Centre de recherche sur l'emploi et les fluctuations économiques (CREFÉ)
Research Center on Employment and Economic Fluctuations (RCEEF)

Université du Québec à Montréal

Cahier de recherche/Working Paper No. 39

Substitution, Risk Aversion, Taste Shocks, and Equity Premia*

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January 1996

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* We would like to thank Benoît Carmichael, Lucie Samson, Larry Epstein and Stanley Zin for allowing us access to the returns data. We are also indebted to Stephen Gordon for useful discussions and comments. Normandin acknowledges financial support from Social Sciences and Humanities Research Council of Canada. St-Amour acknowledges support from Université Laval. We retain full responsibility for any errors.

Résumé: Cette étude vise à expliquer les primes associées aux titres financiers risqués (soit la différence entre les rendements que procurent ces titres et le taux d'intérêt). Les restrictions testées sont dérivées à partir d'un modèle d'agent représentatif dont la fonction d'utilité est non séparable (par rapport au temps et aux états) et inclut des chocs de préférence. La méthodologie empirique consiste à estimer les équations d'Euler linéarisées au moyen de filtres de Kalman et de processus GARCH. Les résultats indiquent d'abord que l'hypothèse de séparabilité n'est pas rejetée. Aussi, les chocs de préférence affectent significativement les primes et engendrent des estimés réalistes des coefficients d'aversion relative au risque. Ce dernier résultat implique que le risque de consommation est faible. Néanmoins, la présence de chocs de préférence permet de reproduire les fortes primes observées. Finalement, ces résultats ne sont pas altérés suite à l'inclusion d'hétéroscédasticité conditionnelle.

Abstract: This paper investigates the testable restrictions on the time-series behavior of equity premia implied by a representative agent model whose state- and time-non-separable preferences are subject to taste shocks. The model nests state- and time-separable preferences with and without taste shocks as special cases. Empirically, the linearized Euler equations are estimated through Kalman filtering, allowing for conditional heteroscedasticity via a common factor GARCH process. With or without conditional heteroscedasticity, (i) the hypothesis that preferences are separable cannot be rejected, (ii) taste shocks influences are statistically significant, and (iii) taste shocks yield reasonable estimates of the coefficient of relative risk aversion. This last result occurs because taste shocks reproduce the large observed equity premium by shifting weight away from consumption risk in favor to taste risk.

Keywords: Conditional Heteroscedasticity, Consumption-Based Capital Asset Pricing Model, Kalman Filter, Latent Variables, State- and Time-Non-Separable Preferences, State- and Time-Separable Preferences.

JEL classification: G12, C12, C32

1 Introduction

An extensive literature has attempted to resolve the empirical problems associated with the standard consumption-based capital asset pricing model (CCAPM) of Breeden (1979). It will be recalled that, under prefect capital markets, for a representative agent maximizing state- and time-separable preferences, the equity premia (i.e. the vector of excess returns of risky over risk-less assets) are proportional to their covariance with consumption growth. The scalar shifting factor can be associated with the Arrow-Pratt coefficient of relative risk aversion, which is restricted to be the reciprocal of the elasticity of inter-temporal substitution. The problem of the time- and state-separable preferences stands in the smooth consumption series relative to the volatile stock returns; the high observed equity premia can only be reconciled with a low consumption covariance by increasing disinclination toward risk to implausible levels (e.g. coefficients of relative risk aversion larger than ten) [Mehra and Prescott (1985)].

The modifications to the original CCAPM which have been presented include (i) alternative distributional assumptions, such as explicit handling of mis-measurement arising from time aggregation issues [Grossman, Melino and Shiller (1987), Breeden, Gibbons and Litzenberger (1989), Heaton (1993)]; time-varying risk premia linked to the presence of conditionally heteroscedastic innovations [c.f. the survey of Bollerslev, Chou and Kroner (1992)]; or the theoretical issues related to the negative serial correlation found in returns [Fama and French (1988), Cecchetti, Lam and Mark (1990), Bonomo and Garcia (1994)]; and (ii) heterogeneous agents / incomplete markets frameworks [Constantinides and Duffie (1991), Telmer and Zin (1993)]. A third line of research focuses on preferences toward inter-temporal substitution and risk. One of the most promising developments in this respect has been the introduction of time- and state-non-separable preferences

[Weil (1990), Epstein and Zin (1989), Heaton (1991)]. Specifications for these preferences allow for a distinction between attitudes toward a-temporal risk and those toward inter-temporal consumption. This disentanglement implies that equity premia are also determined by the conditional covariance between the asset return and the market return [Epstein and Zin (1991)]; the market covariance being empirically large, a consequence is that unreasonably high coefficients of relative risk aversion are not necessary to reproduce the equity premia.

