimal price for permits allows the regulator to determine the appropriate initial allocation of permits, and to make any adjustments needed to reach it.

3.6 Conclusion

This chapter presents an analysis of how the social optimal consumption of green and brown goods differs from the market equilibrium. The social optimum requires addressing two types of market failures: the externality caused by the consumption of the brown good and the unequal marginal rates of substitution of consumers. To achieve a Pareto-improving outcome, a redistribution of income may be necessary.

To address these market failures, the implementation of a market of permits similar to the ITQs model is proposed. The number of permits a consumer holds restricts their individual consumption of the brown good, thereby addressing the externality. However, the allocation of initial permits has income effects, as one permit allows a consumer to increase their total consumption by buying the cheaper brown good. The overall allocation thus has implications for income inequality.

The role of the regulatory agency is to determine the best initial allocation to maximize social welfare. As the entire profile of preferences may not be known, letting consumers trade permits among themselves is a viable alternative, as the market can determine the best price at which to trade. The price of permits is an instrument that effectively changes the marginal rates of substitution for consumers participating in the market. For permit buyers, the brown good becomes more expensive, making it cheaper for them to preserve environmental quality. For permit sellers, the consumption of the brown good also becomes more expensive, as they consider the opportunity cost of not selling the permit.

In the social optimum, the price of permits equalizes the marginal rates of substitution of all consumers participating in the market, who are not restricted by their initial allocation or income. However, consumers who do not participate or are restricted will have a different marginal rate of substitution, which does not invalidate the use of this market. By addressing the externality problem and reducing income inequality, the market for permits generates a better social outcome, although it may not necessarily be optimal.

The regulator has the power to intervene in the market price by redistributing the initial permits among the groups. To achieve a higher equilibrium price, the buyers should receive fewer initial permits. Conversely, to achieve a lower equilibrium price, the buyers should receive more initial permits. It is worth noting that this reallocation of permits has implications for environmental quality. However, reaching the optimal price is a crucial step towards achieving the socially efficient level, particularly if all consumers participate as either buyers or sellers without any income or allocation constraints.

A key feature of this market is that sellers and non-participants may hold a positive amount of permits without trading or consuming them. In a typical situation, this would drive the price of permits down to zero. However, the price does not go to zero in this case, as the permits have value on their own. By holding onto permits, consumers prevent others from increasing their consumption of the brown good and negatively impacting environmental quality.

In conclusion, the proposed market of permits addresses the market failures that prevent the competitive equilibrium from reaching the social optimum. By reallocating resources via the price of permits, the market can efficiently redistribute income and achieve the socially optimum level of environmental quality. The role of the regulatory agency is crucial in determining the initial allocation and intervention to achieve the optimal equilibrium price.

Chapter 4 : Green Consumption and Income Inequality

4.1 Introduction

The purpose of this chapter is to empirically investigate the relationship between green consumption and income inequality, as outlined in the baseline model proposed in Chapter 2. To achieve this objective, I have designed a novel laboratory experiment that examines whether the introduction of income inequality can result in neutral, positive, or negative environmental outcomes, as predicted in the baseline model. The experiment aims to compare the environmental outcomes of three different income distributions with an equal income distribution as a counterfactual. Theoretically, it is possible to create three unequal income distributions, with one generating the same result as an equal distribution, another producing a better environmental outcome, and the third resulting in negative environmental effects. The laboratory experiment will test if the actual environmental outcomes align with the predictions of the baseline model.

Using a laboratory experiment is ideal for controlling market conditions and ensuring that both environmentally friendly (green) and environmentally harmful (brown) goods have consistent prices and characteristics. This helps to eliminate confounding factors such as greenwashing and the tendency to make consumption choices based on a product's perceived environmental benefits (the 'green-halo' effect), thereby improving the internal validity of the experiment. Additionally, the experiment ensures that all individuals have perfect information regarding the actual impact of their consumption choices, the consumption patterns of others in the economy, and the overall environmental quality of the economy.

Moreover, the laboratory experiment enables the introduction of specific income distributions, which is critical for testing the predictions of the baseline model from Chapter 2. In contrast, it would be unethical and impossible to generate different income distributions in the real world for the sole purpose of comparing consumption patterns across them. The experiment allows for the distribution of precise amounts of money needed to create the desired income distributions. It also facilitates the control of unobservable variables such as education, culture, intrinsic preferences for environmental quality, and political preferences, which could confound the results.

As a secondary objective, the laboratory experiment provides an opportunity to observe the consumption choices made by individuals with varying income levels. According to the theoretical predictions, low-income individuals increase their consumption of brown goods as their income rises, until a certain threshold is reached. Beyond that point, further increases in income lead to a reduction in brown goods consumption until they are completely replaced by green goods. This pattern of consumption is commonly referred to as the Environmental Kuznets Curve, and has been used in other studies to describe the relationship between income and environmental degradation. While the primary objective of the experiment is not to test for the existence of the Environmental Kuznets Curve or make any specific predictions regarding individual consumption, analyzing the individual data provides valuable insights into actual deviations from the baseline model's predictions.

The experimental design in my study is based on Uler (2011) and Maurice, Rouaix, and Willinger (2013). I randomly match groups of three subjects who simultaneously make decisions impacting a private outside option, referred to as "private consumption," or the provision of a public good known as "environmental quality." This public good is equally shared among all group members. The study comprises three treatments, each consisting of two parts. In the equal part, all participants receive the same initial endowment, while in the unequal part, they receive heterogeneous endowments. Each part of every treatment has a unique interior dominant strategy equilibrium and is repeated in sequences of 10 rounds.

Within each treatment, I introduce a distinct income distribution in the unequal part, utilizing the equal part as a baseline for comparing the impact of income inequality on environmental quality. Furthermore, I design the three income distributions to test specific hypotheses concerning the potential positive, neutral, or negative effects of income inequality on environmental quality.

The novelty in my design is that I do not present the subjects with the choice between allocating their income for private consumption or contributing to the provision of the public good. Instead, I present them with two options that result in an equal increase in private consumption, with one option (green goods) being more expensive than the other (brown goods). Consuming brown goods negatively affects the public good, while green goods have a neutral impact. Thus, within this framework, brown goods can be classified as an impure public good (Cornes and Sandler 1984, 1994). It is important to note that my design does not allow subjects to directly contribute to the public good; instead, the only way to affect its provision is through the consumption of brown goods, albeit with negative consequences. This design effectively captures the real-life tradeoff faced by consumers when deciding between green goods or brown goods, and enables a comprehensive examination of the effects of income inequality on individuals' choices between environmentally friendly and environmentally harmful goods.

My experiment follows a large body of laboratory experiment that seek to understand the impacts of income inequality on contributions to public goods (i.e., Ledyard 1995; Chan, Mestelman, Moir, and Muller 1996; Zelmer 2003; Cherry, Kroll and Shogren 2005; Buckley and Croson 2006). The results of these experiments have yielded mixed results, as some find a negative relationship between inequality and contributions to the public good, while others have found that this relationship is positive or non-existent. To the best of my knowledge, my research represents the first public goods experiment specifically designed to provide empirical evidence showcasing these three effects, contingent upon variations in the level of income inequality.

Additionally, my experiment represents a novel contribution to the existing literature of experiments on impure public goods. Although previous studies have explored contributions to impure public goods and their implications for direct donations (Munro and Valente 2016; Engelmann, Munro, and Valente 2017), or have compared pure and impure public good mechanisms for funding green energy programs (Mitra and Moore 2018), my research is the first to incorporate impure public goods to investigate the effects of income inequality. This novel approach allows for a deeper understanding of how income inequality influences contributions to public goods in the context of environmentally relevant choices.

The experimental results reveal a weak positive effect of income inequality on environmental quality across all treatments, including the treatment where a decline in environmental quality was anticipated due to income inequality. Particularly, in treatments where participants with low income were expected to allocate their entire income to brown goods, they consistently purchased some units of the green good, which mitigated the anticipated negative impact on environmental quality. Conversely, high-income participants, who could maximize their payoff by consuming only green goods, choose to consume brown goods despite the detrimental effect on their individual payoff. However, their increased consumption of brown goods is not enough to offset the gains made by low-income participants who deviate from the expected consumption of brown goods.

The deviations from the theoretical predictions can be explained by combining two behavioral factors. Firstly, the presence of a warm-glow preference for green goods (Andreoni 1990), which refers to the positive feelings that consumers experience from contributing to environmental protection efforts. Secondly, the theory of conformity (Bernheim 1994), which describes the situation where consumers experience disutility if their own consumption of brown goods differs from the group average. Together, these two factors suggest that individuals are more likely to adopt environmentally friendly behaviors even at lower income levels but take longer to have a fully green consumption pattern than expected. Nonetheless, the experiment still confirmed the existence of an individual Environmental Kuznets Curve, highlighting the complex relationship between income inequality and environmental quality.

The rest of this chapter is structured as follows. In Section 4.2, I conduct a review of the existing literature of public good experiments that study the impact of income inequality and of experiments that involve the study of impure public goods. In Sections 4.3 and 4.4 I introduce the experimental design and experimental procedure, respectively. In Section 4.5 I present the theoretical predictions and experimental hypotheses. In Section 4.6 I analyze the experimental results. Finally, I discuss the behavioral extensions to the baseline model in section 4.7, and I conclude this chapter in Section 4.8

4.2 Literature Review

This chapter contributes to two important areas of literature. Firstly, it adds to the existing body of experimental research that explores the effects of income inequality on the provision of public goods. Secondly, it contributes to the expanding literature on experiments that examine the consumption of impure public goods.

4.2.1 Public goods experiments and income inequality

The impact of income inequality on behavior has been extensively explored in the experimental literature, with a particular focus on public good games. These studies aim to understand how inequality influences both individual and aggregate contribution levels. However, the findings in this field remain inconclusive. Some studies suggest that inequality leads to lower overall contributions (i.e., Cherry, Kroll and Shogren 2005; Anderson, Mellor and Milyo 2008; Oxoby and Spraggon 2013), while others find no significant impact on total contributions (i.e., Sadrieh and Verbon 2006; Hofmeyr, Burns and Visser 2007; Maurice, Rouaix and Willinger 2013). On the other hand, there are studies that report a positive relationship between inequality and contribution levels, particularly when participants have access to full information or can communicate with each other about their behavior (Chan, Mestelman, Moir, and Muller 1999, 2012; Burns and Visser 2008). Additionally, in the presence of redistributive taxation, greater pre-tax inequality tends to increase contributions, whereas greater after-tax inequality decreases total contributions regardless of the initial income distribution (Uler, 2011).

Notably, the prevailing models in experimental settings often fail to predict the changes in behavior caused by inequality. For instance, experiments involving voluntary within-experiment redistribution demonstrate that higher inequality of endowments generally leads to reduced contributions (Chan, Mestelman, Moir, and Muller, 1996; Buckley and Croson, 2006; Côté, House, and Willer 2015). Furthermore, the presence of higher government waste, which diminishes redistribution and increases ex post inequality, has been found to decrease charitable giving in lab experiments (Sheremeta and Uler 2020).

The relationship between inequality and contributions in laboratory experiments is not always consistent, partly due to the use of different payoff functions. Linear payoff functions, commonly used in these experiments, assume constant marginal values for both the public good and the outside option. However, this results in a situation where the Nash equilibrium predicts zero contributions, despite the optimal social choice requiring full contributions from all participants (Sefton and Steinberg 1996; Laury and Holt 2008). To overcome this issue, some studies employ nonlinear payoff functions, such as quasi-linear functions, where the marginal value of the public good or the outside option decreases as group contributions increase. Quasi-linear functions retain the desirable feature of a unique dominant equilibrium observed in linear functions, and in these experiments, the Nash equilibrium generally predicts positive contributions to the public good. (Feng, Saijo, Shen, and Qin 2018).

When focusing on linear experiments, numerous studies consistently show that, in the absence of other treatments, contributions to the public good decrease with income inequality (Bagnoli and McKee 1991; Rapoport and Suleiman 1993; Cherry, Kroll and Shogren 2005; Tavoni, Dannenberg, Kallis and Löschel 2011; Oxoby and Spraggon 2013; Heap, Ramalingam and Stoddard 2016; Martinangeli and Martinsson 2020; Markussen, Sharma and Singhal 2021). While some studies report neutral results (Hofmeyr, Burns and Visser 2007; Keser, Markstädter and Schmidt 2017), their primary focus is to examine whether subjects adhere to a fairness principle in terms of cooperation.

In the case of non-linear experiments (Van Dijk and Grodzka 1992; Chan, Mestelman, Moir, and Muller 1996, 1999; Sadrieh and Verbon 2006; Maurice, Rouaix and Willinger 2013) the effect of inequality is found to be neutral, aligning with predictions from standard theory (Warr 1983; Bergstrom, Blume and Varian 1986) However, the impact of inequality operates in such a way that individuals with lower incomes do not reduce their contributions as much as anticipated, while those with higher incomes contribute a lower share of their endowment as expected. These individual outcomes are also observed in linear public goods experiments that also aim to understand individual contributions within the context of income inequality. (Buckley and Croson 2006, Corazzini, Faravelli and Stanca 2010; Reuben and Rieldl 2013; Lange, Schmitz and Schwirplies 2021) or that explore attitudes towards income redistribution (Cohn, Jessen, Klasnja and Smeets 2019).

4.2.2 Laboratory experiments on impure public goods

The literature on experiments involving impure public goods remains limited, particularly in comparison to research on laboratory experiments and traditional public goods. Within laboratory experiments, the inclusion of an impure public good in the consumption set has been shown to have a negative impact on total contributions to a charity when individuals can independently purchase a private good and make individual donations (Munro and Valente 2016). However, this negative effect is mitigated when the private good is removed from the consumption set, making the impure public good "mandatory" (Koppel and Schulze 2013; Engelmann, Munro, and Valente 2017). Another experimental study examining participation in green electricity markets found that a voluntary contribution mechanism generates higher revenue than the green tariff mechanism (Mitra and Moore 2018). In other words, individual donations have a greater positive impact on environmental quality than the consumption of an impure public good such as green electricity. These findings suggest that the specific mechanisms and design choices related to the consumption and provision of impure public goods can significantly influence individuals' contributions and the overall impact on the public good. Further research is needed to explore the dynamics of impure public goods and their implications for resource allocation and collective decision-making.

4.3 Experimental design

In the experiment, groups of three subjects are randomly matched together and remain anonymous throughout *20* rounds.[12] Each session comprises of two *10*-round phases - an equal and an unequal phase. Participants are aware of the length of the experiment and can observe when a change in the initial conditions takes place. The changes are only communicated after the first phase is complete.

[12] Subjects are not randomly re-matched after every round because there is a unique Nash Equilibrium for this experimental design.

During each round, subjects make a decision that reflects a real-world scenario in which they have the opportunity to buy either green goods (g_i), brown goods (b_i), or both. Their individual decisions will have an impact over two income-generating projects: private consumption (x_i) and environmental quality (Y). Participants earn real money (in US dollars) based on their performance during the experiment. Following the baseline model outlined in Chapter 1, the earnings they receive from their private consumption depend solely on their individual decision. On the other hand, the earnings from environmental quality depend on the collective decision made by all three participants within the same group. The individual payoff (π_i) for each round is calculated using the following formula.

$$\pi_i = \left[45x_i - \frac{1}{2}X_i^2\right] + 12Y \tag{4.1}$$

The payoff function in (4.1) meets the assumptions made for the utility function discussed in Chapter 1.[13] In every round, participant i receives an individual endowment of w_i tokens, which can be spent on purchasing green and /or brown goods.[14] Green goods have a price of 5 tokens per unit ($P_g = 5$), and brown goods have a price of 1 token per unit ($P_b = 1$). Regardless of color, the purchase of each unit increases private consumption by one unit.

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[13] This situation is true if $w_i \leq 225$, which is the case for all treatments in the experiment.

[14] I used a neutral framing when designing the experiment. I refer to green goods as 'circles', brown goods as 'triangles', private consumption as 'Private Income' and environmental quality as 'Public Income'.

$$x_i = g_i + b_i \tag{4.2}$$

The participants in the experiment cannot influence directly the earnings resulting from environmental quality. Instead, each unit of the brown good consumed by any group member reduces environmental quality by one unit. The initial level of environmental quality is 90 units, and this value is known to all participants.

$$Y = 90 - \sum_{i=1}^{3} b_i \tag{4.3}$$

In this setup, the decision to buy one unit of the brown good reflects a choice to prioritize private consumption over environmental quality, as each unit of the brown good generates one unit of pollution. In contrast, the green good provides a cleaner alternative that does not have a negative impact on the environment, but it comes at a higher cost. This situation creates a social dilemma, where individuals must choose between their own interests and those of the group.

Assuming that the subjects are payoff-maximizers, then the predicted consumption of g_i and b_i is given by:

$$
g_i(w_i, Y) = \begin{cases} \frac{w_i}{5} & if \quad w_i \geq 150 \\ \dfrac{w_i - 30}{4} & if \quad w_i \in [30,150] \\ 0 & if \quad w_i \leq 30 \end{cases}
$$

$$
b_i(w_i Y) = \begin{cases} 0 & if \quad w_i \geq 150 \\ \dfrac{150 - w_i}{4} & if \quad w_i \in [30,150] \\ w_i & if \quad w_i \leq 30 \end{cases} \tag{4.4}
$$

It is important to note that the demand functions in 4.4 are independent of the actions made by other group members. This implies that subjects have a dominant strategy, determined solely by their individual endowment w_i. This result is a consequence of using a quasilinear profit function, which I selected due to two essential reasons. First, it simplifies the experimental design and enables subjects to comprehend how the setup works in an easier way. Second, it rules out strategic considerations as a possible confounding variable when analyzing the results.

Specifically, subjects maximize their payoff by solely consuming green goods if they receive an endowment of 150 tokens or more. However, if they receive 30 tokens or fewer, consuming only the brown good maximizes their profit. For those who receive between 30 and 150 tokens, the optimal consumption of green and brown goods depends on their initial endowment. Following the baseline model, I will classify the subjects based on their predicted consumption as ‘Green’, ‘Mixed’, and ‘Brown’ consumers.

Accordingly, the predicted levels of individual private consumption and environmental quality in a Nash Equilibrium can be determined using (4.2) and (4.3):

$$X_i^* = \begin{cases} {}^{w_i}/_5 & if \quad w_i \geq 150 \\ 30 & if \quad w_i \in [30{,}150] \\ 0 & if \quad w_i \leq 30 \end{cases}$$

$$Y^* = 90 - \left[\frac{150}{4} n_M - \frac{1}{4}\sum_{i \in M} w_i\right] - \sum\nolimits_{j \in B} w_j \qquad (4.5)$$

where M denotes the set of Mixed Consumers (i.e., $w_i \in [30{,}150]$), n_M is the number of predicted consumers in M, and B denotes the set of Brown Consumers (i.e., $w_i \leq 30$). Following the theoretical results from the baseline model in Chapter 1, the equilibrium level of environmental quality is determined by the total income of the different sets of consumers. If the total income of Mixed Consumers increases, the environmental quality is predicted to improve. If the total income of Brown Consumers increases, then environmental quality is predicted to decrease. Finally, if the total income of Green Consumers increases, there is no predicted impact on environmental quality.

This experiment investigates the impact of income inequality on environmental quality by comparing three treatments, each consisting of an Equal Phase and an Unequal Phase. During the Equal Phase, all participants receive a homogenous endowment of 90 tokens per round, while during the Unequal Phase, the endowment varies across three income classes. The total group income is fixed at 270 tokens per round for all treatments, and the distribution of tokens is known by every group member in all rounds.

Table 4.1: Individual endowments per treatment (tokens per round)

Treatment	Phase	Low-Income Subject	Mid-Income Subject	High-Income Subject	Total
Neutral (NT)	Equal	90	90	90	270
	Unequal	50	90	130	
Improving (IT)	Equal	90	90	90	270
	Unequal	15	90	165	
Diminishing (DT)	Equal	90	90	90	270
	Unequal	30	30	210	

Note: The Mid-Income subject is identified as a second Low-Income subject for the Diminishing Treatment (DT)

The Unequal Phase in each treatment includes a different income distribution, each one designed to investigate whether income inequality can produce neutral, better, or worse environmental quality compared to an equal income distribution. In the Neutral Treatment (NT), the Low-Income subject receives 50 tokens, the Mid-Income subject receives 90 tokens, and the High-Income subject receives 130 tokens. In the Improving Treatment (IT), the Low-Income subject receives 15 tokens, the Mid-Income subject receives 90 tokens, and the High-Income subject receives 165 tokens. In the Diminishing Treatment (DT), two Low-Income subjects receive 30 tokens each, and one High-Income subject receives 210 tokens. I present the income distributions for all players across every treatment in Table 4.1.

