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**Consumption and  
Precautionary Saving:  
An Empirical Analysis under  
Both Financial and  
Environmental Risks**

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#### Summary

This paper studies the empirical relationship between consumption and saving under two different sources of uncertainty: financial risk and environmental risk. The analysis is carried out using time series data for six advanced economies in the period 1965-2007. The results support the theoretical conclusions that both financial risk alone and the interaction between financial and environmental risks affect consumption. Moreover, we suggest a solution to some shortcomings which concern the empirical analysis performed with one-argument utility functions. Finally, we provide new estimates of indexes of relative risk aversion and relative prudence, and relative preference of environmental quality.

**Keywords:** Consumption, Precautionary Saving, Financial Risk, Environmental Risk, Prudence, Relative Risk Aversion, Uncertainty

**JEL Classification:** D81, E21, Q50

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# Consumption and Precautionary Saving: An Empirical Analysis under Both Financial and Environmental Risks

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## Abstract

This paper studies the empirical relationship between consumption and saving under two different sources of uncertainty: financial risk and environmental risk. The analysis is carried out using time series data for six advanced economies in the period 1965-2007. The results support the theoretical conclusions that both financial risk alone and the interaction between financial and environmental risks affect consumption. Moreover, we suggest a solution to some shortcomings which concern the empirical analysis performed with one-argument utility functions. Finally, we provide new estimates of indexes of relative risk aversion and relative prudence, and relative preference of environmental quality.

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# 1 Introduction

Modern theory of consumption starts from the seminal papers by MODIGLIANI & BRUMBERG (1954) and FRIEDMAN (1957), who studied the life-cycle permanent income model. In this context, a positive saving is motivated by the fact that consumers rationally expect a declining path of labor income. Starting from HALL (1988), a huge body of papers investigate the permanent income hypothesis under rational expectations (see, among others, FLAVIN 1981, HALL & MISHKIN 1982 and ZELDES 1989). These models assume that the utility function is quadratic,<sup>1</sup> which corresponds to analyzing the so-called certainty equivalent case, meaning that agents make the same consumption decisions under certain or uncertain income. This literature finds that the permanent income hypothesis does not exactly capture the behavior of consumption.<sup>2</sup> A recent paper by DEJUAN ET AL. (2010) confirms this conclusion.<sup>3</sup>

Starting from LELAND (1968), a great deal of theoretical literature shows that, when we remove the assumption that the utility function is quadratic, income uncertainty affects consumption and saving decisions. In the certainty case optimal consumption is still determined by permanent income, but when financial risk is introduced and standard assumptions on the utility function are made, uncertainty generates an extra-saving, called ‘precautionary saving’.<sup>4</sup> In this case, consumption dynamics is affected by the variability of future income.

This theoretical result has been empirically analyzed in different papers which estimate a Euler condition either using data from household surveys (see, for instance, GUIZO ET AL., 1992; DYNAN, 1993; LUSARDI, 1998; GUARIGLIA & KIM, 2003), or using aggregate consumption data (e.g. HAHM, 1999; HAHM & STEIGERWALD, 1999; LYHAGEN, 2001; MENEGATTI, 2007 and 2010). In almost all cases, the empirical tests support the relevance of the precautionary saving assumption. However, most of the papers which use aggregate data (e.g. HAHM, 1999; HAHM & STEIGERWALD, 1999; MENEGATTI, 2007 and 2010), the effect of financial risk is clearly detected in reduced-form equations involving saving, rather than in structural-form equations computing optimal consumption growth under CRRA utility functions.<sup>5</sup>

A recent branch of literature has generalized the precautionary saving analysis to

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<sup>1</sup>This implies that the third derivate of the utility function is zero.

<sup>2</sup>In more detail, the empirical analysis suggests that the permanent income hypothesis fails in explaining the dynamics of consumption both for excess sensitivity (FLAVIN, 1981) and for excess smoothness (DEATON, 1992).

<sup>3</sup>However, different evidence which supports the permanent income hypothesis was found by DEJUAN ET AL. (2004).

<sup>4</sup>More specifically, precautionary saving is positive under the convexity of the marginal utility function (e.g. SANDMO 1970, DRÈZE & MODIGLIANI 1972, KIMBALL 1990 and MENEGATTI 2001).

<sup>5</sup>Different justifications for this result are provided in the literature and are related to potential excessive restrictions in the use of a specific class of utility functions, effects of agents impatience, lags in saving adjustment or consequences of subsequent changes in income risk.

the case where financial risk is flanked by a second non-financial and uninsurable risk called ‘background risk’, which is typically either environmental risk or health risk. In this field, COURBAGE AND REY (2007) and MENEGATTI (2009a) study precautionary saving considering some specific bivariate distributions for income and background risk. MENEGATTI (2009b) investigates the same problem for the general case in the presence of small risks. He introduces for the first time the concept of ‘two-source precautionary saving’, defined as the total variation in saving due to the joint influence of income risk and background risk. Finally, DENUIT ET AL. (2011) examine the case where those two risks are positively correlated.

The general conclusion of these contributions is that both income risk and background risk affect optimal consumption and saving, as does the interaction of the two. In particular, the possible presence of precautionary saving is determined by the size of the variance of the two risks, the sign and the size of the covariance between them and the signs of the third-order derivatives of the utility function.<sup>6</sup>

The first aim of our paper is to test the effects of different kinds of uncertainty on consumption choices. In particular, we study the ‘two-source precautionary saving’ motive in six advanced economies, namely Canada, France, Italy, Spain, the United Kingdom and the United States. The test is performed for the period 1965-2007 on time-series data, and is based on three elements: i) a measure of financial risk, along the lines suggested in previous empirical work; ii) a proxy for environmental risk; iii) a variable capturing the interaction between the financial and environmental risks.

Our approach is also new because it contributes to solving the shortcomings which affect the estimates of the precautionary saving effects reported in the previous empirical literature. In fact, a possible reason for failure in testing the effects of financial risk in equation computed optimal consumption growth rules is the omission of other relevant sources of uncertainty, such as environmental risk.

Furthermore, DYNAN (1993) proposed an empirical measure of the strength of the precautionary motive, providing an estimate of the index of relative prudence in a one-risk framework. Dynan, however, found that ‘[...] *the estimated strength of the precautionary motive appears to be simply too small. [...] We can overwhelmingly reject the hypothesis that the coefficient of relative prudence is in the range implied by a reasonably parameterized CRRA utility function*’ [DYNAN (1993), p. 1109]. Dynan also showed that the introduction of liquidity constraints or consumers self-selection is not sufficient to explain these results.<sup>7</sup> In this field the aim of our paper is to provide new estimates of the size

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<sup>6</sup>Note that the contributions mentioned above consider a two-argument utility function, such as  $U(C_t, E_t)$ , where  $C_t$  is consumption and  $E_t$  represents either the quality of environment or the health status at time  $t$ . As a consequence, four different third-order derivatives of  $U(C_t, E_t)$  are involved:  $\partial^3 U / \partial c^3$ ,  $\partial^3 U / \partial c^2 \partial e$ ,  $\partial^3 U / \partial c \partial e^2$  and  $\partial^3 U / \partial e^3$ . As it will be shown in the model described in Section 2, the first three of these partial derivatives are relevant for optimal consumption growth.

