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Abstract

This paper establishes an empirical relationship between CO_2 emissions from burning fossil fuels and household consumption expenditures. Using a conceptual framework specific to the life cycle-permanent income hypothesis, we reject the hypothesis that non-inclusion of CO_2 emissions is not supported by the data. Furthermore, our results suggest the existence of a *distaste effect* (or *negative state dependence*). This result has important policy implications because it suggests that decarbonizing the economy has a positive effect on health conditions, which stimulates consumption for good health. Our results also have implications for both the cyclical behavior and the smoothing process of consumption, which depend on the branch of the environmental Kuznets curve that the country is on and on the prevalence of an intertemporarily dependent preference framework in utility.

Keywords: Private consumption, CO_2 emissions, Portugal
JEL Codes: C22, D12, E21, Q54.

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On the relationship between consumption and CO_2 emissions: the case of Portugal:

1. Introduction

The objective of this work is to evaluate and measure the relationship between CO_2 emissions from burning fossil fuels and cement production and private consumption in Portugal.

There is a vast empirical and conceptual literature devoted to the relationship between economic growth and pollution emissions (or environmental quality), spurred by the growing interest in the interaction between the economic and natural systems [see, among others, Dasgupta and Heal (1974), Tahvonen and Kuuluvainen (1993), Eakin and Selden (1995), Michell and Rotillon (1995), Smulders (1999 and 2000), Xepapadeas (2005), Belbute and Brito (2008) and Kijima et al. (2010)].

The great majority of this literature focuses on technological aspects of the production function, while the preference dimension—which is much smaller and essentially conceptual—is focused on the impact that pollution (or sometimes environmental quality) has on the optimal consumption time pattern. In particular, Michell and Rotillon (1995) suggest that although total utility tends to decrease in the presence of pollution, its effect on the optimal consumption path is ambiguous as it depends on the reaction of the marginal consumption utility to the presence of pollution. In general, the consumption time profile tends to reflect increases in consumption during periods of high marginal utility and the opposite occurs in periods of low marginal utility. Thus, if the increase in pollution causes a reduction in the marginal consumption utility (a situation which the authors call the *distaste effect*), then consumption decreases due to the reduction in its value. Conversely, if increased pollution causes marginal utility to increase, then consumption increases to offset the harmful impact of pollution on the overall welfare index. The authors call this the *compensation effect*. Both effects have different implications for the existence of endogenous cycles (limit) and the consumption smoothing process, which depend both on the branch of the environmental Kuznets curve (EKC, hereafter) that the economy is on [see Heal (1982) and Bosi and Desmarchelier

(2018)], and on the prevalence of an intertemporarily dependent preference framework which may affect saving behavior during the cycle [see Carroll (2000)].

To the best of our knowledge, the empirical relationship between pollution emissions and household consumption has not been studied. There is only one study available by Finkelstein et al. (2013), providing empirical evidence which suggests that there is a complementary relationship between health conditions and consumption, whereby worsening health status reduce marginal consumption utility (which the authors call *negative state dependence*) and as a consequence consumption tends to decrease.

The association between increased pollution and a deterioration in human health is upheld by recent medical evidence suggesting that pollution—in particular air pollution in cities, greenhouse gases or (micro) plastics—is a risk factor in the deterioration of human health [see WHO (2018), CPO24 (2018), IPCC (2018) and Kampa and Castanas (2008)]. Consequently, Michell and Rotillon's (1995) distaste effect corresponds to Finkelstein et al.'s (2013) negative state dependence, as the compensation effect corresponds to positive state dependence.

Our paper contributes to the analysis of the relationship between private consumption and CO_2 emissions. Using data on Portugal and a conceptual framework of the typical life cycle-permanent income hypothesis, our hypothesis is that CO_2 emissions and their effects on present and future well-being can be perceived by forward-looking households as risk factors for health conditions, thereby affecting the human component of permanent income and, concomitantly, the consumption time pattern. While not ignoring the existence of a causal relation from consumption towards emissions [see for example Munksgaard et al (2000) and Salo and Nissinen (2017)], our conjecture is in line with the literature and is based on a strategy for sustainable development, reduction of ecological footprints, encouraging responsible consumption (and production), and particularly on the efforts to tackle climate change that have been pursued in Portugal, in the European Union, and to a certain extent all around the world, prompted by the United Nations [see, among others, the Programa Nacional para as Alterações Climáticas (National Program for Climate Change) 2020-2030 (PNAC 2020-2030), Agenda 2030-The EU Strategy on Adaptation to Climate Change (EU-SACC), the United Nations Framework Convention on Climate Change (UNFCC) and COP24 (2018)]. Underlying this conjecture is

the idea that these policies promote changes in both the pattern and the composition of household consumption, namely by the increase in the demand for good health, for healthy and organic food, or for activities which promote active ageing.

In the last three decades, Portugal has undergone a notable evolution in its energy policy and carbon dioxide emissions, with consumption increasing and its carbon intensity decreasing. Together, the limitation on GHG emissions for all sectors of the economy, the increase in the integration of natural gas in the 1990s, the strategic option chosen in favor of renewable energy sources (in 2017, 54.1% of the total electricity produced in Portugal was obtained through by means of renewable sources), the stimulus towards energy efficiency, the contribution of the land use, land-use change and forestry sectors (LULUCF, hereafter) and the European Emissions Trading System (ETS), help explain Portugal's reduced carbon footprint since 2002. Portugal has followed up these positive results by establishing an ambitious program whitin the European Union and the Paris agreement to reduce emissions by 40% by 2030 compared to 1990 levels. Recently, the Portuguese government even made a commitment to achieve carbon neutrality by 2050 (National Roadmap for Carbon Neutrality).

The rest of the paper is structured as follows: section 2 presents the data with a brief classification of the time pattern of variables and section 3 summarizes the methodological framework of the study. Section 4 gives an analysis of stationarity and cointegration, with the results shown and discussed in section 5. Finally, section 6 provides conclusions to the paper.