This experimental design enables both within-subject and between-subject comparisons. By keeping group membership fixed throughout the session, I am able to examine the effect of income redistribution within groups and analyze the individual effects of adjusting to a new level of income. However, one potential disadvantage of this design is that subjects may have different attitudes towards equalizing and unequalizing redistributions of income. To address the possibility of order effects, I reverse the order of the Equal and Unequal phases in every other session. Furthermore, since each group experiences only one treatment, I use a between-subject comparison to test whether the overall level of environmental quality is sensitive to different income distributions.

4.4 Experimental procedure

For the study, I recruited undergraduate students from the University of Maryland through the Online Recruitment System for Economic Experiments (ORSEE) software. The sample consisted of students who voluntarily enrolled in the Paid Subject Pool affiliated with the Symons Hall Experimental Laboratory (SHEL). These students received an invitation email from ORSEE requesting them to participate. The sample represented a diverse population on campus, including individuals with a range of academic backgrounds, not just economics majors.

I used a survey designed in Qualtrics to conduct the experiment, and I enabled real-time interaction between participants by using the SMARTRIQS open-source add-on (Molnar 2019). Each subject received a unique, single-use link that granted them access to the Qualtrics survey. After completing the experiment, subjects were paid anonymously based on the decisions they made in a randomly selected round. To collect general demographic information, participants were also asked to complete a survey.

I conducted the experiment in the Symons Hall Experimental Laboratory (SHEL) with 6 to 15 subjects participating in each session. All subjects participated at the same time but made their decisions individually and anonymously on their own computers. To ensure consistency, I read the experiment instructions aloud to all participants at the beginning of each session.[15] The participants then answered some practice questions to ensure that they had understood the instructions correctly. Once everyone passed the quiz, all subjects were matched with two other participants, and their roles as Low-, Mid-, or High-Income subjects were assigned.

To aid in the decision-making process of the participants, I offered them the option to use a pre-programmed calculator in each round. Participants could input the quantity of green goods they wanted to buy and could also provide an estimate of the total combined consumption of the brown good made by other group members. The calculator provided information on the earnings from total private consumption and environmental quality for that scenario, as well as the participant's payoff. It is worth noting that calculator usage did not impact individual payoffs in any way. Prior to the first round, participants had two minutes to become acquainted with how the calculator works.

[15] I have included a copy of the experimental instructions in the Appendix to this chapter.

Following Azrieli, Chambers and Healy (2018), I randomly selected only one of the twenty rounds for payment. I converted the payoff calculated from (4.1) to US dollars at an exchange rate of 150 tokens = 1 USD. Additionally, participants had the option to submit their estimate of the combined purchases of the brown good made by other group members. If their estimate was accurate, they received an additional 100 tokens. If the estimate was within an absolute difference of one point from the actual contribution, they received an additional 50 tokens.

A total of 138 subjects participated in the study, with 39 participating in the Neutral Treatment, 45 in the Improving Treatment, and 54 in the Diminishing Treatment. I conducted this study over twelve sessions, with four sessions for each of the three treatments. In every other session, I reversed the order of the Equal and Unequal phases. The payment for subjects ranged from $5.00 to $21.67, with an average payment of $14.00.

4.5 Theoretical predictions and experimental hypotheses

The central hypothesis of this study proposes that income inequality can have varying impacts on environmental quality, with some scenarios leading to an improvement in environmental quality while others may result in no effect or even environmental degradation. I designed three different treatments to test this hypothesis. Following the formulas from (4.4) and (4.5), I present the theoretical predictions and Nash Equilibrium levels for all three treatments in Table 4.2. The prices of the green and brown goods are at $P_g = 5$, and $P_b = 1$, with a total group income of 270 tokens and an initial environmental quality of 90 units for all treatments and sessions.

Table 4.2. Theoretical predictions: Nash Equilibrium consumption and payoffs

Treatment	Subject	Endowment (w_i)	Green Good (g_i^*)	Brown Good (b_i^*)	Private Cons. (X_i^*)	Env Qty (Y^*)	Payoff (π_i)
Equal Phase							
All	Low-income	90	15	15	30	45	1440
	Mid-income	90	15	15	30		1440
	High-income	90	15	15	30		1440
Unequal Phase							
Neutral (NT)	Low-income	50	5	25	30	45	1440
	Mid-income	90	15	15	30		1440
	High-income	130	25	5	30		1440
Improving (IT)	Low-income	15	0	15	15	60	1283
	Mid-income	90	15	15	30		1620
	High-income	165	33	0	33		1661
Diminishing (DT)	Low-income	30	0	30	30	30	1260
	High-income	210	42	0	42		1368

Note: There are two Low-income subjects in the Diminishing Treatment (DT)

4.5.1 Group Behavior

In the Equal Phase, all subjects receive a homogenous endowment of 90 tokens, which places them in the category of Mixed Consumers. According to , the Nash

Equilibrium level of environmental quality is predicted to be 45 units. This prediction is based on the fact that there will be three Mixed Consumers with a total income of 270 tokens. I will use this value of 45 units as a baseline to compare the Nash Equilibrium levels of environmental quality during the Unequal Phase, where there exists income inequality among the group members.

In the Unequal Phase, the overall level of environmental quality is predicted to vary depending on the treatment. In the Neutral Treatment, the income distribution is equivalent to having a transfer of 40 tokens from the Low-Income subject (with an endowment of 50 tokens) to the High-Income consumer (with an endowment of 130 tokens). However, this transfer still places both of them in the category of Mixed Consumers and it does not affect the total income within this set of consumers Consequently, the Environmental Quality level is expected to remain unchanged from the Equal Phase. Although the Low-Income consumer will demand 25 units of the brown good, this will be balanced by the High-Income subject reducing the individual consumption of the brown good to 5 units. Therefore, the group consumption of the brown good will stay at 45 units, the same as in the Equal Phase.

Hypothesis 1: *Environmental quality is the same in the equal and unequal phases of the Neutral Treatment.*

In the Improving Treatment, the income distribution is equivalent to having a transfer of 75 tokens from the Low-Income subject (with an endowment of 15 tokens) to the High-Income subject (with an endowment of 165 tokens). In this situation, the income of the Low-Income subject falls below the critical level of 30 tokens, while the income of the High-Income subject exceeds the critical level of 150 tokens. Consequently, this redistribution of tokens affects the set of Mixed Consumers. To analyze the effects of this income transfer on Environmental Quality, it is possible to divide the analysis into two parts.

The first part involves a transfer of 60 tokens between both subjects so that both are located exactly at the critical income levels to become a Brown and Green Consumer, respectively. Until this point, both subjects are still Mixed Consumers, and this transference does not have an expected impact on Environmental Quality. In the second part, the remaining 15 tokens are transferred from a Brown Consumer to a Green Consumer. As a result, the total income of Brown Consumer decreases and environmental quality is predicted to improve.

Hypothesis 2: *Environmental quality is better in the unequal phase than in the equal phase of the Improving Treatment.*

Finally, in the Diminishing Treatment, the income distribution involves a transfer of 60 tokens from each of the Low-income subjects, who have an initial endowment of 30 tokens each, to the High-income subject, who has an endowment of 210 tokens. To understand the impact of this income distribution, it is convenient to examine the effect of each transfer in sequence. The first transfer occurs between two Mixed Consumers and has no impact on environmental quality. However, this transfer is large enough to bring the High-income subject's income level to the maximum limit for being classified as a Mixed Consumer. Consequently, the second transfer causes the High-income subject to become a Green Consumer, resulting in a decrease in the total income of the Mixed Consumers. As a result, this income distribution is predicted to have a negative impact on Environmental Quality.

Hypothesis 3: *Environmental quality is worse in the unequal phase than in the equal phase of the Diminishing Treatment.*

4.5.2 Individual Behavior

Based on the predictions from 4.4, the effect of an increase in income on the individual consumption of brown goods varies depending on the initial endowment of the subject, specifically whether it exceeds or falls below the critical level of 30 tokens. In the Improving Treatment, low-income subjects receive fewer tokens than those in the Diminishing Treatment, leading to the prediction that the latter will consume more brown goods due to their larger initial endowment. However, when compared to Low-income subjects in the Neutral Treatment, those in the Diminishing Treatment are expected to consume more brown goods.

The predicted behavior of Mid- and High-income subjects also shows a consistent decreasing trend in brown goods consumption with each increase in income, conforming to the Environmental Kuznets Curve, which anticipates a rise in polluting activities followed by a decline as income increases. In other words, the relationship between income and brown goods consumption follows an inverted U-shaped pattern. Initially, an increase in income leads to an increase in the consumption of brown goods. However, beyond a certain point, further increases in income cause a decrease in brown goods consumption.

Hypothesis 4: *The individual consumption of the Brown Good follows a Kuznets-like behavior: it is increasing in income for subjects with a low endowment and decreasing in income for subjects with a high endowment.*

To address the individual consumption of green goods, the predictions derived from 4.4 are less complex. Subjects who receive more than 30 tokens are expected to increase their consumption of green goods as their income increases. The only exception occurs when comparing the Low-income subjects from the Improving and Diminishing Treatments, as both groups are not expected to consume any green goods.

Hypothesis 5: *The individual consumption of the green good increases in income for all subjects above the critical level of 30 tokens.*

4.6 Experimental Results

In Subsection 4.5.1, I examine how different income distributions affect average environmental quality using within- and between-treatment comparisons. In Subsections 4.5.2 and 4.5.3, I analyze the effect of income inequality on individual consumption of green and brown goods and derive the individual Engel Curves. Lastly, in Section 4.5.4, I investigate the determinants that influence the consumption of green versus brown goods among the participants of the experiment. Throughout this section, the letter *N* included in each table corresponds to the number of groups included in each treatment.

4.6.1 Group outcomes

In Table 4.3 I present the summary statistics on environmental quality across treatments and income distributions. Specifically, I compare the results obtained during the equal phase of all groups combined to the unequal phase in each separate treatment, and use the group average across rounds 5 to 9 for statistical analysis to ensure independent units of observation.[16] I utilize the Mann-Whitney U test to conduct a between-subjects comparison of the effect of income inequality on environmental quality. I use this particular test given that there are more units of observation for the equal phase than for each of the treatments in the unequal phase. Additionally, I present the results of the t-test to compare the difference in means with unequal variances.

In general, I find that income inequality has a weakly positive impact on environmental quality. For the unequal distribution in the Neutral Treatment, the average environmental quality is not significantly different from the one observed when

[16] I selected these rounds to control for potential learning and restart effects during the first rounds, as well as for last-round effects.

income is equally distributed across all treatments, supporting Hypothesis 1. However, it is worth noting that environmental quality falls below the Nash Equilibrium prediction (Y^*=45) in both cases. In the unequal distribution of the Improving Treatment, environmental quality increases compared to the equal distribution (with significance at the 10% level), although in a smaller proportion than what the Nash Equilibrium predicts (Y^*=60), which supports Hypothesis 2.

Table 4.3 Summary statistics on environmental quality (between subjects comparisons)

Treatment	Average	Std. Deviation	t-test^*	Mann-Whitney U Test*
Equal Distribution				
All Treatments w = (90,90,90) N=46	35.304	23.499	-	-
Unequal Distribution				
Neutral Treatment w = (50,90,130) N=13	35.077	22.005	p=0.975	p=0.609
Improving Treatment w = (15,90,165) N=15	45.867	14.372	p=0.044	p=0.062
Diminishing Treatment w = (30,30,210) N=18	45.611	19.856	p=0.085	p=0.066

^Two-sample t-test with unequal variances
*p-values reported / Both tests compare the Equal Distribution to the Unequal Distribution in each of the treatments.

Finally, the unequal distribution in the Diminishing Treatment shows that environmental quality also improves compared to the equal distribution (with significance at the 10% level). This result is not consistent with the statement from Hypothesis 3, as this income distribution was predicted to generate a lower environmental quality than the equal income distribution. Moreover, the result is greater than what the Nash Equilibrium predicts (Y^*=30). Therefore, I find that all three unequal income distributions yield an average environmental quality that is at least as high as the equal income distribution.

To ensure that the previous result is not driven by individual characteristics or by the effect of redistributing income within the group, I conduct a within-subjects analysis. I present the summary statistics and tests for the difference of means in Table 4.4 . In addition to the t-test, I also show the results of the Wilcoxon matched-pairs sign rank test. I disaggregate the results for the equal income distribution across each of the three treatments.

For the Neutral and Improving Treatments, I find that there is a small increase in environmental quality when income is distributed unequally. However, these differences are not statistically significant, and thus, it is not possible to reject the null hypothesis that environmental quality is the same under equal and unequal income distributions. These results support Hypothesis 1, but not Hypothesis 2. On the other hand, in the Diminishing Treatment, the results from the between-subjects analysis hold and environmental quality increases significantly when income is distributed unequally. This result is not consistent with Hypothesis 3, as this income distribution was predicted to generate lower environmental quality than the equal income distribution. Based on these findings, I can conclude that income inequality does not have a negative impact on environmental quality across and within all three treatments. As such, I can state the following result:

Result 1: *Income inequality weakly increases environmental quality in all treatments.*

Table 4.4 Summary statistics on environmental quality (within treatments)

Treatment	Income Distribution	Average Environmental Quality	Predicted	t-test^*	Wilcoxon signed-rank test*
Neutral (NT) N=13	Equal	32.000 (26.69)	45		
	Unequal	35.077 (22.01)	45		
	Difference	3.08	0	p=0.708	p=0.774
Improving (IT) N=15	Equal	39.467 (21.62)	45		
	Unequal	45.867 (31.23)	60		
	Difference	6.40	15	p=0.217	p=0.283
Diminishing (DT) N=18	Equal	34.222 (23.43)	45		
	Unequal	45.611 (19.86)	30		
	Difference	11.39	-15	p=0.022	p=0.026

Standard Deviations in parenthesis
^Paired t-test *p-values reported (H0: difference = 0 , Ha: difference ≠ 0)

4.6.2 Individual outcomes

In Table 4.5 I present the summary statistics for individual consumption of the green and brown goods across treatments and income distributions To compare the results obtained during the equal phase with the unequal phase in each treatment, I define overconsumption (underconsumption) as the act of consuming more (fewer) units than predicted by the Nash Equilibrium. For the statistical analysis, I use the individual average consumption across rounds 5 to 9 as the units of observation.[17] To determine if there are systematic deviations from the Nash Equilibrium prediction, I use the Wilcoxon signed-rank test to match each group of subjects to their specific prediction across treatments and phases. Additionally, I present the results of the t-test to compare the difference in means with unequal variances.

During the Equal Phase, the average individual consumption of the green good and the brown good is 14.354 units and 18.232 units, respectively, which are values close to the Nash Equilibrium prediction of 15 units for both goods. However, the deviation is statistically significant at the 5% level (p=0.002), indicating that subjects are consuming more brown goods than predicted. This result explains why environmental quality is lower than expected when the income distribution is equal, as subjects underconsume the green good and favor the brown good.

Result 2*: Subjects overconsume the brown good when the distribution of income is equal.*

[17] I selected these rounds to control for potential learning and restart effects during the first rounds, as well as for last-round effects.

Table 4.5 Individual consumption of the green and brown goods

Treatment	Subject	n	Income	Avg. Green	Prediction	Avg. Brown	Prediction	t-test*	Wilcoxon signed-rank test*
Equal Distribution									
All	All Subjects	138	90	14.354 (2.209)	15	18.232 (11.044)	15	p<0.001	p=0.002
Unequal Distribution									
NT	Low-Income	13	50	4.969 (2.649)	5	25.154 (13.234)	25	p=0.967	p=0.824
	Mid-Income	13	90	14.262 (2.150)	15	18.692 (10.750)	15	p=0.239	p=0.553
	High-Income	13	130	23.785 (1.806)	25	11.077 (9.032)	5	p=0.032	p=0.042
IT	Low-Income	15	15	0.587 (0.723)	0	12.067 (3.615)	15	p=0.007	p=0.008
	Mid-Income	15	90	13.613 (3.210)	15	21.933 (16.051)	15	p=0.117	p=0.131
	High-Income	15	165	30.973 (1.126)	33	10.133 (5.630)	0	p<0.001	p<0.001
DT	Low-Income	36	30	2.289 (1.625)	0	18.556 (8.125)	30	p<0.001	p<0.001
	High-Income	18	210	40.544 (2.396)	42	7.278 (11.984)	0	p=0.019	p<0.001

Standard Deviations in parenthesis
°There are two Low-Income subjects in the Diminishing Treatment
*p-values reported / The null hypothesis for both tests is: Average Consumption = Prediction
Note: Since Green and Brown Consumption are linearly dependent, the mean-comparison test on either one produces the same result.

To test whether the findings from Result 2 are consistent across different income distributions, I analyze individual consumption behavior during the Unequal Phase for all three treatments. In the Neutral Treatment, the average consumption behavior of Low-income subjects deviates from that in the Equal Phase. They consume 4.969 units of the green good and 25.154 units of the brown good, which is not statistically different from the Nash Equilibrium prediction of 5 and 25 units for an endowment of 50 tokens.

Mid-income subjects maintain their consumption pattern from the Equal Phase, with an average consumption of 14.262 units of the green good and 18.692 units of the brown good. It is worth noting that this result is not statistically different from the Nash Equilibrium of 15 units for both goods (p=0.553), as opposed to what occurred during the Equal Phase.

In contrast, High-income subjects consume 23.785 units of the green good and 11.077 units of the brown good, which is statistically different from the Nash Equilibrium prediction of 25 and 5 units (p=0.042). Therefore, these subjects also overconsume the brown good, similar to the behavior observed in the Equal Phase. These results reveal that the demand for the green good increases with income, while the demand for the brown good decreases with income.

In the Improving Treatment, Low-income subjects consume 0.587 units of the green good and 12.067 units of the brown good. Despite the prediction that they would allocate all their income towards the consumption of the brown good to maximize their payoff, their average consumption of the green good is statistically different from zero (p=0.008). This result implies that they do not become Brown Consumers, as predicted, and that they continue to underconsume the brown good.

Mid-income subjects, on the other hand, exhibit a consumption pattern that is only slightly different from the Equal Phase, despite no change in their income. They consume an average of 13.613 units of the green good and 21.933 units of the brown good, which is not statistically different from the Nash Equilibrium of 15 units for both goods. This result is consistent with the consumption pattern observed in the Neutral Treatment.

In contrast, high-income subjects exhibit a significantly different consumption pattern (p<0.001) compared to the Nash Equilibrium prediction of 25 and 5 units. They consume an average of 30.973 units of the green good and 10.133 units of the brown good. Like low-income subjects in this treatment, they do not become Green Consumers, despite the prediction that they would allocate all their income towards the consumption of the green good. As a result, all three subjects in this treatment exhibit a Mixed Consumer pattern, as in the Neutral Treatment.

For this treatment, it is notable that the effect of income on the demand for the brown good does not produce a linear result, as both low-income and high-income subjects consume fewer units of the brown good than mid-income subjects. While this result is consistent with the theoretical predictions, it is important to note that it relied on the assumption that low-income subjects would become Brown Consumers, which is not the case.

The individual behavior in the Unequal Phase of the Improving Treatment sheds light on why environmental quality is better ($Y^* = 45.867$), compared to the average outcome from the Equal Phase across all treatments ($Y^* = 35.304$). This outcome can be attributed to the fact that both Low-income and High-income subjects consume fewer units of the brown good when they receive an unequal income. This results in a positive effect on the average environmental quality, which is significant at the 10% level (p=0.062). However, when comparing the results only within the groups that participated in the Improving Treatment, the difference between average environmental quality in the Equal and Unequal Phase becomes statistically insignificant. Therefore, the changes in individual behavior are not substantial enough to establish conclusively that environmental quality improves under an unequal distribution of income.

In the Diminishing Treatment, Low-income subjects have an average consumption of 2.289 units of the green good and 18.556 units of the brown good. Similar to the behavior seen in the Improving Treatment, these subjects do not become Brown Consumers as their consumption of the green good is significantly greater than zero ($p<0.001$). They also deviate from their behavior in the Equal Phase by underconsuming the brown good. On the other hand, High-income subjects in this treatment deviate from the Nash Equilibrium by consuming an average of 40.544 units of the green good and 7.278 units of the brown good. In this treatment, these subjects were predicted to become Green Consumers, but they do not follow this pattern as their consumption of the brown good is significantly greater than zero ($p<0.001$). This result implies that their behavior follows the pattern seen in the Equal Phase as they also overconsume the brown good.

Overall, the income distribution in the Diminishing Treatment allows us to establish that the demand for the green good increases with income, as this result is consistent with the findings from the other treatments. However, caution should be exercised in making a definitive statement about the relationship between income and the demand for the brown good. While the demand for the brown good decreases with income in this treatment, the results from the other treatments establish this is not a linear nor monotonic relationship.

The individual behavior observed in the Unequal Phase of the Diminishing Treatment provides a key insight into why environmental quality is better in this phase ($Y^* = 45.611$), in comparison to the average outcome from the Equal Phase across all treatments ($Y^* = 35.304$) despite the predictions of the Nash Equilibrium suggesting the opposite outcome. Specifically, Low-income subjects consume as many units of the brown good as all participants did during the Equal Phase, whereas High-income subjects consume a smaller amount. This finding is significant at the 10% level when examining the Equal Phase across all treatments ($p = 0.066$), and the significance level increases when focusing on the within-group analysis of only the groups that experienced the Decreasing Treatment ($p = 0.026$). Therefore, income inequality in this treatment plays a role in achieving a better environmental quality.