<sup>7</sup>CARROLL (1992) justifies Dynan’s low estimated values of the parameters in two ways. First, the effects of parameter heterogeneity between different demographic groups in the population. Second, the

of relative prudence and of relative risk aversion, which are determined by taking into account the effects of environmental risk, together with the effects of financial risk.

The theoretical analysis of a two-risk framework clearly indicates the relevant role in determining agent's optimal behavior of so-called 'cross-prudence'. This is related to the effects of uncertainty in one argument of the utility function (such as environmental quality) for the optimum level of the other argument (consumption) along the lines suggested by EECKHOUDT ET AL. (2007), COURBAGE AND REY (2007), MENEGATTI (2009a,b) and GOLLIER (2010).<sup>8</sup> The third aim of our paper is to propose the first empirical analysis of consumption in a two-risk framework, as well as to examine the relevance of direct and indirect effects of environmental uncertainty on it.

The paper is organized as follows. In Section 2 the theoretical model is presented and the equations to be estimated are derived. Section 3 describes the dataset. Section 4 discusses empirical results. In Section 5 estimates of different indexes of risk aversion and prudence are illustrated. Finally, Section 6 concludes.

## 2 The Theoretical Model and the Estimated Equations

We consider a multiperiod framework where consumer's preferences in period  $t$  are described by the two-argument utility function  $U(C_t, E_t)$  where  $C_t$  is consumption and  $E_t$  is the environmental quality level, which is given for the agent. We assume that  $U(C_t, E_t)$  is increasing and concave with regard to each argument. Letting  $U_c(C_t, E_t) = \partial U / \partial c$ ,  $U_e(C_t, E_t) = \partial U / \partial e$ ,  $U_{cc}(C_t, E_t) = \partial^2 U / \partial c^2$ ,  $U_{ce}(C_t, E_t) = \partial^2 U / \partial c \partial e$  and so on, our assumptions imply  $U_c(C_t, E_t) > 0$ ,  $U_e(C_t, E_t) > 0$ ,  $U_{cc}(C_t, E_t) < 0$  and  $U_{ee}(C_t, E_t) < 0$ . These last two conditions imply aversion toward risk on consumption and aversion toward risk on the environmental quality.

Given such preferences and extending the univariate framework of CARROLL (1992, 1997), we consider a bivariate intertemporal consumption model:

$$\max_{C_t} \mathbb{E} \sum_{t=0}^T \beta^t U(C_t, E_t) \quad (1)$$

subject to

$$W_{t+1} = (1 + r)(W_t + Y_t - C_t)$$

where  $Y$  is income,  $W$  is net wealth,  $r$  is the constant interest rate and  $R = 1 + r$  is the interest factor,  $\delta$  the subjective intertemporal discount rate, and  $\beta = 1 / (1 + \delta)$  is the subjective intertemporal discount factor.

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low frequency of the data, whose variability has generally nothing to do with financial uncertainty.

<sup>8</sup>Examination of the cross-prudence effect on environmental policy is provided by BAIARDI & MENEGATTI (2011).

Problem (1) is solved by maximizing the following Lagrangian:

$$L = \mathbb{E} \sum_{t=0}^T \beta^t [U(C_t, E_t) - \lambda_t (W_{t+1} - R(W_t + Y_t - C_t))]$$

The FOCs are:

$$\frac{\partial L}{\partial C_t} = \beta^t [U_c(C_t, E_t) - R\lambda_t] = 0, \quad (2)$$

$$\frac{\partial L}{\partial W_{t+1}} = -\beta^t \lambda_t + \beta^{t+1} R \mathbb{E}[\lambda_{t+1}] = 0, \quad (3)$$

$$\frac{\partial L}{\partial \lambda_t} = W_{t+1} - R(W_t + Y_t - C_t) = 0. \quad (4)$$

Combining (2) and (3) we get the following Euler's equation

$$\beta R \mathbb{E}[U_c(C_{t+1}, E_{t+1})] = U_c(C_t, E_t). \quad (5)$$

Following DYNAN (1993) approach in the univariate case, we compute a second-order Taylor approximation of  $U_c(C_t, E_t)$ , and substituting in the left-hand side of condition (5), we obtain:<sup>9</sup>

$$\begin{aligned} & \beta R \mathbb{E}[U_c + (C_{t+1} - C_t)U_{cc} + (E_{t+1} - E_t)U_{ce} + 1/2(C_{t+1} - C_t)^2 U_{ccc} + \\ & + 1/2(E_{t+1} - E_t)^2 U_{cee} + (C_{t+1} - C_t)(E_{t+1} - E_t)U_{cce}] = U_c. \end{aligned} \quad (6)$$

After some algebra, and dividing both sides of expression (6) by  $C_t U_{cc}$ :

$$\begin{aligned} \frac{\mathbb{E}(C_{t+1} - C_t)}{C_t} &= \frac{1 - \beta R}{\beta R} \frac{U_c}{C_t U_{cc}} - \mathbb{E}[(E_{t+1} - E_t)] \frac{U_{ce}}{C_t U_{cc}} - \frac{1}{2} \mathbb{E}[(C_{t+1} - C_t)^2] \frac{U_{ccc}}{C_t U_{cc}} \\ & - \frac{1}{2} \mathbb{E}[(E_{t+1} - E_t)^2] \frac{U_{cee}}{C_t U_{cc}} - \mathbb{E}[(C_{t+1} - C_t)(E_{t+1} - E_t)] \frac{U_{cce}}{C_t U_{cc}}. \end{aligned} \quad (7)$$

The environmental quality level  $E_t$  is difficult to measure directly. Generally, it could be proxied by a decreasing function of the level of pollution  $P_t$ . In particular, we assume  $E_t = P_t^{-1}$ . According to SMULDERS & GRADUS (1996) and AYONG LE KAMA & SCHUBERT (2004), a simple two-argument Constant Relative Risk Aversion (CRRA) utility function which proxies the environmental quality by means of pollution, is given by:

$$U(C_t, P_t) = \frac{C_t^{1-\gamma} P_t^{-\phi(1-\gamma)} - 1}{1-\gamma} \quad (8)$$

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<sup>9</sup>To simplify notation we omit the arguments of the utility function and of its derivatives.

where  $\gamma, \phi > 0$ . Simple computations show that parameter  $\gamma$  represents the index of relative risk aversion  $-\frac{U_{cc}C_t}{U_c}$ , which is constant by assumption. From this index we can also compute the index of relative prudence  $-\frac{U_{ccc}C_t}{U_{cc}}$ , which is given by  $1+\gamma$ . Furthermore, as emphasized by AYONG LE KAMA & SCHUBERT (2004),  $\phi = \frac{U_e E_t}{U_c C_t}$  and it '[...] represents relative preference for environmental quality [...]' [see AYONG LE KAMA & SCHUBERT (2004), p. 34].