Unfortunately, the empirical gains of non-separabilities in the context of asset pricing have been modest. Weil's (1989) calibration exercise finds that reasonable coefficients of relative risk aversion and elasticities of inter-temporal substitution do not allow the model to reproduce the observed equity premia. In addition, Jorion and Giovannini's (1993) maximum likelihood estimates suggest that the inverse relationship between the coefficient of relative risk aversion and the elasticity of inter-temporal substitution cannot be rejected, whether conditional heteroscedasticity is allowed or not. Epstein and Zin (1991) reach the opposite conclusion, but the interpretation of their results is complicated by the sensitivity of the Generalized Method of Moments (GMM) estimates to the choice of instruments. Finally, as noted by Epstein and Zin (1991), the impact of the functional forms used remains to be analyzed[1]. Indeed, Epstein and Melino (1995) demonstrate that their results are sensitive to the choice of parametrization for the certainty equivalent, which represents the attitudes of the agent toward risk.

This paper examines whether the equity premium puzzle can be explained by using state- and time-non-separable preferences subject to taste shocks. While in this study we deliberately remain agnostic about the sources of the taste shocks, these can arise for numerous reasons, such as reflecting measurement errors in the variables, stochastic rates of time preference, shocks to the

[1]These authors use iso-elastic preferences toward risk, with a CES aggregator function.

home production technology, as well as mis-specifications of the parametrization of preferences, which are modeled as local departures from an underlying 'true' preference representation. Taste shocks have proved to be useful in various settings, such as consumption [Miron (1986), Caballero (1990), Nason (1991)], money demand [Townsend (1989)]; incentive-compatible contracts [Atkeson and Lucas (1992)]; and business cycle behavior [Bencivenga (1992), Ahmad, Ickes, Wang and Byung (1993), Stockman and Tesar (1995), Greenwood, Rogerson and Wright (1995)]. However, to our knowledge, the effects of taste shocks on the equity premia have not been investigated so far[2]. We find that these shocks can be crucial in understanding the behavior of the equity premia. More precisely, under the assumption of joint log-normality of returns as well as consumption and taste shocks, the linearized Euler equations reveal that, in addition to the consumption and market return risks, the equity premia is also affected by the conditional covariance between the asset return and the taste shock growth. This 'taste risk' can be large enough to ensure that reasonable coefficients of relative risk aversion and elasticities of inter-temporal substitution are able to reproduce the equity premia found in the data. Put differently, a high equity premia may be needed to offset taste shock risk as well as consumption risk, since both affect the inter-temporal marginal rate of substitution between current and future consumption.

Empirically, the unobservable taste shocks can be modeled from an arbitrary law of motion or related to a set of observable variables. Another alternative is to exploit the covariance between innovations in the returns process and the new information contained in taste shocks. To do this, we specify innovations in the returns as the linear combination of a common factor and an idiosyncratic component, specific to each individual asset. This latent variable approach has the advantage

[2]A possible exception is Cochrane (1991), who suggests that fads, or 'waves of irrational optimism and pessimism' might lie behind the residual discount-rate movements, not captured by the standard Euler equation model.

that covariances can be conditionally heteroscedastic if the common factor is characterized by a time-varying conditional variance, such as a generalized conditional auto-regressive heteroscedastic (GARCH) process. As argued by Diebold and Nerlove (1989), this procedure is convenient since it reduces the number of parameters to tractable proportions, as opposed to multivariate GARCH processes. The Kalman filter is subsequently used to construct the log-likelihood function, which is maximized over the parameters of the conditional heteroscedastic structure as well as the preference parameters.

Our results point toward several conclusions. First, we find that the hypothesis of separable preferences is not rejected, whether taste shocks are allowed or not. This result is consistent with the findings of Jorion and Giovannini (1993), in the absence of taste shocks. Secondly, we find that, contrary to the separable case without taste shocks, these disturbances imply reasonable estimates of the coefficient of relative risk aversion. Taste shocks dramatically reduce the weight of consumption risk in the Euler equation, which translates into a lower estimated coefficient of relative risk aversion for the separable preferences. Finally, we observe that these results are robust to the presence of conditional heteroscedasticity, modeled as a GARCH process. Hence, to summarize, our results indicate that while separability across time and states is not rejected for post-War US data, separable preferences with taste shocks allow the asset pricing kernel to reproduce the observed equity premia at reasonable levels of relative risk aversion, thereby accounting for the equity premium puzzle.