2. Data: Sources and Description

2.1 Data Sources

In this paper, we use annual data for private consumption of non-durables, disposable income, household wealth series, and CO_2 emissions from fossil-fuel consumption in Portugal from 1980 to 2014. The economic variables were compiled by Banco de Portugal while CO_2 emissions were compiled from the Carbon-Dioxide Information Analysis Centre [see Le Quére et al. (2015) and Boden et al. (2016)].

The choice of consumption of non-durable goods as an endogenous variable is justified by the option of the life cycle-permanent income hypothesis for empirical work, in which the consumption of durable goods is used as a proxy for implicit consumption.

The literature on estimating the consumption function suggests the use of net wages as a determinant variable for the temporary component of adjustment of private consumption [see, for example, Lettau and Ludvigson (2003)]. However, data on net income from taxes are not available so we will use disposable income as a proxy [see, for example, Castro (2007) or Sousa (2010)].

The household wealth series includes financial assets and liabilities and also non-mortgage housing assets. In our study we take into account not only total net wealth but also break it down into net financial assets, i.e. net financial assets of financial liabilities and the net housing stock from mortgage loans for purchasing a house. All economic variables are measured in millions of euros.

Finally, aggregate CO_2 emissions are defined as a sum of four global CO_2 emission components: CO_2 emissions from burning solid, liquid, and gas fossil fuels and from cement production. The data do not consider emissions from gas flaring or land use, nor from land-use change or forestry. All variables are measured in millions of metric tons of carbon per year (mt hereafter) and were converted into units of carbon dioxide (CO_2) by multiplying the original data by 3.664, the ratio of the two atomic weights.

2.2 Description of the Data

Summary information is presented in Tables 1 and 2.

[Insert table 1 and Figure 1 around here]

Private consumption expenditure accounts for about 64% of aggregate national expenditure, which varies little over the sample period: the lowest recorded value is 60.3% and the highest is 66.3%. Expenditure on consumption of non-durable goods accounted for 93% of the total volume of private consumption expenditure in Portugal, and this indicator is quite stable over the sample period (the variation coefficient equals 0.3%). Portuguese consumption expenses for non-durable goods increased consistently over the sample period from EUR 4,616 million in 1980 to EUR 105,697 million in 2014, which corresponds to an average annual growth rate of 9.65%. It reached its peak of EUR

107,164 million in 2008. With the financial and the public debt crisis, the consumption of non-durable goods underwent an accumulated drop of EUR 1,468 million between 2010 and 2014, an accumulated loss of 1.36%.

The development of disposable income was similar to the consumption time pattern for non-durable goods. Between 1980 and 2014, Portuguese disposable income rose from EUR 6,650 million to EUR 120,065 million, which is an average annual growth rate of 8.88%, reaching a peak of EUR 129,750 million in 2010. The financial and public debt crisis caused disposable Portuguese income to fall by EUR 9,684 million between 2010 and 2014, an accumulated loss of 7.46%. On average, 87% of disposable income was used to purchase non-durable goods and services. However, over the sample period, this indicator demonstrated a steadily rising trend, from 68% in 1980 to 88% in 2014.

Net total wealth increased steadily after 1980, from EUR 26,010 million to EUR 550,511 million in 2010, the year it reached its peak. Over the next 2 years, total net wealth declined significantly, losing more than 8% in accumulated terms by 2012, and then recovered slightly to EUR 527,862 million in 2014. On average, total net wealth represents approximately 553.6% of consumption of durable goods, but this indicator declined consistently from 563.5% of consumption of non-durable goods in 1980 to 499.4% in 2014.

This pattern was largely due to financial assets and reflects a major structural change in the composition of household wealth in Portugal [Castro (2007)]. With the exception of 2012, net financial wealth grew not only steadily, but faster than total net wealth. Consequently, the ratio of net financial wealth to net total wealth increased from 26.5% in 1980 to 65.1% in 2014. In turn, net housing wealth also increased gradually until the end of the 1990s, though at a slower rate than total net wealth. Between 2009 and 2014, non-mortgage housing household assets decreased sharply, falling to 1998 levels, an accumulated loss of EUR 34,231 million (15.7%) over this period.

The proportion of net aggregate wealth in disposable income rose from an average of 406% in the 1980s to 431% in the last decade of the sample. Nonetheless, the two components of net wealth followed a different time path. Indeed, financial assets accounted for about 117% of disposable income (and 168% of consumption) in the 1980s, rising to 268% of disposable income (and 318% of consumption) in the last decade of the

sample. In contrast, housing wealth reduced its share of disposable income from 290% (and consumption of 418%) in the 1980s to 163% (with consumption dropping to 194%) in the period between 2005 and 2014.

Since 1980, total CO_2 emissions from fossil fuel combustion and cement production grew exponentially at an average annual rate of 1.52% to reach around 45,016 million mt in 2014. In this year, total CO_2 emissions from Portugal accounted for 1.36% of the total European Union emissions, and only 0.13% of global CO_2 emissions. During this period, the use of petroleum and its derivatives became the dominant source of emissions, contributing to around 62% of total emissions on average. This trend largely reflects the evolution of the Portuguese economy, which has been characterized by strong growth associated with an increase in energy demand and mobility.

However, our sample period is also characterized by a structural change that would significantly modify the emission time path. Indeed, in 2002 the annual flow of CO_2 emissions from fossil fuels peaked at 66,736 million mt, stabilizing at an average value of roughly 64 million metric tons by 2005. In addition, by 2002 total CO_2 emissions were 1,578 times higher than the emissions of the reference year (1990), well above the country's commitment under the Kyoto Protocol. In subsequent years, Portugal undertook a thorough and consistent decarbonization of its economy, bringing about a cumulative reduction of 21.72 billion mt (about 32.5%) in 2014 compared to the 2002 peak.