Given specification (8), we also note that:

$$U_{pp} = \phi[\phi(1-\gamma) + 1]C_t^{1-\gamma}P_t^{-\phi(1-\gamma)-2} \quad (9)$$

The assumption that agents are risk averse with reference to uncertainty on environment implies  $U_{pp} < 0$ . By expression (9), this occurs if and only if:

$$\phi(1-\gamma) < -1 \quad (10)$$

Finally, a necessary condition for (10) to hold is:

$$\gamma > 1 \quad (11)$$

Conditions (10) and (11) will be relevant for theoretical conclusions on the predicted signs of the coefficients to be estimated.

Based on utility function (8), we obtain the following results:

$$\begin{aligned} \frac{U_c}{U_{cc}C_t} &= -\frac{1}{\gamma}, \\ \frac{U_{cp}}{U_{cc}C_t} &= \frac{\phi(1-\gamma)}{\gamma}P_t^{-1}, \\ \frac{U_{ccc}}{U_{cc}C_t} &= -(1+\gamma)C_t^{-2}, \\ \frac{U_{cpp}}{U_{cc}C_t} &= -\frac{\phi(1-\gamma)[\phi(1-\gamma) + 1]}{\gamma}P_t^{-2} \end{aligned}$$

and

$$\frac{U_{ccp}}{U_{cc}C_t} = -\phi(1-\gamma)C_t^{-1}P_t^{-1}.$$

Substituting those results in expression (7), we get:

$$\begin{aligned} \frac{\mathbb{E}(C_{t+1} - C_t)}{C_t} &= \frac{r - \delta}{(1+r)\gamma} - \frac{\phi(1-\gamma)}{\gamma} \frac{\mathbb{E}(P_{t+1} - P_t)}{P_t} + \\ &\frac{(1+\gamma)}{2} \mathbb{E} \left[ \frac{(C_{t+1} - C_t)}{C_t} \right]^2 + \frac{\phi(1-\gamma)[\phi(1-\gamma) + 1]}{2\gamma} \mathbb{E} \left[ \frac{(P_{t+1} - P_t)}{P_t} \right]^2 + \end{aligned}$$



$$\phi(1 - \gamma)\mathbb{E}\left[\frac{(C_{t+1} - C_t)(P_{t+1} - P_t)}{C_t P_t}\right] \quad (12)$$

Following HAHM & STEIGERWALD (1999), we assume that the data generating process for  $C_{t+1}$ ,  $P_{t+1}$  and  $Y_{t+1}$  is a random walk (RW). Unit-root tests presented in Section 3 confirm that the RW hypothesis is coherent with our data. Given the RW assumption and using the logarithmic transformation of expression (12), we can write:

$$\begin{aligned} \Delta\log(C_{t+1}) = & \alpha_0 + \alpha_1\Delta\log(P_{t+1}) + \alpha_2\text{Var}_t[\Delta\log(C_{t+1})] + \\ & + \alpha_3\text{Var}_t[\Delta\log(P_{t+1})] + \alpha_4\text{Cov}_t[\Delta\log(C_{t+1}), \Delta\log(P_{t+1})] + u_{t+1}. \end{aligned} \quad (13)$$

where

$$\alpha_0 = \frac{r - \delta}{(1 + r)\gamma}, \quad (14)$$

$$\alpha_1 = -\frac{\phi(1 - \gamma)}{\gamma}, \quad (15)$$

$$\alpha_2 = \frac{(1 + \gamma)}{2}, \quad (16)$$

$$\alpha_3 = \frac{\phi(1 - \gamma)[\phi(1 - \gamma) + 1]}{2\gamma} \quad (17)$$

and

$$\alpha_4 = \phi(1 - \gamma). \quad (18)$$

Equation (13), which is at the heart of our estimation strategy, extends the equation analyzed by CARROLL (1992, 1997), DYNAN (1993), HAHM (1999), HAHM & STEIGERWALD (1999), GUARIGLIA & KIM (2003) and MENEGATTI (2007, 2010) among others.<sup>10</sup>

In equation (13) consumption growth (and thus also savings) depends on the dynamic of pollution and on three additional terms which are related to uncertainty in different ways. The first term captures the ‘direct’ effect of financial risk on consumption growth, which characterizes precautionary saving in the usual one-risk framework. The second term indicates the background source of precautionary savings, which is due, in this context, to uncertainty about environmental conditions. Finally, the covariance between the two risks describes the interaction between financial risk and environmental risk, while its sign indicates whether shocks on the environmental quality tend to reinforce (positive covariance) or to counteract (negative covariance) shocks on consumption.

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<sup>10</sup>Expression (13) is similar to the condition describing the ‘two-source precautionary saving’ motive in MENEGATTI (2009b). However, in that paper, optimal consumption growth is implicit, since a generic utility function is considered, while in the present paper optimal consumption growth is explicitly determined.

Using conditions (10) and (11), we can determine the expected signs for all coefficients in equation (13). First,  $\gamma > 0$  ensures  $\alpha_2 > 0$ . Also note that this coefficient is determined by the index of relative prudence. Second, condition (11) implies  $\alpha_1 > 0$  and  $\alpha_4 < 0$ , while conditions (10) and (11) jointly lead to  $\alpha_3 > 0$ . Finally, condition (11) requires the index of relative risk aversion to be larger than 1, and the index of relative prudence to be larger than 2. With reference to the index of relative risk aversion, it is worthwhile noticing that this condition is coherent with the indications provided by the theoretical literature (see GOLLIER (2003), chapter 3).<sup>11</sup> The empirical version of equation (13) is the following unrestricted regression model, with GDP growth as an additional control variable:<sup>12</sup>

$$C_t = \alpha_0 + \alpha_1 P_t + \alpha_2 VARC_t + \alpha_3 VARP_t + \alpha_4 COVCP_t + \alpha_5 Y_t + u_t, \quad (19)$$

Finally, equations (12) and (13) allow us to derive a set of relationships among coefficients  $\alpha_1$ ,  $\alpha_2$ ,  $\alpha_3$  and  $\alpha_4$  and parameters  $\gamma$  and  $\phi$ . In particular, by considering equations (12) and (13) jointly:

$$\alpha_1 = -\frac{\alpha_4}{\gamma} \quad (20)$$

$$\gamma = 2\alpha_2 - 1 \quad (21)$$

and

$$\phi = \frac{-\alpha_1 \gamma}{(1 - \gamma)}. \quad (22)$$

Moreover, if we combine relations (20) and (21), we have:

$$\alpha_1 = \frac{-\alpha_4}{2\alpha_2 - 1} \quad (23)$$

and, from expressions (15), (17) and (18):

$$\alpha_3 = -1/2\alpha_1[\alpha_4 + 1]. \quad (24)$$

In the empirical analysis the following restricted version of equation (19) is estimated:

$$C_t = \alpha_0 + \alpha_1 P_t + \alpha_2 VARC_t + \alpha_3 VARP_t + \alpha_4 COVCP_t + u_t \quad (25)$$

where the non-linear relations (23) and (24) are imposed on the parameters  $\alpha_1$ ,  $\alpha_2$ ,  $\alpha_3$  and  $\alpha_4$ .