We present the model involving state- and time-non-separable preferences subject to taste shocks in section 2. The econometric model is described in section 3, with results presented in section 4. Finally, a conclusion reviews the main findings as well as potential extensions.

2 The Model

This section first describes the problem of an agent which is characterized by preferences which are non-separable across time and states, and which are affected by taste shocks. We subsequently derive the associated expression for the equity premia.

2.1 The Agent's Problem

A representative consumer solves the following problem:

$$\max_{\{C_t, w_{i,t}\}} V_t = \left[(1-\beta) Z_t^{\lambda} C_t^{1-\rho} + \beta (E_t V_{t+1}^{1-\alpha})^{\left(\frac{1-\rho}{1-\alpha}\right)}\right]^{\left(\frac{1}{1-\rho}\right)},\ i = 1, \ldots, n, \tag{2.1}$$

subject to:

$$A_{t+1} = R_{m,t+1}(A_t - C_t), \tag{2.2}$$

where E_t represents the conditional expectation operator, V_t is the utility function in period t, Z_t is a stochastic taste shock, C_t corresponds to consumption, A_t is wealth, $R_{m,t+1} = \sum_{i=1}^{n} w_{i,t} R_{i,t+1}$ is the stochastic gross market return and where $w_{i,t}$ and $R_{i,t+1}$ denote the share and the gross return of asset i. Finally, β, ρ, α, and λ are constant preference parameters whose interpretations are discussed below.

Equation (2.2) represents the usual inter-temporal budget constraint. Equation (2.1) describes the agent's recursive preferences. More precisely, a CES aggregator function expresses the maximand as a function of current consumption and the certainty equivalent of future utility, which is specified from an iso-elastic function. This certainty equivalence represents the attitude toward a-temporal risk, with the coefficient of relative risk aversion (defined in terms of utility V_{t+1}) equal to $\alpha > 0$. Moreover, attitudes toward inter-temporal reallocation of consumption are captured using preferences obtained under a deterministic environment, i.e. $V_t = [(1-\beta)\sum_{j=0}^{\infty}\beta^j Z_{t+j}^{\lambda} C_{t+j}^{1-\rho}]^{\left(\frac{1}{1-\rho}\right)}$, from which the elasticity of inter-temporal substitution is given by $1/\rho > 0$. When $\alpha \neq \rho$, the agent is characterized by state- and time-non-separable preferences. When $\alpha = \rho$, equation (2.1) reduces to state- and time-separable preferences, for which the coefficient of relative risk aversion is the reciprocal of the elasticity of inter-temporal substitution. In both cases, the preferences are affected by taste shocks as long as $\lambda \neq 0$. Finally, $\beta \in (0,1)$ is a constant subjective discount factor.

The multiplicative structure of taste shocks that we use is the one most often encountered in the literature[3]. As noted by Caballero (1988), taste shocks can occur for various forms of mis-specification, such as measurement errors in consumption (which can be related to seasonal effects), stochastic rates of time preference, mis-specification of the parametrization of the preferences, and/or effects that are not explicitly modeled (such as home production technology shocks). In this paper, we remain agnostic about the source of the taste shocks, focusing instead on their potential effects on the equity premia.

2.2 The Equity Premia

Following Weil's (1990) and Epstein and Zin's (1989, 1991) developments, it can be shown that the Euler equation associated with asset i is:

$$1 = E_t\left\{\left[\beta^{\left(\frac{1-\alpha}{1-\rho}\right)}\left(\frac{Z_{t+1}}{Z_t}\right)^{\lambda\left(\frac{1-\alpha}{1-\rho}\right)}\left(\frac{C_{t+1}}{C_t}\right)^{-\rho\left(\frac{1-\alpha}{1-\rho}\right)} R_{m,t+1}^{\left(\frac{\rho-\alpha}{1-\rho}\right)}\right] R_{i,t+1}\right\}, \qquad i = 1, \ldots, n, m. \tag{2.3}$$

[3]Some exceptions include Nason (1991) who focused on a stochastic bliss point, and Townsend (1989) who allowed for stochastic concavity of direct utility. Finally, Stockman and Tesar (1995) introduced differential taste shocks affecting traded and non-traded goods utility within a CES representation.