Upon analyzing the individual behavior of all participants across treatments, it becomes apparent why income inequality did not have the expected impact on environmental quality according to the predictions of the Nash Equilibrium. Low-income subjects consumed the green good in greater amounts than predicted, even when becoming Brown Consumers would have been in their best interest. This observed behavior would suggest a lower total consumption of the brown good within the group, which could have potentially led to a positive effect on environmental quality in the Unequal Phase across all three treatments. However, this positive impact is tempered by the behavior of Mid-income and High-income participants who, on average, consume more of the brown good than predicted, even when it would have been more profitable to become Green Consumers.

Result 3*: In the presence of income inequality, Low-income subjects weakly underconsume the brown good, while Mid-income and High-income subjects weakly overconsume the brown good.*

Result 3 provides a concise summary of the behavioral patterns observed by all subjects in the context of income inequality, as it highlights the systematic deviations from the baseline model and offers insights into how individuals react when they experience a change in their income levels. However, as these deviations vary across income classes, it is necessary to conduct a more comprehensive analysis of the relationship between income and consumption. I provide such an analysis in the following section, which explores the impact of income changes on consumption behavior across different income groups.

4.6.3 Engel curves

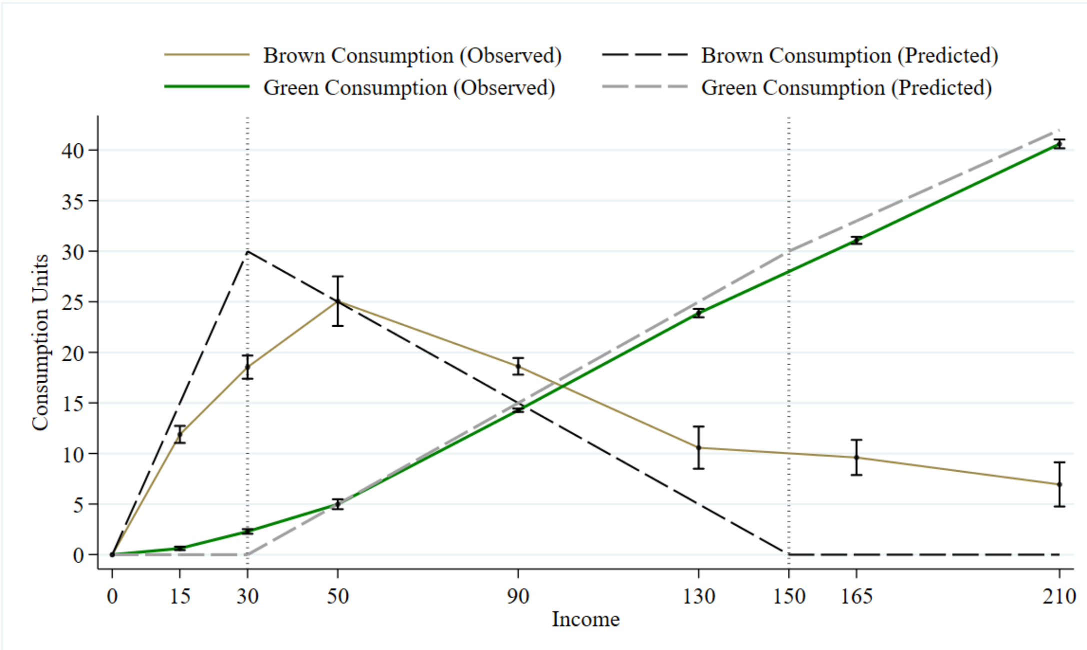
While the baseline model is not entirely accurate in predicting the consumption of all subjects, the results from the experiment show that it effectively describes the relationship between income and individual consumption of green and brown goods. Figure 4.1 presents the predicted and observed average consumption for both the green and brown goods across all the income levels captured during the experiment, with the average consumption plotted for each income level. I pool the results from the Mid-income subjects in the Unequal Phase with those from all subjects in the Equal Phase since they received the same income (90 tokens per participant).

The average consumption of the green good is positively correlated with the income received by each subject, with an increase in consumption observed for each income class. This behavior is expected for Mixed and Green Consumers, but not for Brown Consumers. Nevertheless, all income classes behaved as if they were Mixed Consumers on average, resulting in this consumption pattern being observed even among low-income subjects.

Result 4*: Individual income has a positive effect on the consumption of the green good for every income class.*

In contrast, the consumption of brown goods has a non-monotonic relationship with individual income. Low-income subjects are predicted to increase their consumption of the brown good whenever they receive a larger income. Each of the three treatments has an income distribution with a different endowment for the Low-Income subject. The Improving Treatment has the poorest Low-Income subjects, and this group has, on average, the lowest consumption of the brown good. The Deteriorating Treatment assigns its two Low-income subjects with a greater endowment than the Improving Treatment, and the average consumption of the brown good increases for them. Finally, the Neutral Treatment presents the Low-income subjects with the greatest endowment among all Low-Income subjects, and the results show that this treatment is where the Low-Income subjects consume the greatest amount of the brown good.

Figure 4.1 Predicted consumption vs. observed consumption (Engel curves)



When turning the attention to the consumption decisions of the Mid-income subjects in the Unequal Phase, and the combined behavior of all subjects in the Equal Phase, where every participant received the same endowment of 90 tokens, the consumption of the brown good decreases relative to the consumption behavior of the participants who received an endowment of 50 tokens. This decreasing pattern continues when analyzing how High-income subjects behaved in all three treatments. As the income increases from 130, 165, and 210 tokens, the consumption of the brown good keeps on decreasing.

Therefore, the consumption of the brown good achieves a peak at the income level of 50 tokens, and then it experiences a turning point in which its consumption starts showing a negative relationship with income. It is important to note that consuming one unit of the brown good is equivalent to producing one unit of pollution because it decreases environmental quality by one unit. This consumption pattern follows the same behavior as an Environmental Kuznets Curve. Pollution increases for low levels of income, and then it reaches a maximum in which individuals can now afford to become greener as they get more income.

Result 5*: The consumption of the brown good has a non-monotonic relationship with individual income. It increases for low levels of income until it reaches a turning point where it decreases for high levels of income. This pattern describes an Environmental Kuznets Curve at the individual level.*

The results in Table 4.5 indicate that the average consumption of both the green and brown goods increase in proportion to the income of the Low-income subjects. However, this observed consumption pattern contradicts the predictions from the baseline model, as consumers with low income would benefit from allocating all their income towards the brown good and only start demanding the green good after reaching a critical income level. Despite this theoretical prediction, experimental results demonstrate that consumers consistently purchase small quantities of the green good, even at low income levels, and that the demand for it increases with income.

On the other hand, it is also crucial to understand why high-income consumers continue to purchase the brown good, even when it is financially optimal for them to stop consuming it altogether. While the baseline model does predict that the demand for the brown good decreases with income for high-income consumers, it does not provide an explanation for why the transition to becoming a Green Consumer takes such a long time to occur.

The payoff function used in the experiment (4.1) has the property of inducing a dominant strategy for each subject, dependent solely on their endowment. Nonetheless, it is possible that strategic interactions among subjects within the same group may influence individual consumption choices. For this reason, in the following section, I will examine additional factors and variables that may impact brown consumption decisions, with the aim of better understanding the observed deviations from the theoretical predictions of the baseline model.

4.6.4 Determinants of brown consumption

To gain insight into the reasons why subjects are deviating from the Nash Equilibrium predictions, I conduct a regression analysis to identify the variables that may be influencing their individual consumption of the brown good. Specifically, I employ a panel data specification in which the dependent variable is the consumption of the brown good at each round t. Drawing from the models convergence analysis by Noussair, Plott and Riezman (2013) and beliefs formation in public goods games by Fischbacher and Gächter (2010), I incorporate a time trend variable (t) and the consumption of the brown good from the previous round $(t-1)$ as the primary explanatory variables. Furthermore, given that the analysis from the previous section highlights the relevance of the endowment received by each subject, I also include this variable in the model. The main specification is presented below:

$$Brown\,Cons_{it} = \alpha + \beta_1 t + \beta_2 endowment_{it} + \beta_3 Brown\,Cons_{it-1} + \delta\mathbf{X} + \epsilon_{jt} \quad (4.6)$$

where i determines an individual subject, t is the current round, and j is the group to which subject i belongs. The vector $\mathbf{X}$ is the group of variables that are candidates to have an impact on the individual consumption of the brown good. The standard errors are clustered at the group level to account for the fact that the subjects in every group experienced similar conditions and, as such, their behavior might be correlated.

There are three main variables corresponding to $\mathbf{X}$ that I will analyze in this section: 1) the consumption of the brown good made by the other group members in both the current period (t) and the previous period $(t-1)$, 2) the belief that subject i holds regarding the consumption of the brown good by other group members during period t, and 3) the impact of income redistribution. To avoid any potential biases coming from order or restart effects, I will exclude data from the first and eleventh rounds of the experiment, as these rounds mark the transition from the Equal to the Unequal Phase or vice versa. Additionally, since I will be analyzing the previous round's consumption, I will exclude data from the first round. For every table, I will combine data from all subjects in the first column. In columns 2-4, I will break down the data by the Low-, Mid-, and High-income subjects during the Unequal Phase.

Table 4.6 Impact of time effects and endowments on brown good consumption

	All Subjects	Low-Income	Mid-Income	High-Income
Time trend (t)	-0.126**	-0.08	-0.082	-0.206**
	(0.052)	(0.053)	(0.115)	(0.095)
Endowment	-0.024***	0.008	-	-0.041***
	(0.006)	(0.011)	-	(0.014)
Own Brown (t-1)	0.552***	0.582***	0.583***	0.499***
	(0.044)	(0.049)	(0.16)	(0.053)
Constant	11.178***	7.967***	9.036**	14.635***
	(1.138)	(1.02)	(3.606)	(2.155)
Obs	2484	1152	504	828
Clusters	46	46	28	46

*p<0.10, **p<0.05, ***p<0.01
Standard errors in parenthesis

Table 4.6 presents the results of the regression analysis examining the impact of time effects and individual endowments on the consumption of the brown good. The results confirm that the individual endowment significantly and negatively affects the consumption of the brown good when pooling data from all subjects. However, when the data is disaggregated by income classes, this effect is only observed among high-income subjects. This result occurs because Mid-income consumers do not change their behavior in between phases, while Low-income subjects in the Neutral Treatment increase their consumption of the brown good and those in the Improving Treatment decrease it, which cancels out the effect for low-income subjects.

Table 4.7 Impact of brown consumption from other group members' consumption

	All Subjects	Low-Income	Mid-Income	High-Income
Time trend (t)	-0.097*	-0.057	-0.04	-0.19*
	(0.049)	(0.053)	(0.13)	(0.1)
Endowment	-0.025***	0.006	-	-0.04***
	(0.007)	(0.011)	-	(0.014)
Own Brown (t-1)	0.548***	0.577***	0.585***	0.496***
	(0.047)	(0.05)	(0.161)	(0.055)
Others Brown (t)	0.022	0.022	-0.02	0.042
	(0.018)	(0.015)	(0.042)	(0.029)
Others Brown (t-1)	0.011	0.002	0.05	0.001
	(0.02)	(0.02)	(0.05)	(0.029)
Constant	9.802***	7.092***	7.407*	12.73***
	(1.091)	(1.102)	(3.997)	(2.515)
Obs	2484	1152	504	828
Clusters	46	46	28	46

*p<0.10, **p<0.05, ***p<0.01
Standard errors in parenthesis

I examine the impact of the consumption of the brown good by other group members on individual behavior in Table 4.7 . According to the baseline model, the decisions of others should not play a role in individual behavior since there exists a dominant strategy in brown consumption. The results confirm this prediction, as the consumption of other players has a small and statistically insignificant effect on individual consumption of the brown good, regardless of income class or pooling the data from all subjects.

In Table 4.8 I analyze the impact of beliefs about the consumption of the brown good by other group members on individual behavior. The results show that beliefs have a significant impact on behavior for all subjects, but particularly for low- and high-income subjects. When subjects hold a belief that other group members will increase their consumption of the brown good, they react by increasing their own consumption. This suggests that subjects behave according to the formation of a reference point or at least a parameter by which they deem they should model their own behavior.

Table 4.8 Impact of beliefs about brown consumption from other group members

	All Subjects	Low-Income	Mid-Income	High-Income
t	-0.087*	-0.052	-0.024	-0.18*
	(0.049)	(0.052)	(0.131)	(0.101)
Endowment	-0.026***	0.006	-	-0.038**
	(0.007)	(0.01)	-	(0.015)
Own Brown (t-1)	0.543***	0.573***	0.582***	0.484***
	(0.047)	(0.05)	(0.16)	(0.057)
Belief (t)	0.055***	0.038**	0.049	0.086**
	(0.017)	(0.015)	(0.034)	(0.038)
Constant	9.135***	6.678***	6.77*	11.171***
	(1.066)	(0.983)	(3.977)	(2.509)
Obs	2484	1152	504	828
Clusters	46	46	28	46

*p<0.10, **p<0.05, ***p<0.01
Standard errors in parenthesis

Finally, in Table 4.9 , I assess the impact of income redistribution during the Equal and Unequal Phases within each income group. The variable labeled as "Redistribution" is a dichotomous variable that takes a value of 1 if the consumption decision occurs after the eleventh round, when income has been redistributed within the group. To isolate the effect of redistribution from income inequality, I include a dummy variable with a value of 1 to indicate the Unequal Phase. Additionally, I interact both variables to determine if there is an additional effect of income redistribution that generates income inequality.

Table 4.9 Impact of Income Redistribution

	All Subjects	Low-Income	Mid-Income	High-Income
t	-0.145*	-0.129	0.052	-0.376**
	(0.081)	(0.096)	(0.206)	(0.179)
Endowment	-0.024***	0.192***	-	-0.011
	(0.006)	(0.052)	-	(0.026)
Brown t-1	0.548***	0.558***	0.582***	0.491***
	(0.045)	(0.051)	(0.16)	(0.054)
Redistribution	-0.228	-0.128	-0.873	0.29
	(1.159)	(1.412)	(2.304)	(2.437)
Unequal	-1.734	11.04***	0.98	-5.093***
	(0.987)	(3.246)	(2.101)	(2.536)
RxU	1.09	1.219	-1.64	3.326
	(1.535)	(1.658)	(3.358)	(2.529)
Constant	12.145***	-7.933*	7.904**	14.281***
	(1.323)	(4.255)	(3.827)	(2.557)
Obs	2484	1152	504	828
Clusters	46	46	28	46

*p<0.10, **p<0.05, ***p<0.01
Standard errors in parenthesis

Neither the isolated effect of redistribution nor its interaction with the dummy variable for the Unequal Phase is statistically different from zero. This suggests that the subjects do not alter their consumption decisions when the experiment switches between the Equal and Unequal Phases. However, the effect of income inequality is significant for both Low- and High-income subjects. This result is consistent with the scenario where Low-income subjects receive a smaller endowment, incentivizing them to increase their consumption of the brown good. Conversely, High-income subjects have a higher endowment during the Unequal Phase and, as demonstrated in the previous sections, they reduce their consumption of the brown good.

These findings highlight the importance of considering income redistribution when evaluating the impact of income inequality on consumption decisions. The results suggest that individuals are more responsive to the level of endowment they receive, rather than the distribution of income within their group. Thus, redistributing income within a group may not be sufficient to influence consumption decisions, and policymakers may need to consider other strategies to address income inequality.

Furthermore, the lack of significant interaction between the redistribution and Unequal Phase variables indicates that the effect of redistribution is consistent across the two phases. This suggests that the effect of redistribution is not conditional on the level of income inequality within the group. This finding has important implications for policymakers as it suggests that the impact of redistribution on consumption decisions may not depend on the extent of income inequality in society.

Overall, the regression analysis indicates that beliefs about the consumption decisions of other group members are a significant determinant of individual behavior and a potential explanation for the systematic deviations from Nash Equilibrium predictions. To obtain a more comprehensive model of green and brown consumption, it is imperative to consider the two primary deviations: (1) consumers with low income increase their demand for both green and brown goods, and (2) consumers with high income take more time to switch to green consumption, as they do not substitute the brown good as rapidly as predicted by the baseline model. In the following section, I present an extended model with two behavioral motivations to account for these deviations.

4.7 Behavioral extensions to the baseline model

As I observed systematic deviations from the Nash Equilibrium in the results of my laboratory experiment, I aim to expand the baseline model from the previous chapter to include additional factors that may influence the decision to purchase Green or Brown Goods beyond Environmental Quality and Private Consumption. Specifically, I will incorporate the model of warm-glow consumption of the green good and the theory of conformity over the brown good.

4.7.1 Warm-glow preferences over the green good

The warm-glow model of giving (Andreoni 1990) offers a framework to extend the baseline model by introducing g_i as an additional argument in the utility function. This term reflects the idea that individuals may feel good about their own green consumption. Assuming that the marginal consumption of the green good is strictly positive (i.e., $U_{g_i} > 0$), the consumers now solve the following utility-maximization problem:

$$\max_{x_i, Y, g_i, b_i} \left\{ U_i(x_i, Y, g_i) \,\middle|\, \begin{matrix} w_i = P_g g_i + P_b b_i, & x_i = g_i + b_i \\ Y = Y_{-i} - b_i, & g_i, b_i \geq 0 \end{matrix} \right\} \qquad (4.7)$$

In this model, the first order condition that describes the unique solution to (4.7) would include the additional effect of the marginal consumption of g_i to denote the fact that the demand for total private consumption and environmental quality are now influenced by warm-glow motives:

$$\frac{U_Y + U_{g_i}}{U_{x_i} + U_{g_i}} = \frac{P_g - P_b}{P_g} = \frac{P_Y}{P_x} \quad (\text{if } g_i^* > 0, b_i^* > 0) \tag{4.8}$$

To gain a better understanding of how U_{g_i} affects the solution in (4.8), first it is helpful to re-express it in terms of U_{g_i} to get:

$$U_{g_i} = \frac{P_Y U_{x_i} - P_X U_Y}{P_x - P_Y} > 0 \ \rightarrow \ \frac{U_{x_i}}{U_Y} > \frac{P_x}{P_Y}$$

Therefore, in an interior solution, having warm-glow motives consumers to pay the price difference between g_i and b_i to get additional units of the green good, even when their valuation of one additional unit of environmental quality is lower than that amount. To understand why this is happening, it is useful to use the identity $g_i = x_i + Y - Y_{-i}$. The decision to consume one additional unit of g_i not only increases the consumption of x_i, but it also helps to preserve one unit of Y. Warm-glow motives enhance the effect over private consumption, and now consumers have an additional motivation to increase the consumption of the green good itself.

To simplify the analysis of the demand for environmental quality and total private consumption with warm-glow motives, I will assume that the warm glow component enters the utility function in an additively separable manner. Therefore, the individual demand functions for X_i and Y can be found by solving:

$$\max_{x_i, Y} \left\{ U_i(x_i, Y) + \theta_i f_i(x_i + Y - Y_{-i}) \middle| \begin{matrix} m_i = P_x x_i + P_Y Y, \\ Y_{-i} - x_i \leq Y \leq Y_{-i} \end{matrix} \right\} \tag{4.9}$$

where U_i has the same properties as the utility function from the baseline model, f_i is a strictly increasing and concave function (i.e., $f_i' > 0, f_i'' < 0$), and θ_i is a non-negative constant that serves as a weight parameter ($\theta_i \geq 0$). Assuming an interior solution, the unique solution to (4.9) is:

$$x_i = \tilde{x}_i(P_X, P_Y, m_i, Y_{-i})$$

$$Y = \tilde{y}_i(P_X, P_Y, m_i, Y_{-i})$$

I denote these demand function with a tilde (~) to reflect the fact that they are different from the demand functions obtained in the baseline model. The reason for this difference is that Y_{-i} now has an impact through two distinct channels. The first one comes through the full-income m_i which, similar to the baseline model, takes into consideration the overall level of Y that this consumer wants to achieve. The second channel, which is independent from the other exogenous parameters in the model, comes from the warm-glow preference over the green good.