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<sup>11</sup>DYNAN (1993) suggests that, with a univariate CRRA utility function,  $\gamma$  is between 1 and 4.

<sup>12</sup>The reason for the introduction of this control variable is explained in Section 3.

### 3 The Data

Equation (13) describes the effects of different types of uncertainty on consumption choices. Financial risk is described in equation (13) by the variance of consumption growth. This approach is similar to DYNAN (1993) and, more recently, to GUARIGLIA & KIM (2003).<sup>13</sup> Finally we compute the variance of consumption growth using, for each year, observations of the previous five years.<sup>14</sup> Environmental risk is described by the variance of pollution growth. As in many works in the field of the environmental economics (see, for example, FRIEDL & GETZNER 2003, GALEOTTI ET AL. 2009 and BROCK & TAYLOR, 2010), the proxy for pollution is CO<sub>2</sub> emissions.

Finally, it is common practice in the empirical literature on precautionary savings to introduce the real GDP rate of growth as a control variable at the estimation stage (see DEATON 1992, CARROLL 1992, 1997, HAHM, 1999 and MENEGATTI 2007, 2010). This inclusion is motivated by the possible presence of ‘agents’ myopia’ (see CAMPBELL & MANKIW 1989), liquidity constraints or other market imperfections implying a direct effect of current income on consumption.

Our dataset refers to six advanced economies, namely Canada, France, Italy, Spain, UK and USA. The considered variables are: per capita CO<sub>2</sub> emissions (metric tons), per capita consumption (i.e. household final consumption expenditure) and per capita real GDP. These last two time series are measured in constant 2000 US dollars. The data source is the World Bank Development Indicators (2011). All variables have a yearly frequency and span the time period 1960-2007.<sup>15</sup>

In the empirical analysis,  $c_t$ ,  $p_t$  and  $y_t$  are the logarithm of consumption, the logarithm of CO<sub>2</sub> and the logarithm of GDP respectively, and  $C_t$ ,  $P_t$  and  $Y_t$  are the first differences of  $c_t$ ,  $p_t$  and  $y_t$  respectively. These last variables are the measures of consumption growth, of the growth of CO<sub>2</sub> emissions and GDP growth. The variance of  $C_t$  and the variance of  $P_t$  are indicated with  $VARC_t$  and  $VARP_t$ ;  $COVCP_t$  is the covariance between  $C_t$  and  $P_t$ . Finally,  $COVYP_t$  and  $VARY_t$  are the covariance between  $P_t$  and  $Y_t$  and the variance  $Y_t$ .<sup>16</sup>

In Tables 1 and 2 descriptive statistics of the data are reported. In particular, the correlation matrix among the eight variables which will be used in the regression analysis suggests the positive relationship between consumption growth and financial uncertainty. Similarly, we notice that the correlation coefficient between the consumption growth rate

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<sup>13</sup>Alternative approaches include individual income variability (GUIISO ET AL. 1992, LUSARDI 1998), the unemployment rate (MUELLBAUER, 1994), indicators derived from a survey of professional forecasters (HAHM & STEIGERWALD, 1999), GDP variance (HAHM, 1999 and MENEGATTI 2007, 2010) or households’ one year ahead expectations on the general economic situation (LYHAGEN, 2001).

<sup>14</sup>GUARIGLIA & KIM (2003) use a partially similar approach.

<sup>15</sup>Data on USA consumption start from 1970. For this reason, the empirical analysis for USA is carried out on the period 1970-2007.

<sup>16</sup>The variance of  $Y_t$  and the variance of  $P_t$  are computed following the same procedure used for calculating  $VARC_t$ .

and the variability of  $\text{CO}_2$  is generally positive, with Canada and France as the only exceptions. These empirical findings support the idea that these two types of risk affect consumption and savings. Finally, the data show a clear, positive relationship between consumption and pollution growth rates, while the correlation between  $C_t$  and  $\text{COVCP}_t$  is negative.

Table 1 and 2 about here

Table 3 shows the KPSS unit-root test statistic (KWIATKOWSKI ET AL. 1992) at 5 per cent critical value. The results indicate the presence of a unit-root (i.e. non-stationary behavior) for consumption, pollution and GDP in all countries, which is supportive of the RW hypothesis introduced in the previous section.

Table 3 about here

## 4 Empirical Results

Equations (19) and (25) are estimated with the Generalized Method of Moments (GMM), which is particularly appropriate to tackle unobserved heterogeneity, omitted variable bias, measurement error and endogeneity of the explanatory variables. In this last respect, since  $Y_t$  and  $\text{VARC}_t$  are potentially endogenous variables (see CARROLL 1992, HAHM 1999 and MENEGATTI, 2007 and 2010), lagged values of  $Y_t$ ,  $\text{VARC}_t$  and eventually  $\text{VARY}_t$  are used as instruments. In order to deal with potential endogeneity of  $\text{VARP}_t$ ,  $P_t$  and  $\text{COVCP}_t$ , we instrument the first two variables with their lagged values, while  $\text{COVCP}_t$  is instrumented with its own lagged values and the lagged values of  $\text{COVYP}_t$ . Equations (19) and (25) are estimated using Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors.

As anticipated in Section 2, we estimate two different empirical versions of equation (13). First, along the lines suggested by numerous contributions to the empirical literature on precautionary savings quoted in the previous sections, we estimate equation (19), which includes GDP growth as a control variable. In this case, constraints (23) and (24) are not exactly satisfied, since GDP growth does not appear in equation (12). For this reason, we refer to equation (19) as the unrestricted regression. The estimation results of the unrestricted regression are summarized in Table 4. Second, we exploit the extra-sample information contained in constraints (23) and (24) and we estimate equation (25), which we refer to as the restricted regression. The restricted regression model does not control for GDP growth, since the constraints are meaningful only if the regression equation exactly reflects the structure of equation (12). The estimation results of the restricted regression are reported in Table 5.

Tables 4 and 5 about here

The statistical accuracy of our estimated models is checked using different diagnostic tests, which are reported in Tables 4 and 5. Specifically, according to the J-statistic, the null hypothesis that the overidentifying restrictions are valid is not rejected for both regression models and for all countries. Moreover, the Q-statistic for autocorrelation and the White heteroskedasticity test indicate, in general, absence of residual serial correlation and constant residual variance for both models and countries, with the only exceptions of UK (i.e. some residual heteroskedasticity in the unrestricted regression model), France (some heteroskedasticity in the unrestricted model and some autocorrelation in both unrestricted and restricted models), and Spain (some residual autocorrelation in the restricted regression model).<sup>17</sup> Finally, the Jarque-Bera test show that the empirical distribution of the residuals, for all regression models and countries, is not statistically different from the normal.