The term between the square brackets is interpreted as the inter-temporal marginal rate of substitution (IMRS) between period t and $(t+1)$. Note that the IMRS is affected by the taste shocks if $\lambda \neq 0$. This is a generalization of the IMRS derived by Hansen and Singleton (1982) – with $\alpha = \rho$ and $\lambda = 0$ – and by Weil (1990) and Epstein and Zin (1989, 1991) – with $\lambda = 0$.

Further distributional assumptions allow us to obtain explicit solutions for the equity premia. More precisely, consider the case where the gross market and individual returns as well as consumption and taste shocks are conditionally jointly log-normal[4]. Then, the Euler equations (2.3) yield:

$$E_t r_{i,t+1} - r_{f,t+1} = -\frac{1}{2}\sigma_{ii,t} + \rho\left(\frac{1-\alpha}{1-\rho}\right)\sigma_{ic,t} + \left(\frac{\alpha-\rho}{1-\rho}\right)\sigma_{im,t} - \lambda\left(\frac{1-\alpha}{1-\rho}\right)\sigma_{iz,t}, \tag{2.4}$$

where the reduced form for the net risk-free rate is given by:

$$\begin{aligned} r_{f,t+1} = \quad & -\log\beta - \lambda E_t\Delta z_{t+1} + \rho E_t \Delta c_{t+1} - \tfrac{1}{2}\left(\tfrac{\alpha-\rho}{1-\rho}\right)\sigma_{mm,t} \\ & -\tfrac{1}{2}\left(\tfrac{1-\alpha}{1-\rho}\right)\left[\lambda^2\sigma_{zz,t} + \rho^2\sigma_{cc,t} - 2\lambda\rho\sigma_{cz,t}\right]. \end{aligned} \tag{2.5}$$

Here, $r_{i,t+1} \equiv \log R_{i,t+1}$ is the net return on asset i, and $(r_{i,t+1} - r_{f,t+1})$ is the equity premia for asset i, for $i = 1, \ldots, n, m$. Also, Δ is the first difference operator, while $c_t \equiv \log C_t$, and $z_t \equiv \log Z_t$. Denote by $\sigma_{cc,t} \equiv Var_t(\Delta c_{t+1})$ the conditional variance, and other expressions of the form $\sigma_{xy,t}$ are defined in analogous fashion (with subscripts m and i representing r_m and r_i, respectively). Equation (2.4) states that the expected equity premia is determined by (i) the conditional variance of the net return ($\sigma_{ii,t}$), (ii) the conditional covariance between the net return and the consumption

[4]This assumption is not strictly correct given the definition of the gross market return: a linear combination of log-normal variables is not log-normal. Yet joint log-normality of gross returns can hold exactly in continuous time and might be approximately correct in discrete time since the gross returns do not deviate much from unity [Jorion and Giovannini (1993)].

growth ($\sigma_{ic,t}$), (iii) the conditional covariance between the net return and the net market return ($\sigma_{im,t}$), and (iv) the conditional covariance between the net return and the taste shocks growth ($\sigma_{iz,t}$). Under separable preferences ($\alpha = \rho$), without taste shocks ($\lambda = 0$), the low consumption covariance of returns $\sigma_{ic,t}$ implies that a large coefficient of relative risk aversion is required in order to reproduce the high observed equity premia. When separability is relaxed ($\alpha \neq \rho$), the covariance with the return on the market portfolio $\sigma_{im,t}$, which is found to be empirically large, supplements the consumption risk, therefore reducing the weight of consumption covariance in explaining the equity premia. Note finally that imposing the restriction that $\alpha = 1$ (i.e. log preferences toward risk), under non-separability, yields the static CAPM.

Empirical studies reveal however that the null of state- and time-separable preferences is not rejected when tested against the more general non-separable case [Jorion and Giovannini (1993)]. Furthermore, as mentioned earlier, Weil (1989) showed that, under non-separability, reasonable values of the coefficient of relative risk aversion and the elasticity of inter-temporal substitution cannot explain the observed equity premia and the low net risk-free rate.