Similar to the baseline model, I will impose the following condition to guarantee the existence of a unique Nash Equilibrium:

$$\frac{\partial \tilde{y}_i}{\partial Y_{-i}} = P_Y \tilde{y}_{im} + \tilde{y}_{iY_{-i}} \ \epsilon \ (0,1)$$

where $\tilde{y}_{im}$ is the derivative of $\tilde{y}_i$ with respect to m_i, and $\tilde{y}_{iY_{-i}}$ is the derivative of y_i with respect to its last argument. This condition is useful to state the following proposition:

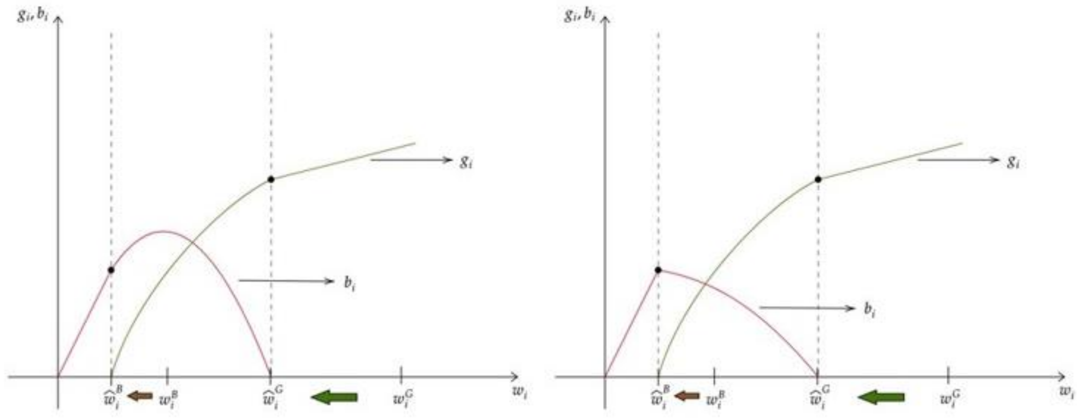
Proposition 4.1: *Assume an interior solution, such that $g_i^* > 0$ and $b_i^* > 0$. If consumer i has a warm-glow preference over the green good (g_i) that enters the utility function in an additively separable manner, and $\frac{\partial \tilde{y}_i}{\partial Y_{-i}} \ \epsilon \ (0,1]$, then:*

i. *Both X_i and g_i are normal with respect to income.*
ii. *The demand for g_i weakly increases everywhere in the income distribution with respect to the baseline model.*
iii. *Y can be inferior for some parts of the income distribution, but then becomes normal as income increases. Equivalently, b_i can be normal for some parts of the income distribution, and then becomes inferior as income increases.*

Parts *i* and *ii* of Proposition 4.1 are intuitively since there is an additional component in the utility function that makes g_i more desirable with respect to the baseline model. As a result, the income levels w_i^B and w_i^G, creating a greater incentive to start consuming g_i earlier. Part *iii* might appear surprising and contradictory given the results of the baseline model. This finding suggests that it is possible for the green and brown goods to be normal at the same time if the marginal utility of consuming the green good is higher than the marginal utility of increasing private consumption, but the value of preserving environmental quality is less than the price difference between the green and brown goods. It should be noted that Part *iii* is not necessarily valid for every utility function, as it only establishes the possibility of such a situation. For some consumers, the brown good may become inferior as soon as they reach the income level w_i^B and become a Mixed Consumer. Panel a of Figure 4.2 depicts the situation where g_i and b_i can be both normal simultaneously, while panel b shows the case where b_i becomes inferior at w_i^B.

The addition of the warm-glow component is helpful in explaining the behavior of Low-income subjects from the experiment, as they exhibit behavior consistent with part iii of Proposition 4.1. However, this extended model fails to account for the fact that High-income consumers do not become Green Consumers. In fact, the warm-glow model predicts that High-income subjects should have become Green Consumers much earlier than what the baseline model suggests. Therefore, while the warm-glow model can explain some of the results, the baseline model needs an additional modification to fully account for all the results obtained throughout the experiment.

Figure 4.2 Consumption of the green and brown good with warm glow preferences



a) Both the green and brown goods are normal at some point of the income distribution.

b) The brown good is inferior whenever the demand for the green good is positive.

4.7.2 A theory of conformity over the brown good

Turning to the theory of conformity over the brown good, I propose that individuals may change their consumption decisions to conform to the behavior of others in their social group. To account for this, I include a term that represents the average consumption of b_i by the other members in the group, denoted as $\bar{B}$. In this scenario, consumer i seeks to buy as many units of the brown good as the average of the group. Any deviations from this parameter will generate a loss of utility for consumer i.

Equivalent to what I did in the warm-glow model, I will simplify the analysis by assuming that the conformity component enters the utility function in an additively separable manner. Therefore, the individual demand functions for X_i and Y can be found by solving:

$$\max_{X_i,Y,g_i,b_i} \left\{ U_i(X_i,Y) + \delta_i h_i(b_i - \bar{B}) \middle| \begin{array}{ll} w_i = P_g g_i + P_b b_i & \bar{B} = \frac{1}{N}\sum_{j=1}^{N} b_j \\ X_i = g_i + b_i, & Y = Y_{-i} - b_i, \\ & g_i, b_i \geq 0 \end{array} \right\}$$

where h is a strictly concave function that achieves its maximum at 0, is increasing when its value is negative, and decreasing when its value is positive, i.e., $h'(0) = 0$, $h' > 0$ if $b_i < \bar{b}$, and $h' < 0$ if $b_i > \bar{b}$.

I include a full characterization of the solution to this utility maximization problem in the Appendix to this chapter. However, I summarize the most important results from this model in Proposition 4.2.

Proposition 4.2: *Assume an interior solution, such that $g_i^* > 0$ and $b_i^* > 0$. Suppose that there exists a function $h_i(\cdot)$ that measures the disutility that consumers suffer if their own consumption of the Brown Good is different than the average of their group, then:*

i. *The critical income level w^B is lower than in the baseline model.*

ii. *The critical income level w^G is greater than in the baseline model.*

iii. *The demand for the Brown Good is decreasing in income.*

iv. The demand for the Green Good is increasing in income.

Proposition 4.2 partially explains the deviations observed in the experiment. According to the model of conformity, consumers have an incentive to start buying green goods at a lower income than what the baseline model predicts. This situation occurs because consumers want to avoid deviating significantly from the average consumption of brown goods within their group. Thus, when a consumers realize that their consumption of brown goods is excessive relative to the group average, they begin to mitigate this difference by consuming green goods. Similarly, high-income consumers have a motive to maintain their consumption of brown goods. Consequently, their transition to becoming green consumers occurs at a slower pace than what the baseline model predicts. Even as their income increases, they may continue to purchase some brown goods to avoid deviating too much from the group average, particularly if other consumers in their group continue to buy brown goods.

These findings suggest that conformity plays a significant role in the decision-making process when choosing between green and brown goods. Although conformity can accelerate the transition towards becoming a Mixed Consumer, it can also act as a deterrent to becoming a Green Consumer. However, this model fails to fully capture the entirety of the behavior observed in the experiment. Specifically, it retains the same prediction as the baseline model regarding the demand for the brown good when the consumer starts buying the green good, that the demand has a negative relationship with income. Nonetheless, the experiment shows that even when consumers demand the green good, an increase in income generates an increase in the demand for the brown good. Conformity cannot explain this result, which the model of warm-glow was capable of doing.

To account for the full range of behaviors observed in the experiment, it is important to consider both the warm-glow and conformity models. Although they cannot independently explain everything that happened in the experiment, together they provide a more comprehensive picture of environmentally friendly consumption and its effects on environmental quality. Furthermore, by incorporating both models, the main structure of the predictions from the baseline model is maintained, while generating a more complete model of consumer behavior.

4.8 Conclusion

To test the validity of my baseline model, I conducted a novel laboratory experiment to test the impact of income inequality on environmental outcomes. The experiment consisted of three treatments, each one featuring a distinct, unequal income distribution. The purpose of each treatment was to simulate a scenario where environmental quality would increase, decrease, or remain the same in relation to an equal income distribution.

The results of the experiment showed that income inequality had a weakly positive effect on environmental quality across all three treatments. Surprisingly, the treatment where environmental quality was expected to decrease resulted in a better environmental outcome. To better understand this deviation from the theoretical prediction, I analyzed the individual consumption patterns of the experimental subjects. Upon analyzing the data, I found that low-income subjects did not behave consistently to maximize their payoff, as they consumed green goods in situations where it was not advantageous to do so. Similarly, high-income subjects also deviated from the prediction by consuming brown goods in situations where they would have been better off consuming only green goods. However, the consumption pattern of the brown good confirms the existence of an individual Environmental Kuznets Curve, as predicted by the baseline model.

These results from the experiment suggest that the assumptions of the baseline model do not fully capture the complexity of individuals' decision-making processes when choosing between green and brown goods. Incorporating warm-glow motives and conformity effects can help explain deviations from the Nash Equilibrium observed in the laboratory experiment. Warm-glow motives refer to the positive feelings that individuals experience when making environmentally friendly choices. These feelings are not always related to a direct financial benefit, but rather to an individual, intrinsic motivation to act in an environmentally responsible manner. In contrast, conformity effects refer to the tendency of individuals to conform to social norms, even if it means deviating from their own preferences or beliefs. In this particular set up, I interpret it as preference from not deviating from the average consumption of brown goods.

Incorporating both of these factors into the model can provide a more accurate understanding of the decision-making process of consumers when choosing between green and brown goods. For example, the warm-glow motive can help explain why individuals make environmentally friendly choices even when they are not financially advantageous. In contrast, conformity effects can explain why individuals may choose to consume brown goods, even when they are aware of the negative environmental consequences.

These findings have significant implications for policymakers who seek to promote sustainable consumption patterns. Addressing the social and psychological factors that influence individual decision-making can be crucial in achieving this goal. The objective of this research is to contribute to a better understanding of the complex interplay between income inequality and environmental quality, with the hope of guiding policy decisions that can help ensure a more sustainable future.

Appendices

Appendix A: Appendix to Chapter 2

Proof that $\boldsymbol{x_i(P_X, P_Y, m_i)}$ and $\boldsymbol{y_i(P_x, P_Y, m_i)}$ are increasing functions in $\boldsymbol{w_i}$

Differentiating $X_i(P_X, P_Y, m_i)$ and $y_i(P_X, P_Y, m_i)$ with respect to Y_{-i} gives:

$$\frac{\partial x_i}{\partial Y_{-i}} = P_Y \frac{\partial x_i}{\partial m_i} \qquad \frac{\partial y_i}{\partial Y_{-i}} = P_Y \frac{\partial y_i}{\partial m_i}$$

Differentiating $x_i(P_x, P_Y, m_i)$ and $y_i(P_x, P_Y, m_i)$ with respect to w_i gives:

$$\frac{\partial x_i}{\partial w_i} = \frac{\partial x_i}{\partial m_i} \qquad \frac{\partial y_i}{\partial w_i} = \frac{\partial y_i}{\partial m_i}$$

From (1.4):

$$P_Y = P_x \left(P_Y \frac{\partial X_i}{\partial m_i}\right) + P_Y \left(P_Y \frac{\partial y_i}{\partial m_i}\right)$$

$$1 = P_x \left(\frac{\partial x_i}{\partial m_i}\right) + P_Y \left(\frac{\partial y_i}{\partial m_i}\right)$$

By assumption (1.15), $P_Y \frac{\partial y_i}{\partial m_i} \in (0,1)$ which makes $\frac{\partial y_i}{\partial w_i} \in \left(0, \frac{1}{P_Y}\right)$ and $\frac{\partial x_i}{\partial w_i} \in \left(0, \frac{1}{P_x}\right)$.

Therefore x_i and y_i are increasing functions in w_i.

Proof of Lemma 1.1:

To prove the existence of the critical income level $w_i^G = w_i^G(P_x, P_Y, Y)$, let the demand for Y be defined as $Y = y_i(P_x, P_Y, m_i)$ and its inverse as $y_i^{-1}(P_x, P_Y, Y) = w_i + P_Y Y_{-i}$. Rearranging gives:

$$w_i = y_i^{-1}(P_x, P_Y, Y) - P_Y Y_{-i} > 0 \qquad (\boldsymbol{A.1.1})$$

From $(\mathbf{1.5})$

$$y_i^{-1}(P_x, P_Y, Y) - P_Y Y \geq y_i^{-1}(P_x, P_Y, Y) - P_Y Y_{-i}$$

$$y_i^{-1}(P_x, P_Y, Y) - P_Y Y > 0$$

$$\frac{y_i^{-1}(P_x, P_Y, Y)}{P_Y} - Y > 0$$

Since $\hat{b}_i(Y)$ is a linearly decreasing function in w_i, then there exists a positive value w_i^G such that:

$$0 = \frac{y_i^{-1}(P_x, P_Y, Y) - w_i^G}{P_Y} - Y$$

$$w_i^G = y_i^{-1}(P_x, P_Y, Y) - P_Y Y$$

This result follows from $(\boldsymbol{A.1.1})$

To prove the existence of the of the critical income level $w_i^B = w_i^B(P_x, P_Y, Y)$, suppose that:

$$\frac{w_i}{P_b} < \frac{y_i^{-1}(P_x, P_Y, Y) - w_i}{P_Y} - Y \;\; \forall\, w_i \in \mathbb{R}$$

This leads to a contradiction with the existence of w_i^G since:

$$\frac{w_i^G}{P_b} > \frac{y_i^{-1}(P_x, P_Y, Y) - w_i^G}{P_Y} - Y = 0$$

Now, suppose that:

$$\frac{w_i}{P_b} > \frac{y_i^{-1}(P_x, P_Y, Y) - w_i}{P_Y} - Y \ \ \forall\, w_i \in \mathbb{R}$$

Setting w_i arbitrarily close to 0 leads to:

$$0 < \frac{y_i^{-1}(P_x, P_Y, Y)}{P_Y} - Y$$

Therefore, by the intermediate value theorem, there exists a value w_i^B such that:

$$\frac{w_i^B}{P_b} = \frac{y_i^{-1}(P_x, P_Y, Y) - w_i^B}{P_Y} - Y$$

or:

$$w_i^B = \frac{P_b}{P_Y + P_b}(y_i^{-1}(P_x, P_Y, Y) - P_Y Y)$$

$$w_i^B = \frac{P_x - P_Y}{P_x}(y_i^{-1}(P_x, P_Y, Y) - P_Y Y)$$

The result in (**A.1.1**) establishes that w_i^B is a positive value.

The functions that implicitly define w_i^G and w_i^B are continuous in Y because $y_i(P_X, P_Y, m_i)$ is a continuous function in m_i. As such, $y_i^{-1}(P_X, P_Y, Y)$ must be a continuous function in Y. To prove that they are increasing functions in Y, let $\widetilde{w_i}$ denote the expression $y_i^{-1}(P_X, P_Y, Y) - P_Y Y$ and differentiate it with respect to Y:

$$\frac{\partial \widetilde{w_i}}{\partial Y} = \frac{\partial y_i^{-1}(P_X, P_Y, Y)}{\partial Y} - P_Y$$

from the inverse function theorem:

$$\frac{\partial \widetilde{w_\iota}}{\partial Y} = \frac{1}{\partial y_i \big/ \partial m_i} - P_Y$$

Condition (**1.15**) implies that:

$$1 \geq \frac{\partial y_i(P_x, P_Y, m_i)}{\partial Y_{-i}} > 0$$

$$1 \geq P_Y \frac{\partial y_i(P_x, P_Y, m_i)}{\partial m_i} > 0$$

Therefore, the expression $y_i^{-1}(P_{Xx}, P_Y, Y) - P_Y Y$ is increasing in Y, which establishes that w_i^G and w_i^B are continuous and increasing functions in Y.

Finally, to prove that $w_i^G > w_i^B > 0$ and $\frac{w_i^B}{w_i^G} = \frac{P_x - P_Y}{P_x}$ $\forall\, Y \in \mathbb{R}$, divide w_i^G over w_i^B to get:

$$\frac{w_i^G}{w_i^B} = \frac{y_i^{-1}(P_x, P_Y, Y) - P_Y Y}{\frac{P_x}{P_x - P_y}\left(y_i^{-1}(P_x, P_Y, Y) - P_Y Y\right)}$$

Rearranging:

$$\frac{w_i^B}{w_i^G} = \frac{P_x - P_Y}{P_x}$$

Since $P_x > P_Y$, it follows that $\frac{w_i^B}{w_i^G} < 1$ and $w_i^G > w_i^B$.

Proof of Lemma 1.2:

From the Maximum theorem, $y_i(P_X, P_Y, m_i)$ is a differentiable and continuous function with respect to its parameters. Since $\hat{b}_i(Y)$ depends on the inverse function of $y_i(P_X, P_Y, m_i)$, then $\hat{b}_i(Y)$ is continuous with respect to Y. To prove that the continuity of $\hat{b}_i(Y)$ implies that $b_i(w_i, Y)$ is a continuous function in Y, it is convenient to show first that $\hat{b}_i(Y)$ is a weakly increasing function. Differentiating with respect to Y gives us:

$$\frac{\partial \hat{b}_i(Y)}{\partial Y} = \frac{1}{P_Y} \cdot \frac{\partial y_i^{-1}(P_x, P_Y, Y)}{\partial Y} - 1$$

Using the inverse function theorem, it is possible to re-write the previous expression as:

$$\frac{\partial \hat{b}_i(Y)}{\partial Y} = \frac{1}{P_Y} \cdot \frac{1}{\frac{\partial y_i(P_x, P_Y, m_i)}{\partial m_i}} - 1$$

Differentiating $y_i(P_x, P_Y, m_i)$ with respect to Y_{-i} and using $(\mathbf{2.15})$ gives us:

$$P_Y \frac{\partial y_i(P_x, P_Y, m_i)}{\partial m_i} < 1 \qquad (\boldsymbol{A.1.2})$$

and therefore:

$$\frac{\partial \hat{b}_i(Y)}{\partial Y} = \frac{1}{P_Y} \cdot \frac{1}{\frac{\partial y_i(P_x, P_Y, m_i)}{\partial m_i}} - 1 > 0$$

which proves that $\widetilde{b_i}(Y)$ is an increasing function in Y and that $b_i(w_i, Y)$ is strictly increasing if $w_i \in \left[w_i^B, w_i^G\right]$. Since the level of Y does not affect the behavior of both Brown and Green Consumers, then:

$$\frac{\partial b_i(w_i, Y)}{\partial Y} = 0 \text{ if } \ w_i \in [0, w_i^B] \cup \left[w_i^G, \infty\right)$$

which proves that $b_i(w_i, Y)$ is a weakly increasing function for all consumers.

Finally, to prove the continuity of $b_i(w_i, Y)$, it is sufficient to show that it is continuous at the points where $w_i = w_i^B(P_x, P_Y, Y)$ and $w_i = w_i^G(P_x, P_Y, Y)$. From Lemma 1, an increase in Y causes the critical income level w_i^B to increase as well. As such, there exists a value Y^B where $w_i = w_i^B(P_x, P_Y, Y^B)$ and:

$$\hat{b}_i(Y^B) = \frac{y_i^{-1}(P_x, P_Y, Y^B) - w_i^B(P_x, P_Y, Y^B)}{P_Y} - Y^B = \frac{w_i^B(P_x, P_Y, Y^B)}{P_b}$$

This result establishes that $b_i(w_i, Y)$ is a continuous function at the point where a Mixed Consumer becomes a Brown Consumer. Similarly, a decrease in Y causes the critical income level w_i^G to decrease as well. As such, there exists a value Y^G where $w_i = w_i^G(P_x, P_Y, Y^G)$ and:

$$\widetilde{b_i}(Y^G) = \frac{y_i^{-1}(P_x, P_Y, Y^G) - w_i^G(P_x, P_Y, Y^G)}{P_Y} - Y^G = 0$$

This result establishes that $b_i(w_i, Y)$ is a continuous function at the point where a Mixed Consumer becomes a Green Consumer. Therefore, $b_i(w_i, Y)$ is a continuous function in Y.

Proof of Proposition 1.1

A Nash Equilibrium exists if there is a value Y^* such that:

$$Y^0 - \sum_{i=1}^{N} b_i(w_i, Y^*) = Y^*$$

The lowest level of Y occurs if every individual behaves as a Brown Consumer. Denote this level as $\underline{Y}$ and define it as:

$$\underline{Y} = Y^0 - \sum_{i=1}^{N} \frac{w_i}{P_b}$$

The highest level of Y occurs if every individual behaves as a Green Consumer. Denote this level as $\bar{Y}$ and define it as:

$$\bar{Y} = Y^0$$

From Lemma 2, $b_i(w_i, Y)$ achieves its lowest possible value if $Y = \underline{Y}$, and its highest possible value if $Y = \bar{Y}$. Then the following relations must hold:

$$Y^0 - \sum_{i=1}^{N} b_i\left(w_i, \underline{Y}\right) \geq \underline{Y}$$

$$Y^0 - \sum_{i=1}^{N} b_i(w_i, \bar{Y}) \leq \bar{Y}$$

Since $b_i(w_i, Y)$ is a continuous and increasing function in Y, and Y is defined over the interval $\left[\underline{Y}, \bar{Y}\right]$, then the intermediate value theorem establishes that there exists a value Y^* such that:

$$Y^0 - \sum_{i=1}^{N} b_i(w_i, Y^*) = Y^* \qquad (\boldsymbol{A.1.3})$$

and a Nash Equilibrium exists. To prove that the equilibrium is unique, assume by contradiction that there exist two different values, Y_1 and Y_2, that form a Nash Equilibrium. Without loss of generality, assume that $Y_2 > Y_1$. Since $b_i(w_i, Y)$ is weakly increasing in Y:

$$b_i(w_i, Y_2) \geq b_i(w_i, Y_1)$$

$$Y^0 - b_i(w_i, Y_2) \leq \mathrm{Y}^0 - b_i(w_i, Y_1)$$

$$Y_2 \leq Y_1$$

which contradicts the initial assumption that $Y_2 > Y_1$. Therefore, the Nash Equilibrium is unique.