Coefficient  $\alpha_2$  describes the effects of financial risk on consumption growth. Its estimated values are positive (as expected) and significant in all countries for both regression models, with the only exception of UK when the restricted model is estimated. This result confirms the hypothesis that financial risk has a positive effect on consumption growth, as suggested by the literature on precautionary saving.

It should be emphasized that this finding is novel compared to the existing literature. Indeed, as anticipated in Section 1, HAHM (1999), HAHM & STEIGERWALD (1999) and MENEGATTI (2007, 2010) do not clearly identify the positive relationship between financial uncertainty and consumption growth, since the precautionary saving motive is significant in those contributions only if saving is the dependent variable. This empirical result has been justified in different ways. First, the utility function could be different from a CRRA. Second, as shown by CARROLL (1992), if consumers are impatient, their consumption choices are totally determined by income growth, which implies that testing equation (13) becomes meaningless.<sup>18</sup> Finally, if adjustment in saving is gradual or if there are several changes in the degree of uncertainty which act in the same direction, it is possible that the effect on saving is immediate, while the reaction of consumption is postponed.

In our work, the presence of two sources of uncertainty (i.e. financial risk and environmental risk) overcomes the problems in estimating the effect of financial risk on consumption growth which arise in the univariate framework. In this context, considering a single kind of risk leads to underestimation of the precautionary motive and to bias the

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<sup>17</sup>CARROLL (1992) states that the presence of serial correlation supports the buffet stock saving hypothesis, since the personal saving rate is a function of the net wealth ratio. This is an omitted variable in the Euler's equation, which justifies the presence of residual serial correlation.

<sup>18</sup>According to CARROLL (1992, 1997), a consumer is impatient when, in the presence of certain income, he/she would like to borrow against future income to finance current consumption. Conversely, a consumer is prudent if, in the presence of risky future income, he/she prefers to save much more today in order to counteract future uncertainty on income (see also KIMBALL, 1990). The so-called 'buffet stock saving behavior' occurs when agents are contemporaneously impatient and prudent.

estimates of its effect on the dynamic of consumption. On the contrary, the introduction of a second source of uncertainty is able to correctly describe the precautionary motive and to detect the presence of precautionary saving.

A second result which confirms the expected effects of uncertainty is obtained for coefficient  $\alpha_4$ , which is negative, as suggested by economic theory, and statistically significant in all regressions. This finding confirms the theoretical conclusion that the interaction between the two risks is relevant in determining precautionary saving and consumption growth.

Results are less conclusive for coefficient  $\alpha_3$ , which measures the direct effect of environmental risk on consumption dynamics. In this case, the expected positive value is obtained in only seven of our twelve regressions and estimates are often not significant. There are different possible explanations of this finding. First, the direct effect of environmental risk on saving can be weak, implying a very small (and possibly insignificant) coefficient. This would mean that the effect of environmental risk occurs mainly indirectly, through the interaction with financial risk. Alternatively, the wrong sign of coefficient  $\alpha_3$  could be related to the choice of the proxy for environmental quality. Although the level of CO<sub>2</sub> emissions is a widely used measure of environmental deterioration, its variance could not be large enough to fully capture uncertainty on the state of the environment.

Moreover, coefficient  $\alpha_1$  has the expected sign, which is positive and significant in all regressions, whereas a positive and significant coefficient is obtained for the control variable GDP growth in all unrestricted regression models. The first result corroborates the conjecture that the level of environmental quality is relevant in consumer's preferences, while the second finding confirms the importance of current GDP as a control variable in the analysis of consumption growth.

Finally, we find that all coefficients have the expected signs in both unrestricted and restricted regression models for Italy. The empirical performance of both regression models, in terms of expected signs of the coefficients, is generally good for USA, Canada, France and Spain. Some discrepancies between theory and empirical findings have arisen within the restricted regression model applied to UK.

## 5 Estimates of risk aversion and prudence

The results reported in Table 5 can be used to estimate the parameters of the utility function,  $\gamma$  and  $\phi$ , as well as to calculate indexes of risk aversion and prudence. These estimates are summarized in Table 6 for Canada, France, Italy, Spain and USA. The estimates of  $\gamma$  and  $\phi$  and the indexes of risk aversion and prudence are not provided for UK, because of the counterintuitive findings reported at the end of the previous section.

Table 6 about here

The estimated value of coefficient  $\gamma$  lies, for all countries, between 1.5 and 3, as shown in Table 6. This result is coherent with our assumptions on the utility function and with constraint (11). The estimate of  $\gamma$  also determines the size of the indexes of relative risk aversion and relative prudence since, given our utility function, the relative risk aversion index is equal to  $-\frac{U_{cc}C_t}{U_c} = \gamma$ , while the relative prudence index is equal to  $-\frac{U_{ccc}C_t}{U_{cc}} = 1 + \gamma$ .

GOLLIER (2003) proposes some numerical examples which are useful indications of a reasonable degree of relative risk aversion. He concludes that, if the utility function is a CRRA, a plausible value of constant relative risk aversion is between 1 and 4.<sup>19</sup> These indications confirm the reliability of our results, since, as explained above, our estimates for parameter  $\gamma$  lie between 1.5 and 3. Our estimates also suggest that France and Spain are the most risk-averse countries, with a risk aversion index equal to 2.85 and 2.78 respectively, while Canada is the least risk-averse, with a risk aversion index of 1.76.

DYNAN (1993) attempted to empirically estimate the index of relative risk aversion by using a univariate precautionary saving model. Her findings were, however, implausible since her estimates are too low and imply a negative index of relative risk aversion. Furthermore, neither the possible presence of liquidity constraints, nor the possible self-selection of consumers were sufficient to motivate her empirical findings. Our paper suggests a solution to Dynan's problem. The omission of relevant sources of uncertainty, such as environmental risk, is the main cause of the bias in her estimation of the relative risk aversion index.

Furthermore, as shown above, parameter  $\gamma$  also allows computations of the index of relative prudence. Since this index is equal to  $\gamma + 1$ , the estimates obtained for it are between 2.5 and 4. The estimated values also indicate a larger precautionary saving motive in France, Spain and USA, an intermediate value for Italy, and the lowest value in Canada.

Finally, the coefficients in Table 5 are used to estimate parameter  $\phi$  in the utility function. This parameter measures the relative preferences of agents for environmental quality. As expected,  $\phi$  is positive. Furthermore,  $\phi$  shows a larger cross-country variability than  $\gamma$ , and its estimated values are smaller, below 1, in France, Spain and USA, while they are larger than 1 in Canada and Italy. Given the interpretation of  $\phi$  suggested by AYONG LE KAMA & SCHUBERT (2004), recalled in Section 2, our reported values indicate a higher preference for environmental quality in Canada and Italy and a lower preference in France, Spain and USA.