3. Methodology

Our methodology is based on the LC-PIH, according to which consumption decisions are determined through an intertemporal optimization process by a representative and forward-looking consumer, whose future income is uncertain [see, among others, Friedman (1957), Ando and Modigliani (1963) or Hall (1978)]. In general terms, the essence of the LC-PIH consists of a theory in which saving is considered as future consumption rather than mere hoarding. That is, the instantaneous decision to distribute income between consumption and saving is determined by both the intertemporal preferences between current and future consumption and the information about future consumption prospects. The LC-PIH proposes a consumption function where the determinant is the present value of the future flow of income, which in turn has an

instantaneous dimension (hence temporary and associated with current wage income) and an intertemporal dimension associated with permanent income (the latter often being referred to as wealth).

In a similar vein, following Michell and Rotillon (1995), Finkelstein at al. (2013), and many others, the state dependence of the utility function from emissions would lead the representative consumer to smooth his consumption path to increase consumption in periods when marginal utility is high and decrease consumption in periods when marginal utility is low. Accordingly, the consumption function which is consistent with the LC-PIH including CO_2 emissions may have the following functional relationship to the aggregate version of net wealth:

Model 1 $$c_t = \alpha + \beta_y y_t + \beta_w w_t + \beta_{co2} co2_t + u_t \quad (1)$$

and the version with the two main components of net wealth:

Model 2 $$c_t = \alpha + \beta_y y_t + \beta_{wf} wf_t + \beta_{wh} wh_t + \beta_{co2} co2_t + u_t \quad (2)$$

where c_t is non-durable private consumption, y_t is aggregate labor income, w_t is total net wealth, wf_t is net financial wealth, wh_t is housing wealth, $co2_t$ is CO_2 emissions from the combustion of fossil fuel and from cement production, and u_t is $I(0)$. All variables are expressed in logarithms, so the parameters β_k with $k = y, w, wf, wh, co2$ stand for the elasticities of private consumption of non-durable goods to aggregate labor income, total net wealth, net financial wealth, net housing financial, and CO_2 emissions, respectively.

For both equations, consistent estimates can be obtained using the ordinary least squares (OLS) method if there is a cointegration relationship between private consumption and the exogenous variables stated [see Phillips and Durlauf (1986)].

4. Preliminary Data Analysis: Unit Roots and Cointegration

We began the empirical work by performing Augmented Dickey-Fuller (ADF, hereafter) tests on the null hypothesis of a unit root in all variables. We used the Schwarz Bayesian information criterion (BIC, hereafter) to determine the number of lags to include in the regressions, and we considered the three usual possibilities for the deterministic component.

Table 2 reports the results of the ADF test for the variables in logarithms and in first differences of logarithms. In logarithms, the t-adf statistics are all lower in absolute value than the critical values for a 5% significance level, and thus the unit root hypothesis cannot be rejected. In turn, for the first differences of logarithms, all the critical values are higher in absolute value than the critical value of 5%, such that the null unit root hypothesis in the variables' growth rates can be rejected. We take this evidence as an indication that the series on first differences are stationary, which is in keeping with the macroeconomic literature involving private consumption of non-durable goods, disposable income, wealth, and CO_2 emissions (see, among others, Belbute and Pereira (2015 and 2017)).

[Insert table 2 around here]

The next step consists of testing the existence of a long-run relationship between the private consumption of non-durable goods and services and the exogenous variables in equations (1) and (2). We use two strategies. The first involves using two residual-based cointegration tests ; the Shin (1994) test, in which the null hypothesis of cointegration is tested and the augmented Engle and Granger test (AEG) proposed by Engle and Granger (1987), in which the null hypothesis of a unit root in the residuals of the cointegrating equation is tested. In both tests we use the residuals of the best specifications for the consumption function in both models. In the Shin (1994) test, the Bartlett window was used to compute the consistent estimator of long-run variance, as suggested by Newey and West (1987). The AEG test is actually an ADF test that uses critical values adjusted to the number of variables in the cointegrating equation. In particular, the Charemza (1990) table was used for the version with no constant and Mackinnon (1991) table for the versions with constant, and constant and trend to obtain the critical values.

Tables 3 and 4 show the results of the Shin (1994) test and the ADF test, respectively, for the two specifications of the consumption function. Both allow the conclusion that there is a long-run relationship for the specification with aggregate and disaggregated net wealth.

[Insert table 3 and 4 around here]

However, when the cointegrating equation has more than two variables, the Engle and Granger (1987) procedure does not prevent the possible existence of more than one cointegration relationship. Consequently, we may be estimating a linear combination of the various possible cointegration vectors. For this reason, we use a second strategy proposed by Johansen (1988), which uses a vector autoregression (VAR, hereafter) and a maximum likelihood estimator approach to estimate all possible cointegrating vectors and thus test hypotheses on these vectors' coefficients. The optimal structure of the lags of the VAR models is chosen using the lowest value of the BIC indicator, with critical values provided by Osterwald-Lenum (1992). Furthermore, the use of the two strategies is also justified as the Engle and Granger (1987) approach suffers from a bias which, for small samples and with annual data, favors rejecting cointegration when it exists, whereas the Johansen procedure (1988) tends to suggest the existence of cointegration when it does not exist.

Table 5 presents the results of the two tests for the aggregate and disaggregated models of wealth. For both specifications, the trace statistic for $r = 0$ (157.28 and 92.68, respectively) exceeds the critical value (53.12 and 76.07, respectively), so the null hypothesis of no-cointegration must be rejected. In contrast, for $r \leq 1$, the trace statistic (30.26 and 52.00, respectively) is lower than the critical value (34.91 and 53.12, respectively) and therefore the null hypothesis is not rejected. We can therefore conclude that the four variables are cointegrated and that there is only one cointegrating vector. The λ-Max test confirms these two results.

[Insert table 5 around here]

To sum up, it can be considered that there is sufficient evidence to suggest a long-run relationship between consumption of non-durable goods, disposable income, total level of wealth, and CO_2 emissions.