Proof of Proposition 1.2:

Let Y^* be the Nash Equilibrium. Disaggregating $b_i(w_i, Y^*)$ from $(\boldsymbol{A.1.3})$ for Mixed, Brown, and Green Consumers gives:

$$Y^0 - \sum_{i \in M} b_i(w_i, Y^*) - \sum_{j \in B} b_i\left(w_j, Y^*\right) - \sum_{k \in G} b_i(w_k, Y^*) = Y^*$$

where M, B, and G denote the sets of Mixed, Brown, and Green Consumers, respectively. Substituting $(\mathbf{1.17})$ and $(\mathbf{1.19})$ and rearranging gives:

$$Y^0 - \sum_{i \in M} \left[\frac{y_i^{-1}(P_x, P_Y, Y^*) - w_i}{P_Y} - Y^* \right] - \sum_{j \in B} \frac{w_j}{P_b} - Y^* = 0$$

$$Y^0 - \sum_{i \in M} \left[\frac{y_i^{-1}(P_x, P_Y, Y^*) - w_i}{P_Y} \right] - \sum_{j \in B} \frac{w_j}{P_b} + (N_M - 1)Y^* = 0$$

where N_M is the number of Mixed Consumers at the Nash Equilibrium. The left-hand side of the equation can be expressed as a function $F(Y^*, \boldsymbol{w})$ that depends on the Nash Equilibrium level of Y and a vector $\boldsymbol{w}$ that contains the individual income of all consumers. Differentiating $F(Y^*, \boldsymbol{w})$ with respect to Y^* gives:

$$\frac{\partial F(Y^*, \boldsymbol{w})}{\partial Y^*} = -\frac{1}{P_Y} \sum_{i \in M} \frac{\partial y_i^{-1}(P_x, P_Y, Y^*)}{\partial Y^*} + (N_M - 1)$$

$$\frac{\partial F(Y^*, \boldsymbol{w})}{\partial Y^*} = -\sum_{i \in M} \frac{1}{P_Y} \cdot \frac{1}{\frac{\partial y_i(P_x, P_Y, m_i)}{\partial m_i}} + (N_M - 1)$$

Using $(\boldsymbol{A.1.2})$

$$\frac{\partial F(Y^*, \boldsymbol{w})}{\partial Y^*} < -\sum_{i \in M} 1 + (N_M - 1) = -N_M + N_M - 1 < 0$$

Therefore, the term $\frac{\partial F(Y^*, \boldsymbol{w})}{\partial Y^*}$ is negative. Using the implicit function theorem, it is possible to find the overall effect on Y^* from a change in the income from any individual. For a Mixed Consumer:

$$\frac{dY^*}{dw_i} = -\frac{\frac{\partial F(Y^*, \boldsymbol{w})}{\partial w_i}}{\frac{\partial F(Y^*, \boldsymbol{w})}{\partial Y^*}}$$

$$\frac{dY^*}{dw_i} = -\frac{\frac{1}{P_Y}}{\frac{\partial F(Y^*,\boldsymbol{w})}{\partial Y^*}} > 0$$

This result proves part *i)*. For a change in income of a Brown Consumer:

$$\frac{dY^*}{dw_j} = -\frac{\frac{\partial F(Y^*,\boldsymbol{w})}{\partial w_j}}{\frac{\partial F(Y^*,\boldsymbol{w})}{\partial Y^*}}$$

$$\frac{dY^*}{dw_j} = -\frac{-\frac{1}{P_b}}{\frac{\partial F(Y^*,\boldsymbol{w})}{\partial Y^*}} < 0$$

This result proves part *ii)*. Finally, for a change in income of a Green Consumer:

$$\frac{dY^*}{dw_k} = -\frac{\frac{\partial F(Y^*,\boldsymbol{w})}{\partial w_k}}{\frac{\partial F(Y^*,\boldsymbol{w})}{\partial Y^*}}$$

$$\frac{dY^*}{dw_k} = -\frac{0}{\frac{\partial F(Y^*,\boldsymbol{w})}{\partial Y^*}} = 0$$

This result proves part *iii)*.

Proof of Corollary 1.1:

Let Y^* be the Nash Equilibrium and individual i be a Mixed Consumer with income w_i^*. Suppose that individual i receives a new income $w_i^{**} > w_i^*$, which leads to a new Nash Equilibrium Y^{**}. From Proposition 2 we have that $Y^{**} > Y^*$, and from

Lemma 2 we have that $b_j\left(w_j, Y^{**}\right) \ \geq \ b_j\left(w_j, Y^*\right) \forall j \neq i$. Suppose that $b_i(w^{**}, Y^{**}) \geq b_i(w_i^*, Y^*)$, such that the brown good is normal for individual i. Then:

$$b_i(w^{**}, Y^{**}) + \sum_{j \neq i} b_j\left(w_j, Y^{**}\right) \geq b_i(w_i^*, Y^*) + \sum_{j \neq i} b_j\left(w_j, Y^*\right)$$

$$Y^0 - b_i(w^{**}, Y^{**}) - \sum_{j \neq i} b_j\left(w_j, Y^{**}\right) \leq \mathrm{K} - \ b_i(w_i^*, Y^*) - \sum_{j \neq i} b_j\left(w_j, Y^*\right)$$

$$Y^{**} \leq Y^*$$

which contradicts the result from Proposition 2. Therefore, the brown good is an inferior good for Mixed Consumers and $b_i(w^{**}, Y^{**}) < b_i(w_i^*, Y^*)$.

Now let individual i be a Brown Consumer and receive a new income $w_i^{**} > w_i^*$. The result follows from the fact that $b_i(w_i, Y) = \frac{w_i}{P_b}$ for Brown Consumers. Therefore, the brown good is a normal good for Brown Consumers.

To prove that the green good is normal for Mixed and Green Consumers, note that from Walras' Law we have:

$$w_i = g_i(w_i, Y) + b_i(w_i, Y)$$

Differentiating with respect to w_i gives us:

$$1 = \left[\frac{\partial g_i}{\partial w_i} + \frac{\partial g_i}{\partial Y} \cdot \frac{\partial Y}{\partial w_i}\right] + \left[\frac{\partial b_i}{\partial w_i} + \frac{\partial b_i}{\partial Y} \cdot \frac{\partial Y}{\partial w_i}\right]$$

From the previous part, the term $\frac{\partial b_i}{\partial w_i} + \frac{\partial b_i}{\partial Y} \cdot \frac{\partial Y}{\partial w_i}$ must be negative for Mixed Consumers since the brown good is an inferior good. Rearranging gives:

$$\frac{\partial g_i}{\partial w_i} + \frac{\partial g_i}{\partial Y} \cdot \frac{\partial Y}{\partial w_i} = 1 - \left[\frac{\partial b_i}{\partial w_i} + \frac{\partial b_i}{\partial Y} \cdot \frac{\partial Y}{\partial w_i}\right] > 0$$

Therefore, the green good is a normal good for Mixed Consumers. For the case of Green Consumers, the result follows from the fact that both $\frac{\partial b_i(w_i,Y)}{\partial w_i} = 0$ and $\frac{\partial Y}{\partial w_i} = 0$. As such:

$$1 = \frac{\partial g_i}{\partial w_i} + \frac{\partial g_i}{\partial Y} \cdot \frac{\partial Y}{\partial w_i}$$

which proves that green good is also normal for Green Consumers.

- <u>Proof that $\widehat{b_i}(Y)$ is a decreasing function in w_i</u>

Alternatively, it is possible to show that the brown good is an inferior good for Mixed Consumers by proving that $\widehat{b_i}(Y)$ is a decreasing function in w_i. From $(\mathbf{2.17})$:

$$\hat{b}_i(Y) == \frac{y_i^{-1}(P_x, P_Y, Y) - w_i}{P_Y} - Y$$

Totally differentiating gives:

$$d\hat{b}_i(Y) = \frac{1}{P_Y}\left[\frac{\partial y_i^{-1}}{\partial Y} \cdot \frac{\partial Y}{\partial w_i} dw_i - dw_i\right] - \frac{\partial Y}{\partial w_i} dw_i$$

$$\frac{d\hat{b}_i(Y)}{dw_i} = \frac{1}{P_Y}\left[\frac{\partial y_i^{-1}}{\partial Y} \cdot \frac{\partial Y}{\partial w_i} - 1\right] - \frac{\partial Y}{\partial w_i}$$

From Proposition 1.2, $\frac{\partial Y}{\partial w_i} > 0$, therefore is it sufficient to show that the term in between brackets is negative to show that $\frac{d\hat{b}_i(Y)}{dw_i} < 0$. From the proof of Proposition 2:

$$\frac{\partial Y}{\partial w_i} = \frac{1}{P_Y \Gamma}$$

where:

$$\Gamma = \sum_{j \in M} \frac{1}{P_Y} \cdot \frac{1}{\frac{\partial y_j(P_X, P_Y, m_j)}{\partial m_j}} - (N_M - 1)$$

Substituting in $\frac{\partial y_i^{-1}}{\partial Y} \cdot \frac{\partial Y}{\partial w_i}$ gives:

$$\frac{\partial y_i^{-1}}{\partial Y} \cdot \frac{\partial Y}{\partial w_i} = \frac{\frac{1}{P_Y} \cdot \frac{\partial y_i^{-1}}{\partial Y}}{\Gamma}$$

$$= \frac{\frac{1}{P_Y} \cdot \frac{\partial y_i^{-1}}{\partial Y}}{\sum_{i \in M} \frac{1}{P_Y} \cdot \frac{1}{\frac{\partial y_i(P_X, P_Y, m_i)}{\partial m_i}} - (N_M - 1)}$$

$$= \frac{\frac{1}{P_Y} \cdot \frac{1}{\frac{\partial y_i(P_X, P_Y, m_i)}{\partial m_i}}}{\sum_{j \in M} \frac{1}{P_Y \frac{\partial y_j(P_X, P_Y, m_j)}{\partial m_j}} - (N_M - 1)}$$

$$= \frac{\frac{1}{P_y \frac{\partial y_i(P_X, P_Y, m_i)}{\partial m_i}}}{\frac{1}{P_Y \cdot \frac{\partial y_i(P_X, P_Y, m_i)}{\partial m_i}} + \left[\sum_{j \neq i} \frac{1}{P_Y \cdot \frac{\partial y_j(P_X, P_Y, m_j)}{\partial m_j}} - (N_M - 1)\right]}$$

$$< \frac{\frac{1}{P_y \frac{\partial y_i(P_X, P_Y, m_i)}{\partial m_i}}}{\frac{1}{P_Y \cdot \frac{\partial y_i(P_X, P_Y, m_i)}{\partial m_i}} + [(N_M - 1) - (N_M - 1)]}$$

$$= 1$$

Since $\frac{\partial y_i^{-1}}{\partial Y} \cdot \frac{\partial Y}{\partial w_i} < 1$, then:

$$\frac{d\widehat{b_i}(Y)}{dw_i} = \frac{1}{P_Y}\left[\frac{\partial y_i^{-1}}{\partial Y} \cdot \frac{\partial Y}{\partial w_i} - 1\right] - \frac{\partial Y}{\partial w_i} < 0$$

which proves that the brown good is an inferior good for Mixed Consumers.

Example: Cobb-Douglas utility function

$$U(x_i, Y) = x_i^{\alpha} Y^{1-\alpha} \qquad \text{s.t.} \qquad m_i = P_x x_i + P_Y Y$$

$$Y \leq Y_{-i}$$

$$x_i \geq Y_{-i} - Y$$

At the interior, the individual demands for x_i and Y are given by:

$$X_i = \frac{\alpha m_i}{P_x} \qquad Y = \frac{(1-\alpha) m_i}{P_Y}$$

From $(\mathbf{1.16})$ and $(\mathbf{1.17})$, the conditional demand of b_i is:

$$\hat{b}_{\boldsymbol{i}}(Y) = \frac{\alpha}{1-\alpha} Y - \frac{w_i}{P_Y}$$

Setting the previous expression equal to 0 and $\frac{w_i}{P_X - P_Y}$ gives the critical income levels for Green and Brown Consumers:

$$w^G = \frac{\alpha}{1-\alpha} P_Y Y$$

$$w^B = \frac{\alpha}{(1-\alpha)} \frac{(P_x - P_Y)}{P_x} P_Y Y$$

The Nash Equilibrium level of Y is given by:

$$Y^* = Y^0 - \sum_{i\in M}\left[\frac{\alpha}{1-\alpha}Y^* - \frac{w_i}{P_Y}\right] - \sum_{j\in B}\frac{w_j}{P_X - P_Y}$$

$$Y^* = \frac{\sum_{i\in M}\frac{w_i}{P_Y} + \left[Y^0 - \sum_{j\in B}\frac{w_j}{P_x - P_Y}\right]}{\frac{\alpha}{1-\alpha}N_M + 1}$$

<u>Proof that a transfer from a Green to a Mixed Consumer can generate a Pareto-improving outcome</u>

Suppose that there are three individuals with identical Cobb-Douglas preferences, initial parameters $\alpha = \frac{1}{2}, P_x = 2$, and $P_Y = 1$,[18] initial incomes $(w_1, w_2, w_3) = (70,20,10)$, and the initial level of environmental quality set at $Y^0 = 50$. With these assumptions, the Nash Equilibrium is $Y^* = 30$, the critical income levels are $w^G = 30$ and $w^B = 15$, and the equilibrium bundles for all individuals are:

	w_i	g_i	b_i	X_i	Y^*	$U(X_i, Y^*)$
Individual 1	70	35	0	35	30	32.40
Individual 2	20	5	10	15	30	21.21
Individual 3	10	0	10	10	30	17.32

[18] These prices are equivalent to $P_g = 2$ and $P_b = 1$.

Let individual 1 transfer one unit of income to individual 2, then the Nash Equilibrium becomes $Y^* = 30.5$, the critical income levels change to $w^G = 30.5$ and $w^B = 15.25$, and the equilibrium bundles for all individuals are now:

	w_i	g_i	b_i	X_i	Y^*	$U(X_i, Y^*)$
Individual 1	69	34.5	0	34.5	30.5	32.43
Individual 2	21	5.75	9.5	15.25	30.5	21.56
Individual 3	10	0	10	10	30.5	17.46

By transferring income from a Green Consumer (Individual 1) to a Mixed Consumer (Individual 2) it was possible to increase the Nash Equilibrium level of Y and, at the same time, make everybody better off than before the redistribution happened.

Example: quasilinear utility function

$$U(X_i, Y) = 2\alpha\sqrt{x_i} + \beta Y \qquad \text{s.t.} \qquad m_i = P_x x_i + P_Y Y$$

$$Y \leq Y_{-i}$$

$$x_i \geq Y_{-i} - Y$$

At the interior, the individual demands for x_i and Y are given by:

$$X_i = \left[\frac{\alpha P_Y}{\beta P_x}\right]^2 \qquad Y = \frac{m_i}{P_Y} - \left[\frac{\alpha}{\beta}\right]^2 \frac{P_Y}{P_x}$$

From ($\mathbf{1.16}$) and ($\mathbf{1.17}$), the conditional demand of b_i is:

$$\hat{b}_{\boldsymbol{i}}(Y) = \left[\frac{\alpha}{\beta}\right]^2 \frac{P_Y}{P_x} - \frac{w_i}{P_Y}$$

Setting the previous expression equal to 0 and $\frac{w_i}{P_X - P_Y}$ gives the critical income levels for Green and Brown Consumers:

$$w^G = \left[\frac{\alpha P_Y}{\beta}\right]^2 \frac{1}{P_x}$$

$$w^B = \left[\frac{\alpha P_Y}{\beta}\right]^2 \frac{P_x - P_Y}{P_x^2}$$

The Nash Equilibrium level of Y is given by:

$$Y^* = Y^0 - \sum_{j \in B} \frac{w_j}{P_X - P_Y} - N_M \left[\frac{\alpha}{\beta}\right]^2 \frac{P_Y}{P_x} + \sum_{i \in M} \frac{w_i}{P_Y}$$

Proof that a transfer from a Green to Brown Consumers can generate a Pareto-diminishing outcome

Suppose that there are three individuals with identical quasilinear preferences, initial parameters $\alpha = 5, \beta = 1 P_x = 5$, and $P_Y = 4$,[19] initial incomes $(w_1, w_2, w_3) = (90,15,15)$, and the initial level of environmental quality set at $Y^0 = 60$. With these assumptions, the Nash Equilibrium is $Y^* = 30$, the critical income levels are $w^G = 80$ and $w^B = 16$, and the equilibrium bundles for all individuals are:

	w_i	g_i	b_i	X_i	Y^*	$U(X_i, Y^*)$
Individual 1	90	18	0	18	30	72.426
Individual 2	15	0	15	15	30	68.729
Individual 3	15	0	15	15	30	68.729

Let individual 1 transfer one unit of income each to individuals 2 and 3, then the Nash Equilibrium becomes $Y^* = 28$, the critical income levels remain the same at $w^G = 80$ and $w^B = 16$, and the equilibrium bundles for all individuals are now:

	w_i	g_i	b_i	X_i	Y^*	$U(X_i, Y^*)$
Individual 1	88	17.6	0	17.6	28	69.952
Individual 2	16	0	16	16	28	68.000
Individual 3	16	0	16	16	28	68.000

[19] These prices are equivalent to $P_g = 5$ and $P_b = 1$.

By transferring income from a Green Consumer (Individual 1) to two Brown Consumers (Individuals 2 and 3) it was possible to decrease the Nash Equilibrium level of Y and, at the same time, make everybody worse off than before the redistribution happened.

Appendix B: Appendix to Chapter 3

Proof of Proposition 3.1

Part i)

To prove that a value $P_{q_i}^{d-max}$ exists and that it is less than $P_g - P_b$, it is sufficient to show that consumer i is better off by not buying any permits if P_q exceeds a certain value. Suppose a situation where $b_i = \overline{q_\iota}$ and $g_i = \frac{1}{P_g}(w_i - P_b\overline{q_\iota})$. Consumer i would be willing to increase $\overline{q_\iota}$ in ε units ($\varepsilon > 0$) if the total change in utility is:

$$dU_i = U_X(dg_i + db_i) + U_Y(-db_i) \geq 0$$
$$= \frac{U_X}{P_g}\left(dw_i - P_b d\overline{q_\iota} + P_g d\overline{q_\iota}\right) - U_Y(d\overline{q_\iota}) \geq 0$$

Let the change in $\overline{q_\iota}$ and w_i be $d\overline{q_\iota} = \varepsilon$ and $dw_i = -P_q\varepsilon$. Then the previous expression becomes:

$$\frac{U_X}{P_g}\left(-P_q - P_b + P_g\right)\varepsilon - U_Y\varepsilon \geq 0$$

Solving for P_q gives:

$$P_q \leq P_g - P_b - P_g\frac{U_Y}{U_X}$$
$$P_q < P_g - P_b$$

Therefore, consumer i will not buy any permits when their price exceeds a value equal to $P_g - P_b - P_g \frac{U_Y}{U_X}$, which is strictly smaller than $P_g - P_b$.