## 6 Conclusions

This paper empirically investigates the joint effects of financial risk and environmental risk on consumption choices. The empirical analysis tests the two-source precautionary saving hypothesis by using time-series data on six advanced economies, namely Canada,

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<sup>19</sup>A similar conjecture is proposed by DYNAN (1993).

France, Italy, UK and USA, in the period 1960-2007. The empirical findings of this paper can be summarized as follows.

First, we find a positive and significant effect of financial risk on consumption growth, which confirms the conclusions of precautionary saving theory. This result provides a solution for problems affecting the conclusions of the previous literature on the CRRA precautionary saving model. Specifically, we show that previous empirical studies generally fail to detect the precautionary effect, because they omit some sources of uncertainty (namely environmental risk) in those analyses.

Second, the relevant effect of the interaction between financial and environmental risks in determining consumption growth is demonstrated. This in turn indicates that the interaction between financial and environmental risks significantly affects precautionary saving. A less conclusive result is obtained with reference to the direct effect of the environmental risk, which is found to be weak and, in some cases, has the opposite sign to that suggested by economic theory.

Third, estimates of the indexes of relative risk aversion and relative prudence are obtained. With reference to relative risk aversion, the estimated values are compatible with a priori conjectures based on simple risk theory. As a consequence, we propose a solution to the problems of estimating relative risk aversion in precautionary saving models found by DYNAN (1993), showing that the bias in her estimates can be due to the omission of environmental risk from her analysis.

Finally, the comparison across countries between the estimates for the parameters of the utility function provides evidence of differences in consumer preferences. In particular France, Spain and USA exhibit larger relative risk aversion and relative prudence than Italy and, particularly, Canada. On the other hand, Canada and Italy show a relatively stronger preference for environmental quality.

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**Table 1: Descriptive statistics (Canada, France and Italy)**

<b>Canada</b>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
Mean	0.90	0.12	0.13	0.42	0.43	2.48	0.68	0.97
Std. Dev.	0.77	0.47	0.56	1.65	0.44	1.58	0.56	0.87
Jarque-Bera	18.37	0.12	2.10	3.96	25.21	9.97	18.41	12.85
Probability	0.00	0.94	0.35	0.14	0.00	0.01	0.000	0.00
Observations	47	43	43	47	43	43	43	47
<i>Correlation matrix</i>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
$C_t$	1							
$COVCP_t$	-0.36	1						
$COVYP_t$	-0.34	0.90	1					
$P_t$	0.23	-0.24	-0.16	1				
$VARC_t$	-0.08	0.44	0.46	-0.29	1			
$VARP_t$	0.12	0.02	0.16	0.18	-0.26	1		
$VARY_t$	-0.26	0.60	0.54	-0.35	0.88	-0.22	1	
$Y_t$	0.82	-0.24	-0.30	0.21	-0.14	0.05	-0.25	1
<b>France</b>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
Mean	1.06	0.40	0.41	0.01	0.20	5.56	0.32	1.06
Std. Dev.	0.66	0.67	0.89	2.37	0.13	4.86	0.33	0.74
Jarque-Bera	1.31	19.97	31.76	0.83	4.31	5.35	52.30	0.56
Probability	0.52	0.00	0.00	0.66	0.12	0.07	0.00	0.76
Observations	47	43	43	47	43	43	43	47
<i>Correlation matrix</i>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
$C_t$	1							
$COVCP_t$	0.19	1						
$COVYP_t$	0.09	0.90	1					
$P_t$	0.55	-0.00	-0.03	1				
$VARC_t$	0.01	0.76	0.64	-0.14	1			
$VARP_t$	-0.05	0.82	0.71	-0.05	0.75	1		
$VARY_t$	-0.04	0.79	0.88	-0.01	0.65	0.74	1	
$Y_t$	0.87	0.09	-0.02	0.52	-0.08	-0.13	-0.14	1
<b>Italy</b>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
Mean	1.22	0.49	0.56	1.16	0.58	1.79	0.63	1.14
Std. Dev.	1.02	0.46	0.76	2.02	0.43	1.46	0.71	0.95
Jarque-Bera	0.21	4.69	35.52	3.27	2.76	13.47	40.07	0.38
Probability	0.90	0.09	0.00	0.19	0.25	0.00	0.00	0.82
Observations	47	43	43	47	43	43	43	47
<i>Correlation matrix</i>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
$C_t$	1							
$COVCP_t$	0.05	1						
$COVYP_t$	0.10	0.84	1					
$P_t$	0.70	0.07	-0.04	1				
$VARC_t$	0.01	0.77	0.45	0.04	1			
$VARP_t$	0.14	0.75	0.92	-0.02	0.40	1		
$VARY_t$	0.83	0.17	0.12	0.73	0.12	0.09	1	
$Y_t$	0.07	0.78	0.95	-0.04	0.35	0.83	0.12	1

Notes:  $C_t$ ,  $P_t$  and  $Y_t$  are the first differences of the logarithm of the level of consumption, of CO<sub>2</sub> emission and of GDP respectively;  $VARC_t$ ,  $VARP_t$  and  $VARY_t$  is the variance of  $C_t$ ,  $P_t$  and  $Y_t$  respectively, while  $COVCP_t$  and  $COVYP_t$  is the covariance between  $C_t$  and  $P_t$  and the covariance between  $P_t$  and  $Y_t$ .

**Table 2: Descriptive statistics (Spain, UK and USA)**

<b>Spain</b>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
Mean	1.34	0.27	0.12	1.48	0.55	3.91	0.50	1.37
Std. Dev.	1.16	0.83	0.81	2.30	0.40	3.01	0.42	1.11
Jarque-Bera	1.01	1.53	1.07	0.48	5.18	4.31	26.80	3.32
Probability	0.60	0.46	0.58	0.79	0.07	0.12	0.00	0.19
Observations	47	43	43	47	43	43	43	47
<i>Correlation matrix</i>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
$C_t$	1							
$COVCP_t$	-0.67	1						
$COVYP_t$	-0.59	0.91	1					
$P_t$	0.59	-0.51	-0.48	1				
$VARCP_t$	0.02	0.21	0.35	0.04	1			
$VARP_t$	0.19	0.05	-0.10	0.31	0.21	1		
$VARY_t$	0.07	0.10	0.15	0.24	0.76	0.33	1	
$Y_t$	0.92	-0.59	-0.55	0.47	-0.06	0.24	-0.03	1
<b>UK</b>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
Mean	1.04	0.20	0.35	-0.21	0.71	2.05	0.59	0.94
Std. Dev.	0.86	0.62	0.67	1.34	0.66	1.80	0.62	0.75
Jarque-Bera	0.27	5.44	9.33	8.78	7.79	64.98	7.93	4.21
Probability	0.87	0.07	0.01	0.01	0.02	0.00	0.02	0.12
Observations	47	43	43	47	43	43	43	47
<i>Correlation matrix</i>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
$C_t$	1							
$COVCP_t$	-0.23	1						
$COVYP_t$	-0.30	0.96	1					
$P_t$	0.22	-0.27	-0.33	1				
$VARCP_t$	-0.42	0.37	0.38	-0.12	1			
$VARP_t$	-0.15	0.78	0.80	-0.35	0.25	1		
$VARY_t$	-0.54	0.55	0.62	-0.18	0.81	0.35	1	
$Y_t$	0.80	-0.30	-0.32	0.40	-0.45	-0.28	-0.35	1
<b>USA</b>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
Mean	1.00	-0.12	0.55	0.64	0.58	1.39	0.77	0.87
Std. Dev.	0.76	1.16	0.63	0.70	0.58	0.97	0.72	0.84
Jarque-Bera	1.70	0.93	5.13	4.75	5.24	4.60	4.50	2.04
Probability	0.43	0.63	0.08	0.09	0.07	0.10	0.10	0.36
Observations	37	37	33	33	33	33	33	37
<i>Correlation matrix</i>								
	$C_t$	$COVCP_t$	$COVYP_t$	$P_t$	$VARC_t$	$VARP_t$	$VARY_t$	$Y_t$
$C_t$	1							
$COVCP_t$	0.12	1						
$COVYP_t$	0.15	0.98	1					
$P_t$	0.74	-0.16	-0.15	1				
$VARCP_t$	0.18	0.98	0.96	-0.10	1			
$VARP_t$	0.08	0.95	0.92	-0.08	0.93	1		
$VARY_t$	0.20	0.92	0.95	-0.09	0.93	0.84	1	
$Y_t$	0.93	0.11	0.13	0.75	0.15	0.09	0.18	1