5. Empirical Results and Discussion

In this section we use the Stock and Watson (1993) procedure —also known as dynamic ordinary least squares, or DOLS for short —to estimate the two following models of the consumption function for Portugal;

Model 1 $$c_t = \alpha + \beta_y y_t + \beta_w w_t + \beta_{co2} co2_t + \sum_{i=-k}^{k} \delta_i \Delta x_{t+i} + \varepsilon_t \quad (3)$$

Model 2 $$c_t = \alpha + \beta_y y_t + \beta_{wf} wf_t + \beta_{wh} wh_t + \beta_{co2} co2_t + \sum_{i=-k}^{k} \delta_i \Delta z_{t+1} + \mu_t \quad (4)$$

where $x_t = y_t, w_t \; e \; co2_t$ and $z_t = y_t, wf_t \; wh_t \; e \; co2_t$. As before, lowercase letters correspond to the logarithms of private consumption of non-durable goods (c), net total wealth (w), net financial wealth (wf), net housing wealth (wh), and CO_2 emissions from burning fossil fuels and the production of cement ($CO2$). The best specifications for lags and leads for both regressions were chosen using BIC (these results are available from the author upon request). The parameters of both regressions correspond to the elasticities in relation to disposable income, total net wealth, net financial wealth, housing wealth and CO_2 emissions. Table 6 presents the results of the consumption function estimates in the two versions, as well as the specification and residual diagnosis.

[Insert Table 6 around here]

5.1 Diagnostics Analysis

The first diagnostic test consists of the RESET specification test (for the square of the estimated value of consumption) which suggests that the functional form is appropriate. For both models, we tested the null hypothesis that including CO_2 emissions in the consumption equation is irrelevant to its respective non-restricted version, and for both models the F-test suggests rejection of the null hypothesis at a significance level of 1%. Therefore, we conclude that the constraint $\hat{\beta}_{CO2} = 0$ is not supported by the data.

The diagnosis of residuals starts with a Jarque-Bera (1980) test, which indicates that the residuals exhibit normality. The White (1980) and Breusch-Pagan (1979) general heteroscedasticity LM tests suggest that residuals are homoscedastic. The Engle (1982) LM-ARCH test was performed for 1, 5 and 10 lags and is not significant, which strongly

suggests the absence of an ARCH effect in both models' residuals. It can confidently be concluded that the variance is time-invariant. The Breusch (1978)/Godfrey (1978) serial correlation LM test suggests no evidence of serial correlation of any lag order up to 10 for model 1, while for the disaggregated model, the absence of autocorrelation is only assured for a lag order up to 2. The Q_k portmanteau test values for the 1st, 5th, and the 12th order serial correlation in $\hat{u}_t$ are high and lie within the rejection band for model 1, while for model 2 we cannot reject the null hypothesis of serial correlation for the 5th and 12th order. Finally, the Q_k^2 portmanteau test values based on $\hat{u}_t^2$ for the 1st, 5th, and the 12th order for the conditional mean are high, confirming that the square standardized residuals are uncorrelated for the two models.

5.2 Stability of the Parameters

For analysis of the stability of the parameters over the sample period we (re)estimated both models using recursive least squares (RLS) and, additionally, we used the cumulative sum control chart (CUSUM) and the cumulative sum control chart of squares (CUSUMSQ) tests.

[Insert figures 2 and 3 around here]

The RLS procedure suggests that the time pattern of the estimated parameters was not affected by the structural changes in the composition of household wealth after 2000 for Model 1 (see figure 2). However, in the disaggregated wealth model, the parameters of disposable income and financial wealth show slight variability during the sample period, while the estimated coefficients of housing wealth and CO_2 emissions are much more stable. In addition, in the CUSUM and CUSUMSQ tests [see figure 4], the accumulated sums never cross the bounds of the 5% confidence level, so the null hypothesis of the stability of the parameters is not rejected. We confidently conclude that the estimated coefficients are stable for both models over the sample period.

[Insert figure 4 around here]

5.3 Estimates of the Elasticity and the Marginal Propensity to Consume

Columns 1 and 4 of table 6 provide the estimates from DOLS estimation for the elasticities of consumption to income, wealth, and CO_2, while columns 3 and 6 report the marginal propensities to consume implicit in the corresponding elasticity. The marginal propensities to consume out of each exogenous variable in each model are computed using the sample averages of the ratios of non-durable consumption to disposable income, non-durable consumption to wealth, and non-durable consumption to CO_2 emissions.

Upon examining the results in greater detail, we find that all estimates are statistically significant at 1% level. The estimated coefficients of the economic variables (disposable income, net aggregate wealth, net financial wealth and non-mortgage housing wealth) have the correct signs in both models. The sign of the CO_2 emissions parameter is negative and will be given detailed analysis later.

The estimated value of long-run elasticity of non-durables consumption to disposable income in Model 1 indicates that an increase of 1% in disposable income will cause an increase of 0.588% in consumption of non-durable goods, and the implied value for the marginal propensity to consume out of disposable income is EUR 0.45. For Model 2 the elasticity of consumption to disposable income is also high (0.561). This estimate is not statistically different from that obtained for Model 1 since we could not reject the null hypothesis of equality between the elasticities in the two models at a 5% significance level. Moreover, the implied marginal propensity to consume out of disposable income in Model 2 (EUR 0.43) is similar to that obtained in Model 1.

The estimates of elasticity and marginal propensity to consume out of disposable income in Model 1 are not different from the values obtained by Castro (2007) (0.64 and 0.48, respectively). In particular, the elasticity of consumption to disposable income lies within the 95% confidence interval in our result [0.439, 0.737]. However, for Model 2, the values obtained by Castro (2007) for elasticity of consumption to disposable income and the implied marginal propensity to consume (0.81 and 0.61, respectively) are substantially higher than ours, and clearly lie outside the 95% confidence interval. There may be two possible explanations for this discrepancy. Firstly, the datasets used by the two studies have different time-frequencies and also cover different time horizons, with the final year of our study being more recent. Secondly, since 2008 the two major components of

wealth (financial assets and liabilities wealth and non-mortgage housing wealth) have been substantially revised, incorporating new sources of information and significant methodological changes [for more detail, see Cardoso et al. (2008)].