Part ii)

To prove that an income level $w_i^{CD}(Y, \overline{q_\iota})$ exists, there should be a positive value of w_i for which the following relationship is true:

$$w_i - P_b \overline{q_\iota} = (P_b + P_q) q_i^d$$

Substituting (3.6) in the previous expression gives us:

$$w_i - P_b \overline{q_\iota} = (P_b + P_q) \left[\frac{y_i^{d^{-1}}(Y, P_X^d, P_Y^d) - w_i}{P_Y^d} - Y - \left(\frac{P_g - P_b}{P_Y^d} \right) \overline{q_\iota} \right]$$
$$w_i = \frac{P_b + P_q}{P_g} \left[y_i^{d^{-1}}(Y, P_X^d, P_Y^d) - P_Y^d Y \right] - P_q \overline{q_\iota}$$

If the RHS has a positive value, then it means that it is equal to the income level $w_i^B(Y, \overline{q_\iota})$. Assume by contradiction that this value is non-positive so that $w_i^B(Y, \overline{q_\iota})$ does not exist:

$$0 \geq \frac{P_b + P_q}{P_g}\left[y_i^{d^{-1}}\left(Y, \mathbf{P^d}\right) - P_Y^d Y\right] - P_q \overline{q_\iota} \qquad (B.1)$$

From the definition of $y_i^{d^{-1}}\left(Y, P_X^d, P_Y^d\right)$ we have:

$$\begin{aligned}
y_i^{d^{-1}}\left(Y, \mathbf{P^d}\right) &= w_i + P_q \overline{q_\iota} + P_Y^d Y_{-i} \\
y_i^{d^{-1}}\left(Y, \mathbf{P^d}\right) &= w_i + P_q \overline{q_\iota} + P_Y^d\left[Y + \overline{q_\iota} + q_i^d\right] \\
y_i^{d^{-1}}\left(Y, \mathbf{P^d}\right) - P_Y^d Y &= w_i + P_q \overline{q_\iota} + P_Y^d\left[\overline{q_\iota} + q_i^d\right] \\
y_i^{d^{-1}}\left(Y, \mathbf{P^d}\right) - P_Y^d Y &> (P_q + P_Y^d)\overline{q_\iota} \\
y_i^{d^{-1}}\left(Y, \mathbf{P^d}\right) - P_Y^d Y &> (P_g - P_b)\overline{q_\iota}
\end{aligned}$$

Substituting in $(B.1)$ gives:

$$\begin{aligned}
0 &> \frac{(P_b + P_q)(P_g - P_b)}{P_g}\overline{q_\iota} - P_q \overline{q_\iota} \\
0 &> \frac{P_b(P_g - P_b - P_q)}{P_g}\overline{q_\iota} > 0 \qquad \perp
\end{aligned}$$

Therefore, $\frac{P_b + P_q}{P_g}\left[y_i^{d^{-1}}\left(Y, P_X^d, P_Y^d\right) - P_Y^d Y\right] - P_q \overline{q_\iota}$ has a positive value and it is equal to the income level $w_i^B(Y, \overline{q_\iota})$.

Part iii)

To prove that $q_i^d(Y, \bar{q}_i)$ is a weakly increasing function in Y, it is sufficient to check equation (3.6) is an increasing function in Y. Differentiating q_i^d with respect to Y gives us:

$$\frac{\partial q_i^d}{\partial Y} = \frac{1}{P_Y^d} \cdot \frac{\partial {y_i^d}^{-1}(Y, P_X^d, P_Y^d)}{\partial Y} - 1$$

From the inverse function theorem we have that $\frac{\partial {y_i^d}^{-1}(Y, P_X^d, P_Y^d)}{\partial Y} = \left[\frac{\partial y_i^d(m_i^d, P_X^d, P_Y^d)}{\partial m_i^d}\right]^{-1}$. From condition (3.2) we have that $\frac{\partial Y}{\partial Y_{-i}} = P_Y^d \frac{\partial y_i^d(m_i^d, P_X^d, P_Y^d)}{\partial m_i^d} < 1$. Therefore, $\frac{1}{P_Y^d} \cdot \frac{\partial {y_i^d}^{-1}(Y, P_X^d, P_Y^d)}{\partial Y} > 1$ which establishes that equation (3.6) is an increasing function in Y.

Proof of Proposition 3.2

To prove that a value $P_{q_i}^{s-min}$ exists and that it is strictly greater than 0, it is sufficient to show that consumer i is better off by not selling any permits if P_q does not exceed a certain value. Suppose that seller i has not entered the market yet. In this scenario, the optimal consumption of the brown good is $b_i = \frac{w_i}{P_b}$. If seller i trades ε units of a permit ($\varepsilon > 0$), then the change in income would be $dw_i = P_q \varepsilon$ and the change in the exogenous environmental quality would be $dY_{-i} = -\varepsilon$. This seller has incentives to trade away a permit as long as:

$$dU_i = U_X(db_i) + U_Y(dY_{-i} - db_i) \geq 0$$
$$U_X\left(\frac{dw_i}{P_b}\right) + U_Y\left(dY_{-i} - \frac{dw_i}{P_b}\right) \geq 0$$
$$U_X\left(\frac{P_q \varepsilon}{P_b}\right) + U_Y\left(-\varepsilon - \frac{P_q \varepsilon}{P_b}\right) \geq 0$$
$$P_q - \frac{P_b}{U_X - U_Y} \geq 0$$

Therefore, $P_{q_i}^{s-min}$ exists if $\frac{P_b}{U_X - U_Y} > 0$. From the first-order conditions of the seller problem we have that:

$$\frac{U_X - U_Y}{P_b} = \frac{U_X + \mu_g}{P_g}$$
$$\frac{U_X - U_Y}{P_b} > \frac{U_X}{P_g}$$
$$U_X - U_y > \frac{P_b}{P_g} U_X$$
$$U_X - U_y > 0$$

Therefore, consumer i will only sell a permit if $P_q \geq \frac{P_b}{U_X - U_Y} > 0$, which proves $P_{q_i}^{s-min}$ exists and is a strictly positive price.

Part ii)

To prove that an income level $w_i^{CS}(Y, \overline{q_\iota})$ exists, there should be a positive value of w_i for which $\overline{q_\iota} = q_i^s + b_i$. Assume by contradiction that it does not exist so that $\overline{q_\iota} > q_i^s + b_i, \forall w_i > 0$. From the budget restriction we get the following relationship:

$$
\begin{aligned}
w_i + P_q q_i^s &< P_b(\overline{q_\iota} - q_i^s) \\
q_i^s &< \frac{P_b \overline{q_\iota} - w_i}{P_b + P_q} \\
q_i^s &< \frac{(P_X^s - P_Y^s)\overline{q_\iota} - w_i}{P_X^s}
\end{aligned}
$$

Substituting this relationship in (3.10) we have:

$$
\begin{aligned}
\frac{(P_X^s - P_Y^s)\overline{q_\iota} - w_i}{P_X^s} &> \frac{P_X^s - P_Y^s}{P_X^s}\left[\frac{{y_i^s}^{-1}(Y, \mathbf{P^s})}{P_Y^s} - Y\right] - \frac{w_i}{P_Y^s} \\
w_i &> {y_i^s}^{-1}(Y, \mathbf{P^s}) - P_Y^S - \overline{q_\iota}
\end{aligned}
$$

This last relationship implies that if $w_i \leq {y_i^s}^{-1}(Y, \mathbf{P^s}) - P_Y^S - \overline{q_\iota}$, then $\overline{q_\iota} = q_i^s + b_i$ and an income level $w_i^{CS}(Y, \overline{q_\iota})$ exists. From the definition of ${y_i^s}^{-1}(Y, \mathbf{P^s})$:

$$
\begin{aligned}
{y_i^s}^{-1}(Y, \mathbf{P^s}) &= w_i + P_Y^s Y_{-i} \\
{y_i^s}^{-1}(Y, \mathbf{P^s}) &= w_i + P_Y^s [Y + b_i + q_i^s] \\
{y_i^s}^{-1}(Y, \mathbf{P^s}) &> w_i + P_Y^s Y \\
{y_i^s}^{-1}(Y, \mathbf{P^s}) - P_Y^s Y &> w_i \\
{y_i^s}^{-1}(Y, \mathbf{P^s}) - P_Y^s Y &> 0
\end{aligned}
$$

Since ${y_i^s}^{-1}(Y, \mathbf{P^s}) - P_Y^s Y$ has a strictly positive value, then the income level $w_i^{CS}(Y, \overline{q_\iota})$ exists only if the initial allocation $\overline{q_\iota}$ is limited (i.e., ${y_i^s}^{-1}(Y, \mathbf{P^s}) - P_Y^s Y \geq \overline{q_\iota}$).

<u>Part iii)</u>

Note that this proof follows the same method as the one used to prove the equivalent result in Proposition 2.1, since it is sufficient to show that:

$$
\frac{\partial q_i^s}{\partial Y} = \frac{1}{P_Y^s} \cdot \frac{\partial {y_i^s}^{-1}(Y, P_X^s, P_Y^s)}{\partial Y} - 1 > 0
$$

<u>**Proof of Lemma 3.6**</u>

Let $P_q^{d-max}(Y^*) > P_q^{s-min}(Y^*)$. If $P_q = P_q^{d-max}(Y^*)$, then:

$$
\begin{aligned}
&Q^D\left(P_q^{d-max}(Y^*), Y^*\right) = 0 \\
&Q^S\left(P_q^{d-max}(Y^*), Y^*\right) > 0 \\
&Q^D\left(P_q^{d-max}(Y^*), Y^*\right) < Q^S\left(P_q^{d-max}(Y^*), Y^*\right)
\end{aligned}
$$

If $P_q = P_q^{s-min}(Y^*)$, then

$$Q^D\left(P_q^{s-min}(Y^*), Y^*\right) > 0$$
$$Q^S\left(P_q^{s-min}(Y^*), Y^*\right) = 0$$
$$Q^D\left(P_q^{s-min}(Y^*), Y^*\right) > Q^S\left(P_q^{s-min}(Y^*), Y^*\right)$$

Since $Q^D\left(P_q, Y^*\right)$ and $Q^S\left(P_q, Y^*\right)$ are continuous function, then by the intermediate value theorem guarantees that a price $P_q^* \in (P_q^{s-min}(Y^*), P_q^{d-max}(Y^*))$ exists such that:

$$Q^D\left(P_q^*, Y^*\right) = Q^S\left(P_q^*, Y^*\right)$$

<u>Proof of Proposition 3.7</u>

Proposition 2.1 and Lemma 3.5 guarantee that Y^* exists regardless of if there is trading or not. Suppose that at Y^* there cannot be a price P_q that clears the market. Therefore either $Q^D\left(P_q, Y^*\right) - Q^S\left(P_q, Y^*\right) < 0$ or $Q^D\left(P_q, Y^*\right) - Q^S\left(P_q, Y^*\right) > 0$. In the first case, it can only happen if $P_q > P_q^{s-min}(Y^*) > P_q^{d-max}(Y^*)$, which contradicts the assumption that $P_q^{d-max}(Y^*) > P_q^{s-min}(Y^*)$. Therefore, by Lemma 2.6, if $P_q^{d-max}(Y^*) > P_q^{s-min}(Y^*)$ there must exist a market-clearing price and a market equilibrium with tradable permits.

For the second case, it can only happen if $P_q^{s-min}(Y^*) > P_q^{d-max}(Y^*) > P_q$, which is also a contradiction. Finally, if $P_q^{s-min}(Y^*) \geq P_q \geq P_q^{d-max}(Y^*)$, then

$Q^D(P_q, Y^*) = Q^S(P_q, Y^*) = 0$, then all $P_q \in [P_q^{d-max}(Y^*), P_q^{s-min}(Y^*)]$ would be a market clearing price.

Proof of Proposition 3.8

The two equations that characterize the market equilibrium with tradable permits are:

$$F^Y := Y^0 - \sum b_i - Y = 0$$
$$F^{P_q} := Q^D(P_q, Y) - Q^S(P_q, Y) = 0$$

Using the implicit function theorem, we get:

$$\begin{bmatrix} \frac{\partial Y}{\partial \bar{q}_\iota} \\ \frac{\partial P_q}{\partial \bar{q}_\iota} \end{bmatrix} = -\frac{1}{\Delta}\begin{bmatrix} \Delta_{11} & \Delta_{12} \\ \Delta_{21} & \Delta_{22} \end{bmatrix}\begin{bmatrix} \frac{\partial F^Y}{\partial \bar{q}_\iota} \\ \frac{\partial F^{P_q}}{\partial \bar{q}_\iota} \end{bmatrix}$$

where:

$$\Delta_{11} = \frac{\partial Q^D(P_q, Y)}{\partial P_q} - \frac{\partial Q^S(P_q, Y)}{\partial P_q} < 0 \; (Assumptions\ A.2.1\ and\ A.2.2)$$
$$\Delta_{12} = -\frac{\partial Q^D(P_q, Y)}{\partial Y} + \frac{\partial Q^S(P_q, Y)}{\partial Y}$$
$$\Delta_{21} = \frac{\sum b_i}{\partial P_q} < 0 \; (Assumption\ A.2.3)$$
$$\Delta_{22} = -\frac{\sum b_i}{\partial Y} - 1 < 0 \; (Lemma\ 2.4)$$
$$\Delta = \Delta_{11}\Delta_{22} - \Delta_{12}\Delta_{21} > 0 \; (Assumption\ A.2.4)$$
$$\frac{\partial F^Y}{\partial \bar{q}_\iota} = -\frac{\sum b_i}{\partial \bar{q}_\iota} = -\frac{P_q}{P_Y^d} < 0$$
$$\frac{\partial F^{P_q}}{\partial \bar{q}_\iota} = \frac{\partial q_i^d}{\partial \bar{q}_\iota} = -\left(1 + \frac{P_q}{P_Y^d}\right) < 0$$

Therefore:

$$\frac{\partial P_q}{\partial \bar{q}_\iota} = -\frac{1}{\Delta}\left[-\frac{P_q}{P_Y^d}\Delta_{21} - \left(1 + \frac{P_q}{P_Y^d}\right)\Delta_{22}\right] < 0$$

which proves that the equilibrium price falls when a regular buyer receives one additional permit for the initial allocation.

<u>Proof of </u>Proposition 3.9

Suppose that the price $P_q \neq \frac{P_b}{P_g + P_b}(P_g - P_b)$ but that the market equilibrium with permits is socially optimal. In this case, $\frac{P_X^d}{P_Y^d} \neq \frac{P_X^s}{P_Y^s}$ which contradicts the First Fundamental Theorem of Welfare Economics.

Suppose that the price $P_q = \frac{P_b}{P_g + P_b}(P_g - P_b)$, but that the market equilibrium with permits is not socially optimal. From the method used to prove Proposition 8, it is possible to show that a redistribution of either income or permits within sellers or within buyers will cause no changes on Y^* or P_q^*. If the redistribution happens across groups, then the P_q^* will be affected, and it would contradict the First Fundamental Theorem of Welfare Economics as well.

Appendix C: Appendix to Chapter 4

Warm-Glow Model

Proof of Proposition 4.1

To proof that X_i is normal, first differentiate the full-income constraint with respect to w_i. The result is:

$$P_x \tilde{x}_m = 1 - P_Y \tilde{y}_m$$

If Y is inferior, then x_i is clearly normal. I will only focus on the case where Y is normal.

Then differentiate the full-income constraint with respect to Y_{-i} while keeping m_i fixed. The result is:

$$-P_x \tilde{x}_{Y_{-i}} = P_Y \tilde{y}_{Y_{-i}}$$

If Y_{-i} decreases, followed by an equivalent increase in w_i to keep m_i fixed, then the demand for Y can be at most the same level as before this change in income. Therefore, the sign of $\tilde{y}_{Y_{-i}}$ is positive By assumption, $0 \leq P_Y \tilde{y}_m + \tilde{y}_{Y_{-i}} \leq 1$. All these results combined give the following result:

$$1 - P_Y \tilde{y}_m \geq 0$$

Therefore, x_i is a normal good in the warm glow model.

To proof that g_i is normal, substitute the identities $b_i = \frac{w_i}{P_b} - \frac{P_g}{P_b} g_i$ and $X_i = \frac{w_i}{P_b} + \frac{(P_g - P_b)}{P_b} g_i$ into U_i to get:

$$U_i\left(\frac{w_i}{P_b} - \frac{P_g - P_b}{P_b} g_i\,, Y_{-i} - \frac{w_i}{P_b} + \frac{P_g}{P_b} g_i\right) + \theta_i f_i(g_i)$$

By differentiating with respect to g_i, and setting the result equal to zero, we get:

$$-\frac{P_g - P_b}{P_b} U_x + \frac{P_g}{P_b}\, U_Y + \theta_i f_i' = 0$$

$$-P_Y U_x + P_x U_Y + (P_x - P_Y)\theta_i f_i' = 0$$

This result gives us an implicit function of the demand for g_i. Using the implicit function theorem, we get the change in g_i as θ_i increases:[20]

[20] The first term in brackets in the denominator is guaranteed to be a negative number due to the quasiconcavity and normality assumptions placed on U_i. Combined with the fact that f_i is a strictly concave function gives us the desired result.

$$\frac{dg_i}{d\theta_i} = -\frac{(P_x - P_Y)f_i'}{[P_Y^2 U_{xx} - P_X^2 U_{YY} + 2P_x P_Y U_{xY}] + (P_x - P_Y)\theta_i V_i''} > 0$$

If $\theta_i = 0$, we get the same demand as in the baseline model. Since an increase in this parameter induces a greater demand of g_i, then it cannot be that g_i is an inferior good. Therefore g_i is a normal good in this model as well. Additionally, it shows that both critical income levels must shift to the left, which implies that a lower income is needed to become a Mixed, and then a Green consumer.

To prove that b_i can be a normal good, substitute this parameter into the utility function.

$$U_i\left(\frac{w_i}{P_g} + \frac{P_g - P_b}{P_g} b_i, Y_{-i} - b_i\right) + \theta_i f_i\left(\frac{w_i}{P_g} - \frac{P_b}{P_g} b_i\right)$$

By differentiating with respect to b_i, and setting the result equal to zero, we get:

$$\frac{P_g - P_b}{P_g} U_x - U_Y - \theta_i \frac{P_b}{P_g} f_i' = 0$$

$$P_Y U_x - P_x U_Y - (P_x - P_Y)\theta_i f_i' = 0$$

This result gives us an implicit function of the demand for b_i. Using the implicit function theorem, we get the change in b_i as w_i increases:

$$\frac{db_i}{dw_i} = -\frac{P_Y U_{xx} - P_x U_{xY} - (P_x - P_Y)\theta_i f_i''}{[P_Y^2 U_{xx} - P_x^2 U_{YY} + 2P_x P_Y U_{xY}] + (P_x - P_Y)\theta_i f_i''}$$

Since the denominator is negative, then the sign of this equation is given by the numerator. From the first order conditions from this problem, we get the following relationships:

$$U_x + \theta_i f_i' = \lambda P_X$$

$$U_Y + \theta_i f_i' = \lambda P_Y$$

where λ is the lagrange multiplier associated with the full-income constraint. By substituting it into the previous equation, we get that the numerator can be positive if:

$$-\frac{f_i''}{f_i'} > -\left[\frac{U_Y U_{xx} - U_x U_{XY}}{P_Y U_x - P_x U_Y}\right] - U_{xx} + U_{xY}$$

where the left-hand side is the coefficient of absolute risk aversion associated to the utility function that describes the warm-glow preference over the green good. A function that shows this property for low levels of income is the Cobb-Douglas function.

If b_i can be a normal good, it follows that Y can be inferior at some point in the income distribution.

Income Redistribution with Warm Glow

Using the function $\tilde{y}_i(m_i, Y_{-i})$, it is convenient to express b_i as:

$$b_i = Y_{-i} - \tilde{y}_i(m_i, Y_{-i})$$

Totally differentiating gives:

$$\begin{aligned}
db_i &= dY_{-i} - \tilde{y}_m[dw_i + P_Y dY_{-i}] - \tilde{y}_{Y_{-i}} dY_{-i} \\
&= dY_{-i}\left[1 - P_Y y_m - y_{Y_{-i}}\right] - \tilde{y}_m dw_i \\
&= (dY + db_i)\left[1 - P_Y \tilde{y}_m - \tilde{y}_{Y_{-i}}\right] - \tilde{y}_m dw_i \\
&= \frac{1 - P_Y \tilde{y}_m - y_{Y_{-i}}}{P_Y \tilde{y}_m + \tilde{y}_{Y_{-i}}} dY - \frac{\tilde{y}_m}{P_Y \tilde{y}_m + \tilde{y}_{Y_{-i}}} dw_i
\end{aligned}$$

$$= \left(\frac{1}{P_Y \tilde{y}_m + \tilde{y}_{Y_{-i}}} - 1\right) dY - \frac{y_m}{P_Y \tilde{y}_m + \tilde{y}_{Y_{-i}}} dw_i \qquad (\boldsymbol{C.1})$$

From the Equilibrium condition:

$$Y^* = K - \sum_{i \in M} b_i - \sum_{j \in B} b_j$$

$$Y^* = K - \sum\nolimits_{i \in M} [Y_{-i} - \tilde{y}_i(m_i, Y_{-i})] - \sum\nolimits_{j \in B} \frac{w_j}{P_b}$$

Totally differentiating and substituting in $(\boldsymbol{C.1})$:

$$dY^* = \sum\nolimits_{i \in M} \left[\frac{\tilde{y}_m}{P_Y \tilde{y}_m + \tilde{y}_{Y_{-i}}} dw_i - \left(\frac{1}{P_Y \tilde{y}_m + \tilde{y}_{Y_{-i}}} - 1 \right) dY^* \right] - \sum\nolimits_{j \in B} \frac{dw_j}{P_b}$$

$$dY^* = \alpha \left[\sum\nolimits_{i \in M} \frac{\tilde{y}_m}{P_Y \tilde{y}_m + \tilde{y}_{Y_{-i}}} dw_i - \sum\nolimits_{j \in B} \frac{dw_j}{P_b} \right] \qquad (\boldsymbol{C.2})$$

where $\alpha = \left(\sum_{i \in M} \frac{1}{P_Y y_m + y_{Y_{-i}}} - (n_M - 1) \right)^{-1} > 0$

From $(\boldsymbol{C.2})$, it is possible to see that, in equilibrium, Environmental Quality decreases if a Brown Consumer gets a marginal increase in income and remains the same if a Green Consumer gets a marginal increase in income. However, as opposed to the prediction from the baseline model, an increase in the income of Mixed Consumers can have a negative effect if their income is located in the part of the distribution where the brown good is normal.