Notes:  $C_t$ ,  $P_t$  and  $Y_t$  are the first differences of the logarithm of the level of consumption, of CO<sub>2</sub> emission and of GDP respectively;  $VARC_t$ ,  $VARP_t$  and  $VARY_t$  is the variance of  $C_t$ ,  $P_t$  and  $Y_t$  respectively, while  $COVCP_t$  and  $COVYP_t$  is the covariance between  $C_t$  and  $P_t$  and the covariance between  $P_t$  and  $Y_t$ .

**Table 3:** *Kwiatkowski-Phillips-Schmidt-Shin unit-root test statistic: 5 per cent significance level*

	<i>Canada</i>	<i>France</i>	<i>Italy</i>	<i>Spain</i>	<i>UK</i>	<i>USA</i>
$c_t$	0.889 (0.463)	0.879 (0.463)	0.879 (0.463)	0.878 (0.463)	0.901 (0.463)	0.748 (0.463)
$p_t$	0.469 (0.463)	0.364 (0.347)*	0.728 (0.463)	0.782 (0.463)	0.820 (0.463)	0.425 (0.347)*
$y_t$	0.895 (0.463)	0.877 (0.463)	0.881 (0.463)	0.888 (0.463)	0.907 (0.463)	0.747 (0.463)

*Notes:* The KPSS (1992) test assumes that the series are stationary under the null hypothesis; Test performed by including the intercept in the test equation; Asymptotic critical values in the brackets; A \* indicates significance at 10 per cent level;  $c_t$ ,  $p_t$  and  $y_t$  are the logarithm of consumption, the logarithm of CO<sub>2</sub> and the logarithm of GDP respectively.

**Table 4:** *GMM estimation of the unrestricted regression model (19)*

<i>Dependent variable: <math>C_t</math></i>	<i>Canada</i>	<i>France</i>	<i>Italy</i>	<i>Spain</i>	<i>UK</i>	<i>USA</i>
$\alpha_0$	0.01 (0.25)	0.33 (0.00)***	0.00 (0.04)	0.07 (0.03)**	0.28 (0.00)***	0.63 (0.04)***
$\alpha_1$	0.01 (0.00)***	0.00 (0.00)**	0.20 (0.02)***	0.06 (0.00)***	0.20 (0.00)***	0.19 (0.01)***
$\alpha_2$	0.69 (0.00)***	0.37 (0.04)***	0.72 (0.13)***	0.24 (0.02)***	0.07 (0.00)***	1.67 (0.13)***
$\alpha_3$	0.12 (0.00)***	0.03 (0.00)***	0.42 (0.03)***	-0.01 (0.00)***	0.01 (0.00)**	-0.63 (0.03)***
$\alpha_4$	-0.80 (0.00)***	-0.30 (0.00)***	-1.23 (0.16)***	-0.19 (0.01)***	-0.43 (0.00)***	-0.57 (0.12)***
$\alpha_5$	0.57 (0.00)***	0.57 (0.00)***	0.35 (0.04)***	0.87 (0.02)***	1.07 (0.00)***	0.66 (0.03)***
S.E. of regression	0.48	0.43	0.57	0.34	0.79	0.35
Durbin-Watson stat	1.05	1.16	1.59	1.57	1.79	2.24
Sum squared resid	7.29	5.83	10.07	3.50	19.62	2.86
<i>Diagnostics</i>						
J-statistic	9.46	9.52	22.25	8.58	14.28	6.83
Degrees of freedom	29	29	30	26	30	23
p-value	0.99	0.99	0.92	0.74	0.99	0.99
Residual serial correlation						
Q-statistic	2.47	7.21	0.98	1.77	0.41	0.84
p-value	0.11	0.00	0.32	0.18	0.52	0.36
White's test for heteroskedasticity						
Obs*R-squared	18.06	19.51	9.76	13.47	23.30	15.6
p-value	0.05	0.03	0.46	0.20	0.00	0.11
Normality test						
Jarque-Bera	0.41	0.29	2.14	0.32	0.62	5.14
p-value	0.81	0.86	0.34	0.85	0.73	0.08

*Notes:* All the variable are in log and in first difference; Asymptotic standard errors are reported in brackets; A \*(\*\*)[\*\*\*] indicates significance at 10(5)[1] per cent level; The J-statistic verifies the validity of the over-identifying restriction when there are more instruments than parameters to estimate (as in our cases); Q-Statistic at lag  $k$  tests the null hypothesis of no residual serial correlation up to order  $k$ ,  $k = 1, \dots, 10$ ; To save space, the Q-statistic and the corresponding p-value reported in the table are for  $k = 1$ ; White's test is a test of the null hypothesis of no heteroskedasticity against heteroskedasticity of some unknown general form; Jarque-Bera statistic tests the null hypothesis that the standardized residuals are normally distributed; The coefficient covariance matrix is weighted with Kernel Bartlett Bandwidth Fixed (without prewhitening) for Canada, France, Spain and USA, while Kernel Quadratic Bandwidth Andrews (with prewhitening) and Kernel Bartlett Bandwidth Andrews (without prewhitening) are used for Italy and UK respectively; Instruments (I) for each country are as follows. Canada I=[constant,  $C_{t-h}$ ,  $COVCP_{t-i}$ ,  $P_{t-j}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $Y_{t-i}$ , for  $i = 1, \dots, 6$ ,  $j = 1, \dots, 8$  and  $h = 1, 2$ ]; France I=[constant,  $COVCP_{t-i}$ ,  $P_{t-i}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $Y_{t-i}$ , for  $i = 1, \dots, 5$ ]; Italy I=[constant,  $COVCP_{t-i}$ ,  $COVYP_{t-1}$ ,  $P_{t-i}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $VARY_{t-1}$ ,  $Y_{t-i}$ , for  $i = 1, \dots, 3$ ]; Spain I=[constant,  $COVCP_{t-i}$ ,  $P_{t-i}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $Y_{t-i}$ , for  $i = 1, \dots, 8$ ]; UK I=[constant,  $COVCP_{t-j}$ ,  $COVYP_{t-j}$ ,  $P_{t-i}$ ,  $VARC_{t-j}$ ,  $VARP_{t-h}$ ,  $VARY_{t-j}$ ,  $Y_{t-j}$ , for  $i = 1, 2$ ,  $j = 1, \dots, 6$  and  $h = 1, \dots, 3$ ]; USA I=[constant,  $COVCP_{t-j}$ ,  $P_{t-i}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $Y_{t-i}$ , for  $i = 1, \dots, 3$  and  $j = 1, \dots, 4$ ].