The elasticity of consumption to aggregate net wealth is also high (0.575) and indicates that a 1.000% change in total net wealth causes a change of 0.575% in private consumption of non-durable goods. The implicit marginal propensity to consume out of the aggregate net wealth is EUR 0.10, suggesting that a one-euro increase in net wealth will increase household consumption by EUR 0.10. Moreover, the marginal propensity to consume out of total net wealth is very close to the convex combination of the marginal propensities to consume out of the two components of net total wealth; net financial assets and liabilities wealth (EUR 0.16) and non-mortgage housing wealth (EURO 0.06) .It should also be noted the sum of the elasticity of consumption to the two net wealth components (0.543) is not statistically different from the value obtained for elasticity of consumption to aggregate wealth (Model 1), with a simple t-test at a significance level of 1%.

Furthermore, a 1% increase in household financial assets and liabilities wealth causes a much higher increase in household consumption (0.37%) than that caused by the same stimulus in housing wealth (0.17%). This result is in line with most of the empirical literature, which suggests that financial wealth and housing wealth have statistically different impacts on household consumption [see, for example, Poterba and Samwick (1995), Sousa (2010), or Case et al. (2005)]. However, our result contrasts with that obtained by Castro (2007), where the difference between the two effects is much more modest (0.17 and 0.14, respectively for financial and housing wealth). It should also be noted that a t-test on two independent samples at a significance level of 1% shows that the sum of elasticities of consumption to the two net wealth components (0.543) is not statistically different from the value obtained for elasticity of consumption to aggregate wealth (Model 1).

Let us now focus our attention on the coefficient that measures the effect of emissions on household consumption β_{CO2}. For both models, the elasticity of consumption to CO_2 emissions is highly significant, negative, and equal to -0.121 and -0.148 for the model with aggregate and disaggregated wealth, respectively. It should also be noted that it was not

possible to reject the null hypothesis of equality between the two coefficients for a simple t-test of two independent samples, for a 5% significance level. Therefore, whenever emissions increase (decrease) by 1%, household consumption can be expected to decrease (increase) by 0.121% according to Model 1 or 0.148% according to Model 2.

Using the sample average of the carbon intensity of consumption, our findings suggest that an increase (decrease) of one ton of CO_2 will decrease (increase) household non-durable consumption by EUR 0.14 according to Model 1 or EUR 0.17 according to Model 2. The fact that the elasticity of consumption of non-durable goods with respect to CO_2 emissions is negative suggests that the distaste effect hypothesis proposed by Michell and Rotillon (1995) is supported by the data in Portugal. That is, the marginal utility of consumption and consumption tend to increase (decrease) when CO_2 emissions decrease (increase).

6. Conclusions and Implications

In this paper we present evidence of the effect of CO_2 emissions from burning fossil fuels and cement production on Portuguese private consumption from 1980 to 2014. Using a DOLS procedure, our results point overwhelmingly to the conclusion that CO_2 emissions have a negative effect on marginal consumption utility, such that reducing emissions leads to increased demand in consumption for good health.

More specifically, all the estimated parameters are highly significant and consistent with the relevant conceptual requirements. In the aggregate wealth model, our results suggest that an increase of EUR 1.00 in disposable income will cause an increase in consumption of EUR 0.45, while the same wealth stimulus causes an increase in consumption of EUR 0.10. In the disaggregated wealth model, the results for elasticity and marginal propensity to consume indicate that consumption is more sensitive to changes in financial wealth than housing wealth for the same causal disturbance.

These results are in keeping with those obtained by Castro (2007) regarding the effect of disposable income and aggregate wealth on consumption, but they are in contrast when the two components of wealth are considered. This dissonance may result not only from the methodological changes that occurred in constructing the wealth series in Portugal in

this period, but also from changes in the national financial system, which reinforces the conviction that the size of the disaggregated effect of wealth on household consumption may be an eminently empirical issue. Our findings suggest that there is a substitution relationship between CO_2 emissions and household consumption expenditure (a distaste effect). Specifically, a reduction in emissions will cause an increase in consumption of EUR 0.14 in Model 1 and EUR 0.17 in Model 2. This result is also in line with negative state dependence, according to which improvements in health are complementary to the increase in consumption for good health. Accordingly, reducing pollution will improve health conditions, which affects permanent income and stimulates consumption for good health—for example, increasing one's practice of regular physical exercise, healthy eating or leisure activities, particularly related to active aging.

These results have two important implications. Firstly, our findings have implications for the existence of endogenous (limit) cycles, which is also dependent on the branch of the environmental Kuznets curve which the economy is on. Indeed, the tendency for a cyclical behavior of household consumption under the distaste effect arises only when the economy lies on the downward-sloping branch of the environmental Kuznets curve [see Bosi and Desmarchelier (2018]. Consider an exogenous decrease in pollution. Forward-looking households perceive the decrease in pollution as both an improvement in their health conditions and an increase in their permanent income. Under the distaste effect, households will increase their consumption for good health, while decreasing savings. If the economy is on the downward-sloping branch of the EKC, the fall in capital stock induced by the decrease in savings causes pollution to rise in the next period, giving rise to a deterministic cycle.

Furthermore, the existence of deterministic cycles also depends on savings behavior during the cycle. In particular, in an intertemporarily dependent preferences framework, saving may be determined by economic growth (not the other way around), and thus be complementary to consumption [see Carroll (2000)]. In this context, forward-looking households will tend to smooth their consumption for the same reasons that households operating under the constant relative risk aversion utility function' smooth their level of consumption, regardless of the dominant effect (distaste or compensation). Indeed, under the distaste effect, reducing pollution will increase consumption as well as savings

due to the presence of a habit-formation process in the utility function. In a richer, healthier and cleaner economy, the rise in capital stock induced by the increase in savings reduces pollution emissions in the next period, so that the deterministic cycle vanishes.