Conformity Model

Proof of Proposition 4.2

The first-order conditions for this problem are:

$$U_x - \lambda P_x = 0$$

$$U_Y - \delta_i(n-1)h' - \lambda P_x = 0$$

$$m_i - P_x - P_Y = 0$$

And the let the related Hessian Matrix be denoted by Δ:

$$\Delta = \begin{bmatrix} U_{xx} & U_{xY} & -P_x \\ U_{xY} & U_{YY} + \delta_i(n-1)^2 h_i'' & -P_Y \\ -P_x & -P_Y & 0 \end{bmatrix}$$

By the implicit function theorem, it is possible to isolate and sign the effects of m_i, Y_{-i}, and δ_i on $X_i(m_i, Y_{-i})$ and $y_i(m_i, Y_{-i})$:

$$\begin{bmatrix} x_m & x_{Y_{-i}} & x_\delta \\ y_m & y_{Y_{-i}} & y_\delta \\ \lambda_m & \lambda_{Y_{-1}} & \lambda_\delta \end{bmatrix} = -\frac{\Delta^{-1}}{\det\ |\Delta|} \begin{bmatrix} 0 & 0 & 0 \\ 0 & -\delta_i n(n-1)h'' & -(n-1)h' \\ 1 & 0 & 0 \end{bmatrix}$$

where:

$$\Delta^{-1} = \begin{bmatrix} \Delta_{11} & \Delta_{12} & \Delta_{13} \\ \Delta_{12} & \Delta_{22} & \Delta_{23} \\ \Delta_{13} & \Delta_{23} & \Delta_{33} \end{bmatrix}$$

$\Delta_{11} = -P_Y^2 < 0$

$\Delta_{12} = P_x P_Y > 0$

$\Delta_{13} = [-\mathrm{P}_Y U_{xY} + P_x U_{YY}] + \delta_i P_x (n-1)^2 h'' < 0$

$\Delta_{22} = -P_x^2 < 0$

$\Delta_{23} = [-P_x U_{xY} + P_Y U_{xx}] < 0$

$\det|\mathit{\Delta}| = -P_x \Delta_{13} - P_Y \Delta_{23} > 0$

Therefore:

$$x_m = \frac{-\Delta_{13}}{\det|\mathit{\Delta}|} > 0 \qquad y_m = \frac{-\Delta_{23}}{\det|\mathit{\Delta}|} > 0$$

$$x_{Y_{-1}} = \frac{\delta_i n(n-1)h'' \Delta_{12}}{\det|\mathit{\Delta}|} < 0 \qquad y_{Y_{-i}} = \frac{\delta_i n(n-1)h'' \Delta_{22}}{\det|\mathit{\Delta}|} > 0$$

These results establish that both x_i and Y are normal to Mixed Consumers with respect to the full income. It also helps to establish that:

$$P_Y y_m + y_{Y_{-i}} = \frac{-P_Y \Delta_{23} - \delta_i n(n-1)h'' \Delta_{22}}{\det|\mathit{\Delta}|} \in (0,1]$$

- Proof that the critical income levels change:

To prove that the income level to become a Green Consumer shifts to the right, all that we need is to show that the demand for the brown good is positive at w_i^G from the baseline model. Since $b_i = 0$ at this point, the consumption of the brown good cannot be greater than the average consumption. Therefore, h' is positive at this point. From the previous part:

$$\frac{\partial y_i}{\partial \delta_i} = -\frac{-(n-1)h'^{\Delta_{22}}}{\det|\Delta|} < 0$$

Considering a change of δ_i from zero (baseline model) to any positive value (conformity model), shows us the demand for y_i is lower, and implies that the demand for the brown good increases at this level of income. Therefore it takes more income for a consumer to become Green and the critical income level shifts to the right.

Conversely, for consumers with an income level equal to w_i^B from the baseline model, the critical level will shift depending on whether their consumption of the brown good is greater than, lower than, or equal to the average consumption. If $U_i = U(X_i, Y)$ for all consumers, then the consumption of the brown good cannot be less that the average consumption and h' is negative. Therefore:

$$\frac{\partial y_i}{\partial \delta_i} = -\frac{-(n-1)h'\Delta_{22}}{\det|\Delta|} > 0$$

which shows that, at the income level w_i^B, consumers with a positive δ_i will demand fewer units of the brown good than the amount predicted by the baseline model. This result establishes that the critical income level must shift to the left.

- <u>Proof that the Nash Equilibrium exists and is unique</u>

From the baseline model, proving that $b_i(Y, w_i)$ is a weakly increasing function of Y is enough to guarantee existence and uniqueness. Since $y_i(m_i, Y_{-i})$ is an increasing function in m_i, its inverse function exists.

$$w_i + P_Y Y_{-i} = y_i^{-1}(Y, Y_{-i})$$

Using the identity $Y_{-i} = Y + b_i$:

$$w_i + P_Y(Y + b_i) - y_i^{-1}(Y, Y + b_i) = 0 \qquad \textbf{(C.3)}$$

By the implicit function theorem:

$$\frac{\partial b_i}{\partial Y} = -\frac{P_Y - \frac{\partial y_i^{-1}}{\partial Y} - \frac{\partial y_i^{-1}}{\partial Y_{-i}}}{P_Y - \frac{\partial y_i^{-1}}{\partial Y_{-i}}}$$

Using the inverse function theorem:

$$\frac{\partial b_i}{\partial Y} = -1 + \frac{\frac{1}{y_m}}{P_Y + \frac{y_{Y_{-i}}}{y_m}} = -1 + \frac{1}{P_Y y_m + y_{Y_{-i}}} \geq 0$$

Hence the Nash Equilibrium exists and is unique.

- <u>Effect of environmental quality with changes in individual income</u>

Similar to the model with Warm-Glow, it is convenient to express b_i as a function of $y_i(m_i, Y_{-i})$

$$b_i = Y_{-i} - y_i(m_i, Y_{-i})$$

Totally differentiating

$$\begin{aligned} db_i &= dY_{-i} - y_m[dw_i + P_Y dY_{-i}] - y_{Y_{-i}} dY_{-i} \\ &= dY_{-i}\left[1 - P_Y y_m - y_{Y_{-i}}\right] - y_m dw_i \\ &= (dY + db_i)\left[1 - P_Y y_m - y_{Y_{-i}}\right] - y_m dw_i \\ &= \frac{1 - P_Y y_m - y_{Y_{-i}}}{P_Y y_m + y_{Y_{-i}}} dY - \frac{y_m}{P_Y y_m + y_{Y_{-i}}} dw_i \end{aligned}$$

$$= \left(\frac{1}{P_Y y_m + y_{Y_{-i}}} - 1\right) dY - \frac{y_m}{P_Y y_m + y_{Y_{-i}}} dw_i \qquad \textbf{(C.4)}$$

From the Equilibrium condition:

$$Y^* = K - \sum\nolimits_{i \in M} b_i - \sum\nolimits_{j \in B} b_j$$

$$Y^* = K - \sum\nolimits_{i \in M} [Y_{-i} - y_i(m_i, Y_{-i})] - \sum\nolimits_{j \in B} \frac{w_j}{P_b}$$

Totally differentiating and substituting $(\boldsymbol{C.3})$:

$$dY^* = \sum\nolimits_{i \in M} \left[\frac{y_m}{P_Y y_m + y_{Y_{-i}}} dw_i - \left(\frac{1}{P_Y y_m + y_{Y_{-i}}} - 1 \right) dY^* \right] - \sum\nolimits_{j \in B} \frac{dw_j}{P_b}$$

$$dY^* = \alpha \left[\sum\nolimits_{i \in M} \frac{y_m}{P_Y y_m + y_{Y_{-i}}} dw_i - \sum\nolimits_{j \in B} \frac{dw_j}{P_b} \right] \qquad (\boldsymbol{C.5})$$

where $\alpha = \left(\sum_{i \in M} \frac{1}{P_Y y_m + y_{Y_{-i}}} - (n_M - 1) \right)^{-1} > 0$

From $(\boldsymbol{C.4})$, it is possible to see that, in equilibrium, Environmental Quality increases if a Mixed Consumer gets a marginal increase in income, decreases if a Brown Consumer gets a marginal increase in income, and remains the same if a Green Consumer gets a marginal increase in income.

- <u>Proof that the Brown Good is inferior for a Mixed Consumer</u>

Let Y^* be the equilibrium level of Environmental Quality. From $(\boldsymbol{C.3})$, a change in income for a Mixed Consumer:

$$\frac{\partial b_i(Y^*, w_i)}{\partial w_i} = -\frac{1 + P_Y \cdot \frac{\partial Y^*}{\partial w_i} - \frac{\partial y_i^{-1}}{\partial Y} \cdot \frac{\partial Y^*}{\partial w_i} - \frac{\partial y_i^{-1}}{\partial Y_{-i}} \cdot \frac{\partial Y^*}{\partial w_i}}{P_Y - \frac{\partial y_i^{-1}}{\partial Y_{-i}}}$$

$$= -\frac{1 + \left(P_Y - \frac{1}{y_m} + \frac{y_{Y_{-i}}}{y_m}\right)\frac{\partial Y^*}{\partial w_i}}{P_Y + \frac{y_{Y_{-i}}}{y_m}}$$

$$= -\frac{y_m + \left(P_Y y_m + y_{Y_{-i}} - 1\right)\frac{\partial Y^*}{\partial w_i}}{P_Y y_m + y_{Y_{-i}}} < 0$$

The result follows because $y_m > 0$, $P_Y y_m + y_{Y_{-i}} \leq 1$, and $\frac{\partial Y^*}{\partial w_i} < 0$, which makes both the numerator and denominator positive numbers.

- <u>Effect of Income Redistribution on Environmental Quality</u>

Similar to the baseline model, $(\boldsymbol{C.5})$ establishes that a transfer of income has no effect on Environmental Quality if it only involves Green Consumers or Brown Consumers, it has a positive effect if it redistributes income in favor of Mixed Consumers and/or against Brown Consumers, and it has a negative effect if it redistributes income in favor of Brown Consumers and/or against Mixed Consumer. The difference is that a redistribution involving only Mixed Consumers can have either a positive or negative effect, because the term $\frac{y_m}{p_Y y_m + y_{Y_{-i}}}$ can be different for each consumer.

Let $\beta_i = \frac{y_m}{p_Y y_m + y_{Y_{-i}}}$ for consumer i, and let consumer 1 receive an income transfer from consumer 2. If both consumers are Mixed Consumers, then $(\boldsymbol{C.5})$ becomes:

$$dY^* = \alpha[\beta_1 - \beta_2]$$

If consumer 1 is more sensitive to this transfer, then Environmental Quality increases. If consumer 2 is more sensitive, Environmental Quality decreases. Finally, if both consumers are equally sensitive, then Environmental Quality is not affected by this redistribution of income.

Appendix D: Experiment Instructions

General Information

Thank you for agreeing to participate in this study. This is an experiment in the economics of decision making. Your participation in this experiment is voluntary. In addition to the $5 for showing up, you will have the opportunity to earn additional money based on the decisions that you and 2 other participants in this meeting make. The total amount of money earned during the experiment will be paid to you by cash or, if preferred, via an Amazon e-gift card at the end.

The experiment is divided into three separate parts. As the experiment proceeds you will get more detailed information on each part. The experiment will be conducted on the computer screen in front of you.

Parts I and II both consist of a sequence of 10 decision-making rounds each (**20 rounds total**). You will be a member of a group of **3 participants** randomly chosen among the people in this room. The composition of your group will remain the same throughout the 20 rounds of Parts I and II. You will be unable to know the identity of each individual belonging to your group. Each group will have three roles: Player A, Player B, and Player C. Each group member will be assigned to one of these roles randomly before Part I begins and will keep this assigned role for the duration of the experiment.

Part III consists of some questions about you. Your answers to the questions in Part III will not affect your earnings in the experiment.

During the experiment, your earnings will be calculated in Tokens. At the end of the experiment, we will **randomly** select one round from either Part I or Part II. **So, in total 1 round out of the 20 rounds will be used for your payment.** At the end of the experiment the total amount of Tokens you have earned will be converted to US Dollars at the following rate: 100 Tokens = 0.80 US Dollars.

The published results of our research will not identify any individuals or the choices they made in any way. All records will be linked to an anonymous subject ID only.

Please do not communicate with the other participants during the experiment. Should you have any questions, please contact one of the experimenters directly. At the end of the experiment, we will collect your name, email, and mailing address and give you your payment.

The following pages describe the first part of the experiment in detail.

Please click “Continue”.

Please wait for everyone to continue.

Part I

This part consists of 10 rounds. Your group will be endowed with 270 tokens. At the beginning of every round, each group member will receive an individual endowment. This endowment will be distributed as follows: Every group member will receive 90 tokens This distribution of tokens will remain fixed for the duration of Part I.

You will have the opportunity to buy two different types of shapes in every round. Each **circle** costs **5 tokens**. After you select how many **circles** to buy, your remaining tokens will be automatically used to buy **triangles**. Each **triangle** costs **1 token**. You will not be able to buy more shapes than the ones you can afford.

Your **payoff** in each round will come from two sources: a **Public Income** and a **Private Income**. The **Public Income** depends on the total number of **triangles** acquired by all 3 group members (including you). The **Public Income** will be the same for every group member. Your **Private Income** depends on the **total shapes** you buy (circles + triangles). Your payoff will be the sum of **your Private Income** plus the **Public Income**. If the sum of your Private Income plus the Public Income is **negative**, then your payoff will be equal to **zero (0).**

Table 1 and Table 2 show how the **Public Income** and your **Private Income** will be calculated, respectively. Please note that the **Public Income** decreases for every **triangle** acquired by anyone in your group. For your **Private Income**, increasing your

total shapes is helpful in some situations but not in others. Table 3 shows the rate of conversion between circles, triangles, and total shapes for each player. You will receive two (2) additional minutes to examine these tables after we finish reading the instructions.

BONUS: In each round, you will also have to **guess the sum of the triangles your other two group members will acquire**. If you are exactly right, your payoff will increase by 100. If your guess is off from the correct result by 5 shapes or less, your payoff will increase by 50. If your guess is off by 6 or more shapes, then you will not receive any additional payoff.

Calculator: To help you make the decision of how many **circles** to get, you will have the option to use a pre-programmed calculator. To use it, first write down how many **circles** you would like to buy, and then write down any guess for the **sum of the triangles acquired by the other group members**. The calculator will inform you about the number of triangles you would get, your total shapes, your **Private and Public Income** under that scenario, as well as the **payoff** you would receive. You do not need to use the calculator but may find it helpful. The calculator will be available in every round, and you can use it as many times as you need. **The information you provide to the calculator will not affect your payoff in any way.**

(Insert calculator here)

To make your **actual decision**, you will have to answer the question that will appear **below the Calculator**. You will also be asked to type in your guess for the Bonus payment. To submit your responses, please click on the NEXT Button. You will have **60 seconds per round** to make your decision.

(Insert slider)

After each round, you will receive information about how many circles you bought, how many triangles each group member acquired, your Private Income, the Public Income, Bonus payment, and your own payoff in that period as well as in each previous round. You will have 30 seconds to review that information before the next round begins.

(Insert table)

Remember, everyone in your group is being asked to make the same consumption decisions. Further, your group members' payoff, like yours, depend on the total amount of triangles the group gets. Your decisions in every round have the potential to affect your actual earnings from the experiment. One round out of the next 20 rounds will be selected randomly to determine your payment. Each round has equal chances of being selected. Since you do not know in advance which round will be selected, you should decide carefully as if each round is the selected one.

The instructions for **Part I** have concluded. Before continuing with the experiment, you will have to answer some questions to make sure you have understood the instructions correctly. The calculator will be available to help you answer each question. After that, you will be matched with two other participants and your role as Player, A, B, or C will be assigned.

Part II

The experiment will now extend for another sequence of 10 rounds. These instructions, as well as a summary of them, will be available to you in each round.

The 10 additional rounds are entirely identical to the previous part, except that the distribution of the total endowment of your group will be changed. This modification is completely independent of the outcome of the 10 previous rounds. The 270 tokens of the group will now be distributed as follows: Player A will get 50 tokens, Player B will get 90 tokens, and Player C will get 130 tokens. This distribution of tokens will remain fixed for the next 10 rounds.

Apart from this change in the token's distribution, you will make the same decision as in the previous part: determine how many **circles** to buy. Remember that your remaining tokens will be automatically converted into triangles.

The Private Income and Public Income will be calculated in the same way as in Part I (tables available at the end). The calculator will still be provided in each round, and you can use it as many times as you need. You will also have to guess the number of **triangles** that the other group members will buy.

You will have 60 seconds per round to make your decision.

The instructions for **Part II** have concluded. What follows has the potential to affect your earnings: One round out of the 20 rounds from Parts I and II will be selected randomly to determine your payment. Each round has equal chances of being selected. Since you do not know in advance which round will be selected, you should decide carefully as if each round is the selected one.

You will have 2 minutes to use and get acquainted with how the Calculator works with your new income before round 1 begins.

Bibliography

Anderson, L. R., Mellor, J. M., & Milyo, J. (2008). Inequality and public good provision: An experimental analysis. *The Journal of Socio-Economics*, *37*(3), 1010-1028.

Andreoni, J. (1989). Giving with impure altruism: Applications to charity and Ricardian equivalence. *Journal of political Economy*, *97*(6), 1447-1458.

Andreoni, J. (1990). Impure altruism and donations to public goods: A theory of warm-glow giving. *The economic journal*, *100*(401), 464-477.

Andreoni, J., & Payne, A. A. (2013). Charitable giving. In *Handbook of public economics* (Vol. 5, pp. 1-50). Elsevier.

Annala, J. H. (1996). New Zealand's ITQ system: have the first eight years been a success or a failure?. *Reviews in Fish biology and Fisheries*, *6*, 43-62.

Arnason, R. (1990). Minimum information management in fisheries. *Canadian Journal of economics*, 630-653.

Arnason, R. (2002). *A review of international experiences with ITQs*. Portsmouth: Centre for the economics and management of aquatic resources, University of Portsmouth.

Arnason, R. (2005). Property rights in fisheries: Iceland’s experience with ITQs. *Reviews in Fish Biology and Fisheries*, *15*, 243-264.

Arnason, R. (2007). Fisheries self-management under ITQs. *Marine Resource Economics*, *22*(4), 373-390.

Arnason, R. (2009). Conflicting uses of marine resources: can ITQs promote an efficient solution?. *Australian Journal of Agricultural and Resource Economics*, *53*(1), 145-174.

Arnason, R. (2012). Property rights in fisheries: How much can individual transferable quotas accomplish?.

Atkinson, A. B., & Stern, N. H. (1974). Pigou, taxation and public goods. *The Review of economic studies*, *41*(1), 119-128.

Azrieli, Y., Chambers, C. P., & Healy, P. J. (2018). Incentives in experiments: A theoretical analysis. *Journal of Political Economy*, *126*(4), 1472-1503.

Baek, J., & Gweisah, G. (2013). Does income inequality harm the environment?: Empirical evidence from the United States. *Energy Policy*, *62*, 1434-1437.

Bagnoli, M., & McKee, M. (1991). Voluntary contribution games: Efficient private provision of public goods. *Economic Inquiry*, *29*(2), 351-366.

Bardhan, P., Ghatak, M., & Karaivanov, A. (2007). Wealth inequality and collective action. *Journal of Public Economics*, *91*(9), 1843-1874.

Banerjee, A., & Piketty, T. (2005). Top indian incomes, 1922–2000. *The World Bank Economic Review*, *19*(1), 1-20.

Baumol, W. J., & Oates, W. E. (1988). *The theory of environmental policy*. Cambridge university press.

Bergstrom, T., Blume, L., & Varian, H. (1986). On the private provision of public goods. *Journal of public economics*, *29*(1), 25-49.

Bernheim, B. D. (1994). A theory of conformity. *Journal of political Economy*, *102*(5), 841-877.

Berthe, A., & Elie, L. (2015). Mechanisms explaining the impact of economic inequality on environmental deterioration. *Ecological economics*, *116*, 191-200.

Betts, A. (2003). Public goods theory and the provision of refugee protection: The role of the joint-product model in burden-sharing theory. *Journal of refugee studies*, *16*(3), 274-296.

Boadway, R., & Hayashi, M. (1999). Country size and the voluntary provision of international public goods. *European Journal of Political Economy*, *15*(4), 619-638.

Boadway, R., & Keen, M. (1993). Public goods, self-selection and optimal income taxation. *International Economic Review*, 463-478.