**Table 5:** *GMM estimation results with restrictions (23) and (24) on coefficients*

<i>Dependent variable: <math>C_t</math></i>	<i>Canada</i>	<i>France</i>	<i>Italy</i>	<i>Spain</i>	<i>UK</i>	<i>USA</i>
$\alpha_0$	0.24 (0.22)	0.68 (0.04)***	0.00 (0.15)	0.29 (0.12)**	1.66 (0.02)***	0.70 (0.02)***
$\alpha_2$	1.38 (0.29)***	1.92 (0.25)***	1.69 (0.21)***	1.89 (0.17)***	-0.62 (0.02)***	2.12 (0.06)***
$\alpha_4$	-0.77 (0.15)**	-0.11 (0.03)***	-1.52 (0.21)***	-0.89 (0.07)***	0.30 (0.03)***	-1.72 (0.09)***
<i>Indirect estimation</i>						
$\alpha_1$	0.44 (0.09)***	0.04 (0.00)***	0.64 (0.05)***	0.32 (0.02)***	0.13 (0.00)***	0.53 (0.01)***
$\alpha_3$	-0.05 (0.04)	-0.02 (0.00)***	0.17 (0.06)**	-0.02 (0.01)	-0.09 (0.01)***	0.19 (0.03)***
S.E. of regression	0.99	0.57	0.84	0.78	0.83	0.60
Durbin-Watson stat	1.63	1.14	1.87	0.88	1.26	1.67
Sum squared resid	36.64	11.01	26.07	20.64	22.66	9.71
<i>Diagnostics</i>						
J-statistic	7.39	8.26	10.51	10.53	29.25	7.14
Degrees of freedom	10	25	12	36	34	10
p-value	0.69	0.99	0.57	0.98	0.65	0.71
Residual Correlation						
Q-statistic	0.67	5.69	0.50	10.33	2.77	0.24
p-value	0.41	0.02	0.48	0.00	0.10	0.63
White's test for heteroskedasticity						
Obs*R-squared	7.60	7.78	12.42	8.53	9.93	10.25
p-value	0.47	0.45	0.13	0.38	0.27	0.25
Normality test						
Jarque-Bera	3.52	0.03	1.8	0.91	2.53	4.09
p-value	0.17	0.98	0.40	0.63	0.28	0.13

*Note:*  $\alpha_1$  and  $\alpha_3$  are computed considering the parameters restrictions (23) and (24); All the variable are in log and in first difference; Asymptotic standard errors are reported in brackets; A \*(\*\*)[\*\*\*] indicates significance at 10(5)[1] per cent level; The J-statistic verifies the validity of the over-identifying restriction when there are more instruments than parameters to estimate (as in our cases); Q-Statistic at lag  $k$  tests the null hypothesis of no residual serial correlation up to order  $k$ ,  $k = 1, \dots, 10$ ; To save space, the Q-statistic and the corresponding p-value reported in the table are for  $k = 1$ ; White's test is a test of the null hypothesis of no heteroskedasticity against heteroskedasticity of some unknown general form; Jarque-Bera statistic tests the null hypothesis that the standardized residuals are normally distributed; The coefficient covariance matrix is weighted with Kernel Bartlett Bandwidth Fixed (without prewhitening) for Canada, France, Spain and USA, while Kernel Quadratic Bandwidth Andrews (with prewhitening) and Kernel Bartlett Bandwidth Andrews (without prewhitening) are chosen for Italy and UK respectively; Instruments (I) for each country are as follow. Canada: I=[constant,  $C_{t-h}$ ,  $COVCP_{t-i}$ ,  $P_{t-j}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $Y_{t-i}$ , for all  $i = 1, \dots, 6$ ,  $j = 1, \dots, 8$  and  $h = 1, 2$ ]; France: I=[constant,  $COVCP_{t-i}$ ,  $P_{t-i}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $Y_{t-i}$ , for all  $i = 1, \dots, 5$ ]; Italy: I=[constant,  $COVCP_{t-i}$ ,  $COVYP_{t-1}$ ,  $P_{t-i}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $VARY_{t-1}$ ,  $Y_{t-i}$ , for all  $i = 1, \dots, 3$ ]; Spain: I=[constant,  $COVCP_{t-i}$ ,  $COVYP_{t-i}$ ,  $P_{t-i}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ , for all  $i = 1, \dots, 8$ ]; UK: I=[constant,  $COVCP_{t-j}$ ,  $COVYP_{t-j}$ ,  $P_{t-i}$ ,  $VARC_{t-j}$ ,  $VARP_{t-h}$ ,  $VARY_{t-j}$ ,  $Y_{t-j}$ , for all  $i = 1, 2$ ,  $j = 1, \dots, 6$  and  $h = 1, \dots, 3$ ]; USA: I=[constant,  $COVCP_{t-j}$ ,  $P_{t-i}$ ,  $VARC_{t-i}$ ,  $VARP_{t-i}$ ,  $Y_{t-i}$ , for all  $i = 1, \dots, 3$  and  $j = 1, \dots, 4$ ].



**Table 6:** *Estimation of relative risk aversion, relative prudence and relative preference of environmental quality*

	<i>Canada</i>	<i>France</i>	<i>Italy</i>	<i>Spain</i>	<i>USA</i>
$\gamma$	1.76 (0.58)	2.85 (0.51)	2.39 (0.42)	2.78 (0.35)	2.64 (0.12)
$\phi$	1.01 (0.62)	0.06 (0.00)	1.10 (0.21)	0.50 (0.06)	0.73 (0.00)
Relative risk aversion	1.76	2.85	2.39	2.78	2.64
Relative prudence	2.76	3.85	3.39	3.78	3.64

*Note:* Asymptotic standard errors in the brackets; The relative risk aversion index is equal to  $-\frac{U_{ccc}C_t}{U_c} = \gamma$ , while the relative prudence index is equal to  $-\frac{U_{ccc}C_t}{U_{cc}} = 1 + \gamma$ .

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