Secondly, our results on the relationship between CO_2 emissions and aggregate household consumption suggest that it is possible to reconcile the decarbonization of the economy with the increase in household consumption. Certainly, the environmental public policies that have been implemented in the last 30 years to promote sustainable and responsible consumption or to tackle climate change have not only affected the level of aggregate consumption. Indeed, such a result would not have been possible without a substantial change in the composition of household consumption. Our study does not allow an assessment of whether or not the changes in both the pattern and the composition of the Portuguese household consumption are in line with the goals of responsible consumption (see the 2030 United Nations Agenda for Sustainable Development (UNASD)). However, recent studies in Portugal (generally inquiry studies) seem to suggest that, despite the financial crisis that has plagued the country since 2012, in general, traditional consumer profiles are giving way to new consumer profiles which are much more anchored in environmental values or reducing waste, especially food waste. In addition, these studies also point to increased environmental awareness, as well as the value of healthy lifestyles, which translates into an increase in leisure activities related to the environment and nature [see Schmidt et al. (2016)].

Our work suggests three avenues for future research. Firstly, it will be important to carry out further analysis on the effects of consumption on marginal utility using microeconometric data on household consumption expenditures rather than aggregate consumption. Secondly, given that the branch of the curve on which the economy lies is a determining factor in cyclical behavior of consumption, the estimation of the environmental Kuznets curve using recent data is clearly a natural extension of this paper. It should be noted that the existing literature on the EKC in Portugal only covers the upward-slope period of the EKC. However, recent data indicates that from 1999 onwards, the complementarity that had historically characterized the relationship between CO_2 emissions and capital stock in the Portuguese economy was reversed. This suggests that currently the country is beyond the turning point of the curve, and thus already lies on

the downward-slope branch of the EKC. Finally, the third line of future research consists of measuring the (short and long) inertial properties of aggregate consumption expenditure, since this property is of crucial importance for the smoothing process of household consumption.

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Table 1 – Household non-durable consumption, disposable income, total net wealth and CO2 emissions

	Disposable Income	Non-Durable Consumption	Total Net Wealth	Shares (%)		CO2 emissions (10^6 Tons)	Carbon Intensity[1]
				Net Finantial Wealth	Non-Mortage Housing Wealth		
	10^6 Euros						

1980-1985	12,254.03	8,412.30	49,943.93	27.29	72.71	28.33	3.80
1986-1990	31,138.38	21,998.52	127,447.67	31.04	68.96	35.67	1.66
1991-1995	57,969.16	43,981.90	251,332.27	37.39	62.61	47.71	1.10
1996-2000	79,156.98	61,760.26	348,464.25	48.42	51.58	57.68	0.93
2001-2005	103,168.50	82,926.64	444,950.14	55.97	44.03	63.79	0.77
2006-2010	124,121.80	103,042.34	536,522.48	60.59	39.41	55.54	0.54
2011-2014	121,452.53	105,214.23	519,635.47	65.29	34.71	45.99	0.44
Overall sample							
μ	72,488.81	58,282.26	312,051.13	45.49	54.51	47.31	1.42
se_μ	7,016.99	6,073.32	30,534.06	2.36	2.36	2.12	0.21
CV	0.10	0.10	0.10	0.05	0.04	0.04	0.15

Notes:
μ , se_μ and CV stand for the mean, standard error and coefficient of variation respectively.
[1] Tons of CO_2 emissions per euro spend in non-durable consumption goods and services