Borghesi, S. (2006). Income inequality and the environmental Kuznets curve. *Environment, inequality and collective action*, *33*.

Boyce, J. K. (1994). Inequality as a cause of environmental degradation. *Ecological economics*, *11*(3), 169-178.

Brinson, A. A., & Thunberg, E. M. (2016). Performance of federally managed catch share fisheries in the United States. *Fisheries Research*, *179*, 213-223.

Brumme, A. (2022). How Does a "Green" Good Affect Environmental Quality and Social Welfare?. *Journal of Economics and Statistics (Jahrbuecher fuer Nationaloekonomie und Statistik)*, *242*(3), 371-401.

Brumme, A., Buchholz, W., & Rübbelke, D. (2020). Impure public goods and the aggregative game approach. *Ancillary Benefits of Climate Policy: New Theoretical Developments and Empirical Findings*, 141-155.

Buckley, E., & Croson, R. (2006). Income and wealth heterogeneity in the voluntary provision of linear public goods. *Journal of Public Economics*, *90*(4-5), 935-955.

Burns, J., & Visser, M. (2008). Income inequality and the provision of public goods: when the real world mimics the lab. *University of Cape Town, Working Paper*.

Carothers, C., & Chambers, C. (2012). Fisheries privatization and the remaking of fishery systems. *Environment and Society*, *3*(1), 39-59.

Chan, K. S., Mestelman, S., Moir, R., & Muller, R. A. (1996). The voluntary provision of public goods under varying income distributions. *Canadian Journal of Economics*, 54-69.

Chan, K. S., Mestelman, S., Moir, R., & Muller, R. A. (1999). Heterogeneity and the voluntary provision of public goods. *Experimental Economics*, *2*(1), 5-30.

Chan, K. S., Mestelman, S., Muller, R. A., & Moir, R. (2012). Communication, equity and the voluntary provision of a public good by heterogeneous groups. *The Journal of Socio-Economics*, *41*(1), 87-94.

Chan, N. W. (2015). Misinformation and its implications for green markets. *Strategic Behavior and the Environment*, *5*(3–4), 301-316.

Chan, N. W. (2019). Funding global environmental public goods through multilateral financial mechanisms. *Environmental and resource economics*, *73*, 515-531.

Chan, N. W., & Dinelli, M. (2020). Optimal cost sharing for green goods. *Journal of the Association of Environmental and Resource Economists*, *7*(6), 1033-1068.

Chan, N. W., & Kotchen, M. J. (2014). A generalized impure public good and linear characteristics model of green consumption. *Resource and Energy Economics*, *37*, 1-16.

Che, Y. K., Gale, I., & Kim, J. (2013). Assigning resources to budget-constrained agents. *Review of Economic Studies*, *80*(1), 73-107.

Cherry, T. L., Kroll, S., & Shogren, J. F. (2005). The impact of endowment heterogeneity and origin on public good contributions: evidence from the lab. *Journal of Economic Behavior & Organization*, *57*(3), 357-365.

Chu, C. (2009). Thirty years later: the global growth of ITQs and their influence on stock status in marine fisheries. *Fish and Fisheries*, *10*(2), 217-230.

Coase, R. H. (1960). Law economics. *Journal of Law and Economics*, *3*, 1-44.

Cohn, A., Jessen, L. J., Klasnja, M., & Smeets, P. (2019). Why do the rich oppose redistribution. *An Experiment with America's Top 5*.

Corazzini, L., Faravelli, M., & Stanca, L. (2010). A prize to give for: An experiment on public good funding mechanisms. *The Economic Journal*, *120*(547), 944-967.

Cornes, R., & Hartley, R. (2007). Aggregative public good games. *Journal of Public Economic Theory*, *9*(2), 201-219.

Cornes, R., & Sandler, T. (1984). Easy riders, joint production, and public goods. *The Economic Journal*, *94*(375), 580-598.

Cornes, R., & Sandler, T. (1994). The comparative static properties of the impure public good model. *Journal of public economics*, *54*(3), 403-421.

Cornes, R., & Sandler, T. (2000). Pareto-improving redistribution and pure public goods. *German Economic Review*, *1*(2), 169-186.

Copes, P., & Charles, A. (2004). Socioeconomics of individual transferable quotas and community-based fishery management. *Agricultural and Resource Economics Review*, *33*(2), 171-181.

Côté, S., House, J., & Willer, R. (2015). High economic inequality leads higher-income individuals to be less generous. *Proceedings of the National Academy of Sciences*, *112*(52), 15838-15843.

Cullenward, D., & Coghlan, A. (2016). Structural oversupply and credibility in California's carbon market. *The electricity journal*, *29*(5), 7-14.

Dales, J. H. (1968). *Pollution, property & prices*. University of Toronto Press.

Demailly, D., & Quirion, P. (2008). European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry. *Energy economics*, *30*(4), 2009-2027.

Dong, X. Y., & Hao, Y. (2018). Would income inequality affect electricity consumption? Evidence from China. *Energy*, *142*, 215-227.

Downey, L. (2015). *Inequality, democracy, and the environment*. NYU Press.

Engelmann, D., Munro, A., & Valente, M. (2017). On the behavioural relevance of optional and mandatory impure public goods. *Journal of Economic Psychology*, *61*, 134-144.

Feng, J., Saijo, T., Shen, J., & Qin, X. (2018). Instability in the voluntary contribution mechanism with a quasi-linear payoff function: An experimental analysis. *Journal of behavioral and experimental economics*, *72*, 67-77.

Fiala, L., & Noussair, C. N. (2017). Charitable giving, emotions, and the default effect. *Economic Inquiry*, *55*(4), 1792-1812.

Filiz-Ozbay, E., & Uler, N. (2017). Demand for Giving to Multiple Charities: An Experimental Study. *Journal of the European Economic Association*.

Fischbacher, U., & Gächter, S. (2010). Social preferences, beliefs, and the dynamics of free riding in public goods experiments. *American economic review*, *100*(1), 541-556.

Goda, T., Onaran, Ö., & Stockhammer, E. (2017). Income inequality and wealth concentration in the recent crisis. *Development and Change*, *48*(1), 3-27.

Golley, J., & Meng, X. (2012). Income inequality and carbon dioxide emissions: The case of Chinese urban households. *Energy Economics*, *34*(6), 1864-1872.

Gordon, H. S. (1954). The economic theory of a common-property resource: the fishery. *Journal of political economy*, *62*(2), 124-142.

Gorman, W. M. (1980). A possible procedure for analysing quality differentials in the egg market. *The Review of Economic Studies*, *47*(5), 843-856.

Grafton, R. Q. (1996). Individual transferable quotas: theory and practice. *Reviews in Fish Biology and Fisheries*, *6*, 5-20.

Grant, L., & Langpap, C. (2019). Private provision of public goods by environmental groups. *Proceedings of the National Academy of Sciences*, *116*(12), 5334-5340.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The quarterly journal of economics*, *110*(2), 353-377.

Grunewald, N., Klasen, S., Martínez-Zarzoso, I., & Muris, C. (2017). The trade-off between income inequality and carbon dioxide emissions. *Ecological Economics*, *142*, 249-256.

Hao, Y., Chen, H., & Zhang, Q. (2016). Will income inequality affect environmental quality? Analysis based on China's provincial panel data. *Ecological indicators*, *67*, 533-542.

Hardin, G. (1968). The tragedy of the commons: the population problem has no technical solution; it requires a fundamental extension in morality. *science*, *162*(3859), 1243-1248.

Heap, S. P. H., Ramalingam, A., & Stoddard, B. V. (2016). Endowment inequality in public goods games: A re-examination. *Economics Letters*, *146*, 4-7.

Heaps, T. (2003). The effects on welfare of the imposition of individual transferable quotas on a heterogeneous fishing fleet. *Journal of Environmental Economics and Management*, *46*(3), 557-576.

Heerink, N., Mulatu, A., & Bulte, E. (2001). Income inequality and the environment: aggregation bias in environmental Kuznets curves. *Ecological Economics*, *38*(3), 359-367.

Herrmann, M. (2000). Individual vessel quota price-induced effects for Canadian Pacific halibut: before and after Alaska IFQs. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *48*(2), 195-210.

Hilborn, R., Orensanz, J. M., & Parma, A. M. (2005). Institutions, incentives and the future of fisheries. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1453), 47-57.

Hofmeyr, A., Burns, J., & Visser, M. (2007). Income inequality, reciprocity and public good provision: an experimental analysis. *South African Journal of Economics*, *75*(3), 508-520.

Holzer, J., & McConnell, K. (2023). Extraction rights allocation with liquidity constraints. *Resource and Energy Economics*, *71*, 101345.

Intergovernmental Panel on Climate Change. IPCC (2007). Climate change 2007: synthesis report. *Contribution of Working Groups I, Ii and Iii to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Ipcc, Geneva, Switzerland*.

Itaya, J. I., De Meza, D., & Myles, G. D. (1997). In praise of inequality: public good provision and income distribution. *Economics Letters*, *57*(3), 289-296.

Jorgenson, A. K. (2015). Inequality and the carbon intensity of human well-being. *Journal of Environmental Studies and Sciences*, *5*, 277-282.

Keser, C., Markstädter, A., & Schmidt, M. (2017). Mandatory minimum contributions, heterogeneous endowments and voluntary public-good provision. *Games and Economic Behavior*, *101*, 291-310.

Kim, I. (2009). The Effects of Uncertainty on the Voluntary Private Provision of Impure Public Goods. *The Singapore Economic Review*, *54*(01), 61-73.

Kingma, B. R. (1989). An accurate measurement of the crowd-out effect, income effect, and price effect for charitable contributions. *Journal of Political Economy*, *97*(5), 1197-1207.

Knapp, G. (2011). Local permit ownership in Alaska salmon fisheries. *Marine Policy*, *35*(5), 658-666.

Koppel, H., & Schulze, G. G. (2013). The importance of the indirect transfer mechanism for consumer willingness to pay for fair trade products—evidence from a natural field experiment. *Journal of Consumer Policy*, *36*, 369-387.

Kotchen, M. J. (2005). Impure public goods and the comparative statics of environmentally friendly consumption. *Journal of environmental economics and management*, *49*(2), 281-300.

Kotchen, M. J. (2006). Green markets and private provision of public goods. *Journal of Political Economy*, *114*(4), 816-834.

Kotchen, M. J. (2009). Voluntary provision of public goods for bads: A theory of environmental offsets. *The Economic Journal*, *119*(537), 883-899.

Kotchen, M. J., & Moore, M. R. (2007). Private provision of environmental public goods: Household participation in green-electricity programs. *Journal of Environmental Economics and management*, *53*(1), 1-16.

Kuhn, K. U., & Uler, N. (2019). Behavioral sources of the demand for carbon offsets: An experimental study. *Experimental Economics*, *22*, 676-704.

Laffont, J. J., & Robert, J. (1996). Optimal auction with financially constrained buyers. *Economics Letters*, *52*(2), 181-186.

Lancaster, K. (1971). *Consumer demand: A new approach*. New York: Columbia University Press

Lange, A., Schmitz, J., & Schwirplies, C. (2021). Inequality, role reversal and cooperation in multiple group membership settings. *Experimental economics*, 1-43.

Lange, A., Schwirplies, C., & Ziegler, A. (2017). On the interrelation between the consumption of impure public goods and the provision of direct donations: Theory and empirical evidence. *Resource and Energy Economics*, *47*, 72-88.

Lange, A., & Ziegler, A. (2017). Offsetting versus mitigation activities to reduce CO 2 emissions: A theoretical and empirical analysis for the US and Germany. *Environmental and Resource Economics*, *66*(1), 113-133.

Laury, S. K., & Holt, C. A. (2008). Voluntary provision of public goods: experimental results with interior Nash equilibria. *Handbook of experimental economics results*, *1*, 792-801.

Ledyard, J. O. (1995). Is there a problem with public goods provision. *The handbook of experimental economics*, 111-194.

Libecap, G. D. (2007). Assigning property rights in the common pool: implications of the prevalence of first-possession rules for ITQs in fisheries. *Marine Resource Economics*, *22*(4), 407-423.

Liu, C., Jiang, Y., & Xie, R. (2019). Does income inequality facilitate carbon emission reduction in the US?. *Journal of Cleaner Production*, *217*, 380-387.

Liu, Q., Wang, S., Zhang, W., Li, J., & Kong, Y. (2019). Examining the effects of income inequality on CO2 emissions: Evidence from non-spatial and spatial perspectives. *Applied Energy*, *236*, 163-171.

Long, N. V. (2020). Warm glow and the transmission of pro-socialness across generations. *Journal of Public Economic Theory*, *22*(2), 371-387.

Markussen, T., Sharma, S., Singhal, S., & Tarp, F. (2021). Inequality, institutions and cooperation. *European Economic Review*, *138*, 103842.

Martin, R., Muûls, M., & Wagner, U. J. (2016). The impact of the European Union Emissions Trading Scheme on regulated firms: what is the evidence after ten years?. *Review of environmental economics and policy*.

Martinangeli, A. F., & Martinsson, P. (2020). We, the rich: inequality, identity and cooperation. *Journal of Economic Behavior & Organization*, *178*, 249-266.

Maurice, J., Rouaix, A., & Willinger, M. (2013). Income redistribution and public good provision: an experiment. *International Economic Review*, *54*(3), 957-975.

McCay, B. J., Creed, C. F., Finlayson, A. C., Apostle, R., & Mikalsen, K. (1995). Individual transferable quotas (ITQs) in Canadian and US fisheries. *Ocean & Coastal Management*, *28*(1-3), 85-115.

McMahon, M. J. (2015). Optimal taxation and impure public goods. *Unpublished manuscript*.

Mitra, A., & Moore, M. R. (2018). Green electricity markets as mechanisms of public-goods provision: theory and experimental evidence. *Environmental and Resource Economics*, *71*, 45-71.

Molnar, A. (2019). SMARTRIQS: A simple method allowing real-time respondent interaction in Qualtrics surveys. *Journal of Behavioral and Experimental Finance*, *22*, 161-169.

Montoya-Villalobos, M. J. (2023). Green consumption: The role of confidence and pessimism. *Ecological Economics*, *205*, 107733.

Munro, A., & Valente, M. (2016). Green goods: Are they good or bad news for the environment? Evidence from a laboratory experiment on impure public goods. *Environmental and Resource Economics*, *65*, 317-335.

Murdoch, J. C., & Sandler, T. (1984). Complementarity, free riding, and the military expenditures of NATO allies. *Journal of public economics*, *25*(1-2), 83-101.

Narassimhan, E., Gallagher, K. S., Koester, S., & Alejo, J. R. (2018). Carbon pricing in practice: A review of existing emissions trading systems. *Climate Policy*, *18*(8), 967-991.

Noussair, C. N., Plott, C. R., & Riezman, R. G. (2013). An experimental investigation of the patterns of international trade. In *International Trade Agreements and Political Economy* (pp. 299-328).

Okten, C., & Weisbrod, B. A. (2000). Determinants of donations in private nonprofit markets. *Journal of public economics*, *75*(2), 255-272.

Olson, J. (2011). Understanding and contextualizing social impacts from the privatization of fisheries: An overview. *Ocean & Coastal Management*, *54*(5), 353-363.

Olszewski, W., & Rosenthal, H. (2004). Politically determined income inequality and the provision of public goods. *Journal of Public Economic Theory*, *6*(5), 707-735.

Oxoby, R. J., & Spraggon, J. (2013). A clear and present minority: Heterogeneity in the source of endowments and the provision of public goods. *Economic Inquiry*, *51*(4), 2071-2082.

Payne, A. A. (1998). Does the government crowd-out private donations? New evidence from a sample of non-profit firms. *Journal of public economics*, *69*(3), 323-345.

Piketty, T. (2015). About Capital in the Twenty-First Century. *American Economic Review*, *105*(5), 48-53.

Piketty, T., Yang, L., & Zucman, G. (2019). Capital accumulation, private property, and rising inequality in China, 1978–2015. *American Economic Review*, *109*(7), 2469-2496.

Rapoport, A., & Suleiman, R. (1993). Incremental contribution in step-level public goods games with asymmetric players. *Organizational behavior and human decision processes*, *55*(2), 171-194.

Ravallion, M., Heil, M., & Jalan, J. (2000). Carbon emissions and income inequality. *Oxford Economic Papers*, *52*(4), 651-669.

Rey, S. J., & Gutiérrez, M. L. S. (2015). Comparative spatial inequality dynamics: The case of Mexico and the United States. *Applied geography*, *61*, 70-80.

Reuben, E., & Riedl, A. (2013). Enforcement of contribution norms in public good games with heterogeneous populations. *Games and Economic Behavior*, *77*(1), 122-137.

Rübbelke, D. T. (2003). An analysis of differing abatement incentives. *Resource and energy economics*, *25*(3), 269-294.

Sadrieh, A., & Verbon, H. A. (2006). Inequality, cooperation, and growth: An experimental study. *European Economic Review*, *50*(5), 1197-1222.

Saez, E., & Zucman, G. (2016). Wealth inequality in the United States since 1913: Evidence from capitalized income tax data. *The Quarterly Journal of Economics*, *131*(2), 519-578.

Scott, A. D. (1989). Conceptual origins of rights based fishing. In *Rights based fishing* (pp. 11-38). Dordrecht: Springer Netherlands.

Scruggs, L. A. (1998). Political and economic inequality and the environment. *Ecological economics*, *26*(3), 259-275.

Sefton, M., & Steinberg, R. (1996). Reward structures in public good experiments. *Journal of Public Economics*, *61*(2), 263-287.

Sheremeta, R. M., & Uler, N. (2021). The impact of taxes and wasteful government spending on giving. *Experimental Economics*, *24*, 355-386.

Shotton, R. (Ed.). (2000). *Use of property rights in fisheries management: proceedings of the FishRights99 Conference, Fremantle, Western Australia, 11-19 November 1999* (No. 404). Food & Agriculture Org..

Smith, V. H., Kehoe, M. R., & Cremer, M. E. (1995). The private provision of public goods: Altruism and voluntary giving. *Journal of Public Economics*, *58*(1), 107-126.

Soliman, A. (2014). Individual transferable quotas in world fisheries: addressing legal and rights-based issues. *Ocean & coastal management*, *87*, 102-113.

Squires, D., Kirkley, J., & Tisdell, C. A. (1995). Individual transferable quotas as a fisheries management tool. *Reviews in Fisheries Science*, *3*(2), 141-169.

Stewart, J., Walshe, K., & Moodie, B. (2006). The demise of the small fisher? A profile of exiters from the New Zealand fishery. *Marine Policy*, *30*(4), 328-340.

Tavoni, A., Dannenberg, A., Kallis, G., & Löschel, A. (2011). Inequality, communication, and the avoidance of disastrous climate change in a public goods game. *Proceedings of the National Academy of Sciences*, *108*(29), 11825-11829.

Torras, M., & Boyce, J. K. (1998). Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. *Ecological economics*, *25*(2), 147-160.

Uler, N. (2009). Public goods provision and redistributive taxation. *Journal of Public Economics*, *93*(3-4), 440-453.

Uler, N. (2011). Public goods provision, inequality and taxes. *Experimental Economics*, *14*, 287-306.

United Nations. (2022). - *SDG indicators*. United Nations. https://unstats.un.org/sdgs/report/ 2022/

Uzar, U., & Eyuboglu, K. (2019). The nexus between income inequality and CO2 emissions in Turkey. *Journal of Cleaner Production*, *227*, 149-157.

Uzar, U. (2020). Is income inequality a driver for renewable energy consumption?. *Journal of Cleaner Production*, *255*, 120287.

Van Dijk, E., & Grodzka, M. (1992). The influence of endowments asymmetry and information level on the contribution to a public step good. *Journal of Economic Psychology*, *13*(2), 329-342.

Vicary, S. (2000). Donations to a public good in a large economy. *European Economic Review*, *44*(3), 609-618.

Wang, S. (1995). The surf clam ITQ management: an evaluation. *Marine Resource Economics*, *10*(1), 93-98.

Warr, P. G. (1983). The private provision of a public good is independent of the distribution of income. *Economics letters*, *13*(2-3), 207-211.

Weitzman, M. L. (1974). Prices vs. quantities. *The review of economic studies*, *41*(4), 477-491.

Weninger, Q. (1998). Assessing efficiency gains from individual transferable quotas: An application to the mid-Atlantic surf clam and ocean quahog fishery. *American Journal of Agricultural Economics*, *80*(4), 750-764.

Wichman, C. J. (2016). Incentives, green preferences, and private provision of impure public goods. *Journal of Environmental Economics and Management*, *79*, 208-220.

Wilkinson, R., & Pickett, K. (2010). The spirit level. *Why equality is better for everyone*.

World Bank. (2022). *Social Dimensions of Climate Change*. https://www.worldbank.org/en/ topic/social-dimensions-of-climate-change

Zelmer, J. (2003). Linear public goods experiments: A meta-analysis. *Experimental Economics*, *6*, 299-310.