Figure 1 Economic and CO2 variables

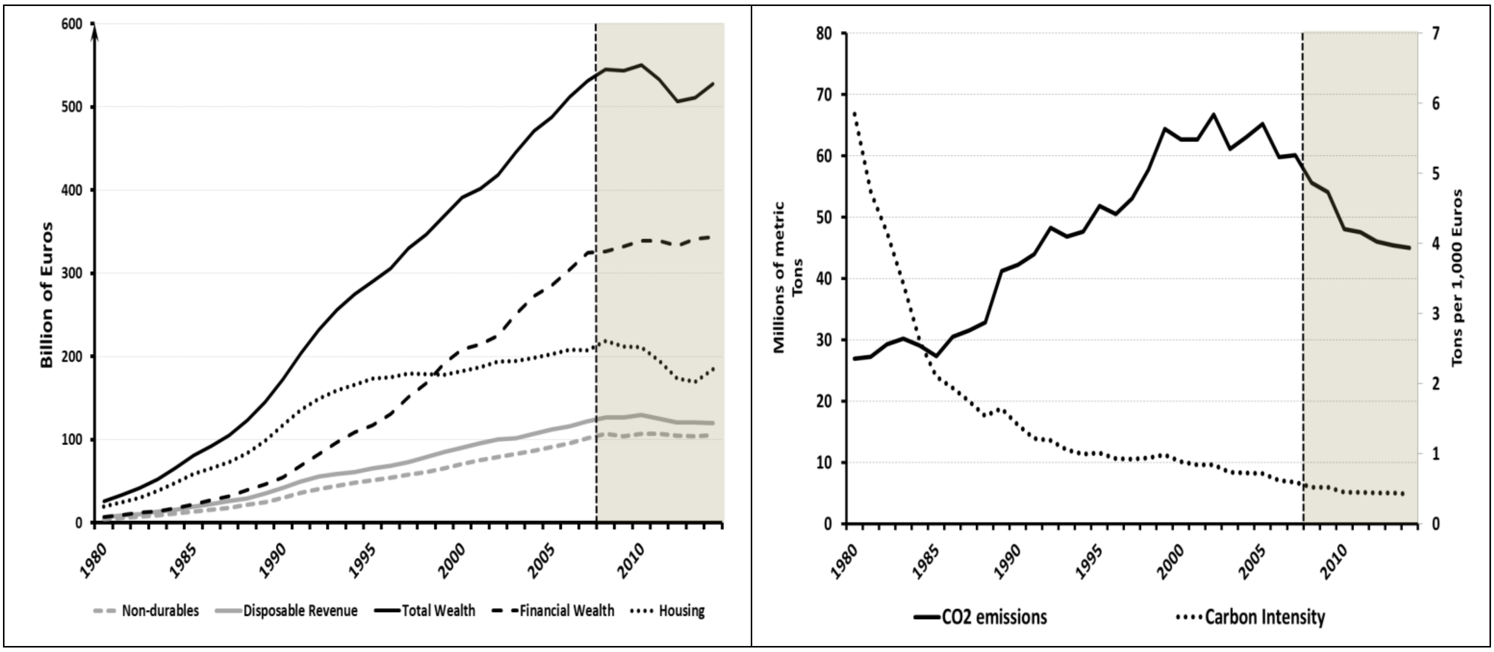


Table 2 - ADF unit roots tests

Variables	Deterministic Component	Lags	t-Stat ADF	BIC
Logs				
Consumption of non durable goods	Constant and trend	0	-3.041	-147.153
Disposable income	Constant and trend	1	-2.101	-142.136
Net total wealth	None	1	0.516	-140.927
Net finantial wealth	Constant and trend	0	-1.094	-132.537
Non finantial wealth (housing)	None	1	0.652	-108.157
Percapita CO2 emissions	Constant	0	-1.870	-83.047
First Differences (Logs)				
Consumption of non durable goods	Constant and trend	1	-3.564 **	-137.999
Disposable income	None	0	-2.283 **	-141.462
Net total wealth	None	0	-2.507 **	-144.142
Net finantial wealth	Constant and trend	1	-5.700 ***	-128.928
Non finantial wealth (housing)	None	0	-2.105 **	-111.204
Percapita CO2 emissions	Constant and trend	0	-6.124 ***	-79.558

Critical values for a 1%, 5% and 10% significance ADF unit root test, respectively : None: −2.62, −1.95, and −1.61; Constant: −3.58, −2.93, and −2.60; Constant and trend; −4.15, −3.50, and −3.18.

Note: *, ** and *** stand for 0.10<p, 0.01<p<0.05 and p<0.01, respectively.

Table 3 - Shin's Cointegration Test

Lags	C_μ	
	Model 1	**Model 2**
1	0.081	0.037
2	0.086	0.050
3	0.109	0.063
4	0.141	0.087
Critical value (5%)	0.159	

Table 4 – Augmented Engel and Granger Cointegration Tests

Deterministic Component	Lags	t-Stat ADF		BIC
Model 1				
None	0	-4.932	***	-164.356
Constant	0	-4.823	**	-161.137
Constant and trend	3	-4.930	**	-143.678
Model 2				
None	0	-6.293	***	-168.912
Constant	0	-6.150	***	-165.875
Constant and trend	0	-6.145	***	-163.795

Using Charemza (1990) for "None" and Mackinnon (1991) for "Constant" and "Constant and Trend" critical values.

Note: *, ** and *** stand for 0.10<p, 0.01<p<0.05 and p<0.01, respectively.

Table 5 – Johansen's Cointegration Tests

Eigenvalues	λ-Trace Test					λ-Max test				
	H_0	H_A	Statistic	Critical Value		H_0	H_A	Statistic	Critical Value	
Model 1 (Aggregate Wealth)										
0.976	r = 0	r ≥ 1	157.28	53.12	*	r = 0	r = 1	127.02	28.14	*
0.414	r ≤ 1	r = 2	30.26	34.91		r ≤ 1	r = 2	18.16	22.00	
0.255	r ≤ 2	r = 3	12.10	19.96		r ≤ 2	r = 3	10.03	15.67	
0.059	r ≤ 3	r = 4	2.07	9.24		r ≤ 3	r = 4	2.07	9.24	
Model 2 (Disaggregate Wealth)										
0.661	r = 0	r ≥ 1	92.68	76.07	*	r = 0	r = 1	35.68	34.40	*
0.531	r ≤ 1	r = 2	52.00	53.12		r ≤ 1	r = 2	24.95	28.14	
0.411	r ≤ 2	r = 3	32.04	34.91		r ≤ 2	r = 3	17.46	22.00	
0.251	r ≤ 3	r = 4	14.59	19.96		r ≤ 3	r = 4	9.55	15.67	
0.142	r ≤ 4	r = 5	5.04	9.24		r ≤ 4	r = 5	5.04	9.24	

Note: * stands for the rejection at the 95% critical values.

Table 6: Regression results and residuals diagnosis

Parameter	Model 1			Model 2		
	Elasticity		MPC	Elasticity		MPC
Contant (α)	-2.457	(0.215) ***		-1.273	(0.157) ***	
Disposable Income (β_{yd})	0.588	(0.076) ***	0.45	0.561	(0.071) ***	0.43
Net Wealth (β_{w})	0.575	(0.077) ***	0.10			
Net Financial Wealth (β_{wf})				0.369	(0.054) ***	0.16
Net Housing Wealth (β_{wh})				0.174	(0.018) ***	0.06
Co2 Emissions (β_{co2})	-0.121	(0.021) ***	-0.14	-0.148	(0.021) ***	-0.17
			Diagnosis Analysis			
Residual Sum of Squares (RSS)	0.002			0.001		
DW	2.011			2.007		
Log-Likelihood	87.635			94.003		
BIC	- 142.689			- 146.652		
RESET (F-test)	3.906	[0.067]		1.109	[0.313]	
F-Test (all coefficients)	35,166	[0.000]		176,189	[0.000]	
F[m,(T-k)] test for β_{co2}=0	29.963	[0.000]		27.111	[0.000]	
Jarque-Bera	2.967	[0.227]		0.360	[0.835]	
LM-White test	20.720	[0.294]		20.425	[0.672]	
LM-Breusch-Pagan test	4.402	[0.883]		7.622	[0.814]	
LM-ARCH (1)	1.386	[0.239]		1.948	[0.163]	
LM-ARCH (5)	2.149	[0.828]		4.736	[0.449]	
LM-ARCH (10)	8.534	[0.577]		7.772	[0.651]	
LM (2)	0.304	[0.858]		2.404	[0.301]	
LM (5)	9.154	[0.103]		21.639	[0.001]	
LM (10)	17.632	[0.062]		24.721	[0.006]	
Q_1	0.059	[0.965]		0.029	[0.864]	
Q_5	5.205	[0.391]		12.037	[0.034]	
Q_{12}	12.649	[0.395]		21.042	[0.051]	
Q^2_1	1.592	[0.207]		2.210	[0.137]	
Q^2_5	2.719	[0.743]		8.328	[0.139]	
Q^2_{12}	9.300	[0.677]		12.081	[0.439]	

Notes: Standard Errors in brackets and p-values in square brackets. m stands for the number of restrictions, T is the number of observations and k is the number of regressors in the unrestricted regression.
"MPC" stands for marginal propensity to consume.

Figure 2- Stability of Estimates of the coefficients using Recursive Least-Squares procedure (RLS): Model 1

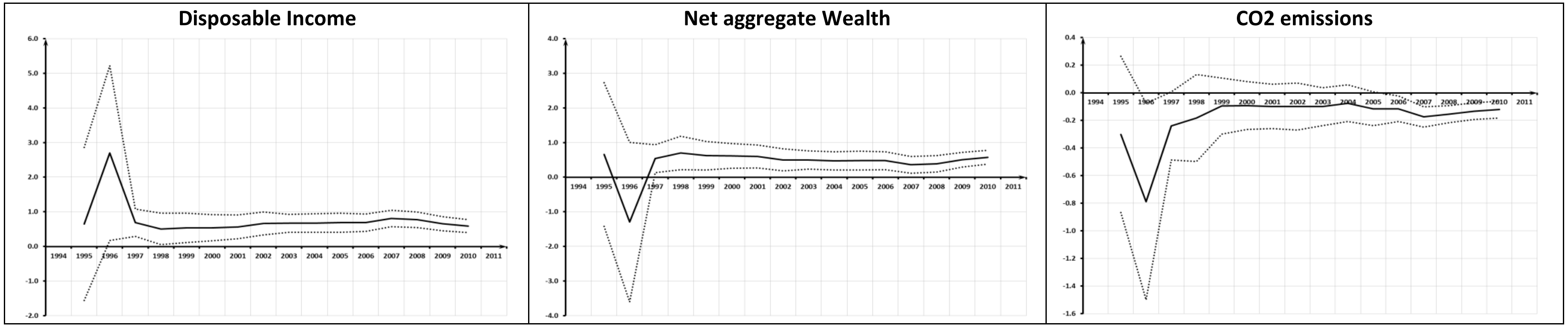
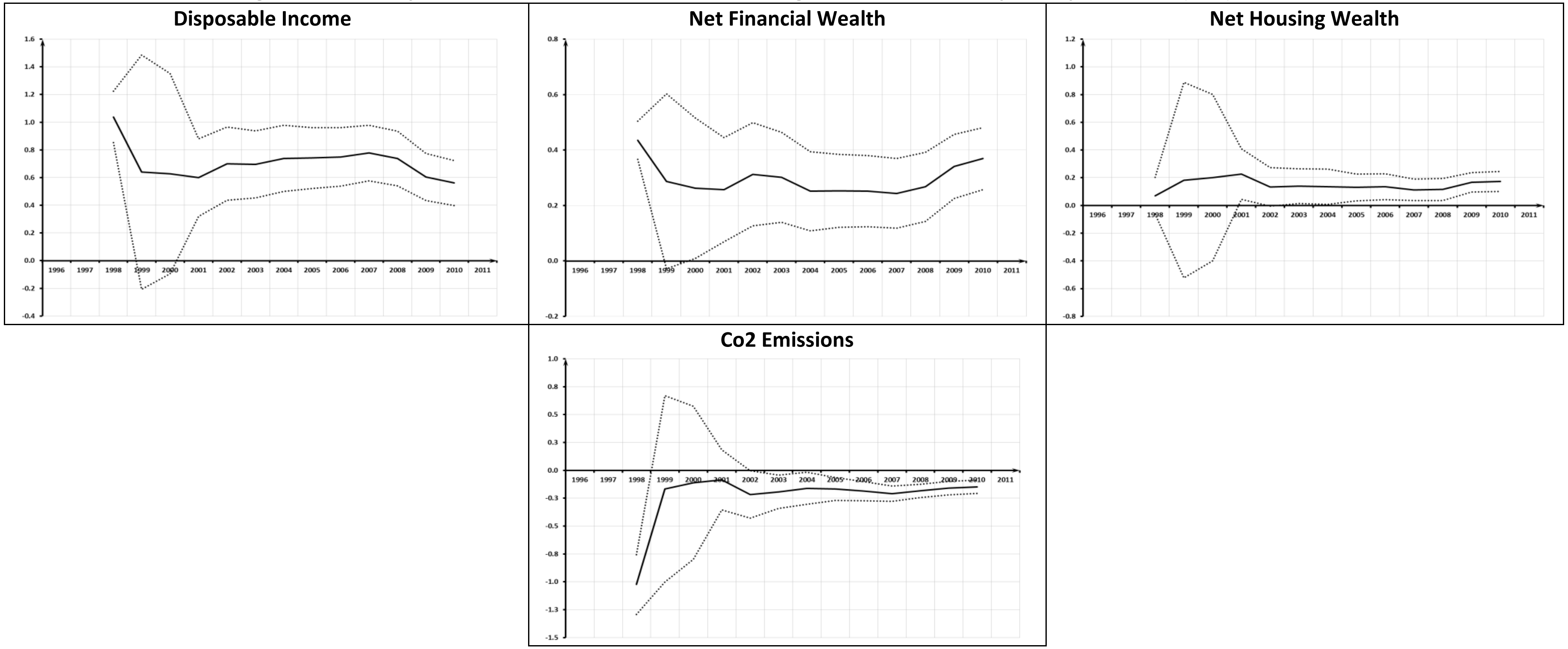


Figure 3- Stability of Estimates of the coefficients using Recursive Least-Squares procedure (RLS): Model 2



Notes: Black line stands for the recursive estimates of the coefficients over the sample period while dotted lines stands for the 95% confidence bandwidth

Figure 3 Stability analysis: CUSUM and CUSUMSQ tests