On the other hand, taste shocks could help resolving the equity premium puzzle if $\lambda(1-\alpha)/(1-\rho) < (>) \, 0$, and $\sigma_{iz,t} > (<) \, 0$. Put differently, the presence of taste shocks could provide the additional degree of freedom necessary to reproduce the high equity premia, without requiring unreasonable coefficients of relative risk aversion, via the incremental taste covariance it implies. A large equity premia would be required to offset the impact of shifting marginal utilities of consumption due to the presence of the taste shocks. This second source of risk would justify a higher net market return of the risky asset relative to the risk-free asset, regardless of the degree of separability of preferences across state or time.

3 Empirical Method

Our estimation strategy consists of assuming joint log-normality for gross returns[5], taste shocks and consumption and to use maximum likelihood estimation (MLE) for the joint system consisting of equity premia as well as some arbitrary law of motion for consumption[6]. This unrestricted reduced form (URF) for consumption is given by the following ARMAX process:

$$\Delta c_t = \phi_0 + \sum_{j=1}^{p_c} \phi_{c,j} \Delta c_{t-j} + \sum_{i=1}^{n,m} \sum_{j=1}^{p_i} \phi_{i,j} r^e_{i,t-j} + \epsilon_{c,t}, \tag{3.1}$$

which is estimated jointly with

$$r^e_{i,t} = -\frac{1}{2}\sigma_{ii,t-1} + \rho\left(\frac{1-\alpha}{1-\rho}\right)\sigma_{ic,t-1} + \left(\frac{\alpha-\rho}{1-\rho}\right)\sigma_{im,t-1} - \lambda\left(\frac{1-\alpha}{1-\rho}\right)\sigma_{iz,t-1} + \epsilon_{i,t}. \tag{3.2}$$

Here, we denote $r^e_{i,t} \equiv r_{i,t} - r_{f,t}$, the equity premium for $i = 1, \ldots, n, m$, where the innovation process $\boldsymbol{\epsilon}_t = [\epsilon_{c,t}, \epsilon_{1,t}, \ldots, \epsilon_{n,t}, \epsilon_{m,t}, \epsilon_{z,t}]'$ can be conditionally heteroscedastic, with $\epsilon_{z,t}$, the innovation in taste shocks growth.

Because the focus of this paper is on the equity premia, we proceed by estimating the *realized* values of the excess return on equity, $r^e_{i,t}$, using equation (3.2), rather than estimating the net returns on risky assets ($r_{i,t}$), imposing the restriction (2.5) on the risk-free rate ($r_{f,t}$), as in Jorion and Giovannini (1993). Two reasons motivate this choice: first we do not have to estimate the subjective discount factor (β), and more importantly, we do not have to specify some arbitrary law

[5]Recent skewness and kurtosis tests show that joint log-normality is considered a good approximation for the monthly post-war US data base we use in estimating the model [Jorion and Giovannini (1993)].

[6]Here we do not attempt to obtain closed-form solutions for optimal consumption, whose derivation can be extremely challenging for non-separable preferences. This approach is also followed by Hansen and Singleton (1983), Giovannini and Weil (1989) and Jorion and Giovannini (1993).

of motion for the taste shock growth (z_t).

Instead, in Section 3.1, we use a latent variable structure which has the advantages (i) of allowing the measurement of the unobservable covariance between the net return and the growth of taste shocks affecting the equity premia (3.2) and (ii) of providing a parsimonious description of the conditional second moments [Diebold and Nerlove (1989)]. Then, in Section 3.2, we discuss the identification issues with respect to the preference and the scedastic parameters – i.e. the conditional covariance parameters. Finally, in Section 3.3 we present the estimation procedure based on the Kalman filter.

3.1 Latent Variable Structure

The major difficulty in estimating the equity premia (3.2) is that we do not observe taste shocks. Several approaches are available for addressing this problem, such as relating the unobservable components to an arbitrary set of observable variables, or as modeling the taste shock growth from a given law of motion, using data augmentation techniques (i.e. Markov Chain Monte-Carlo) [Gordon and St-Amour (1995)]. An attractive alternative is to exploit exclusively the covariance between the unanticipated components of net returns and taste shock growth ($\sigma_{iz,t}$). To do this, consider the following latent variable structure:

$$\boldsymbol{\epsilon}_t = \boldsymbol{\tau} e_t + \boldsymbol{\nu}_t, \qquad \begin{bmatrix} e_t \\ \boldsymbol{\nu}_t \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} s_t^2 & 0 \\ 0 & \boldsymbol{\Omega} \end{bmatrix} \right) \tag{3.3}$$

where, $\boldsymbol{\tau} = [\tau_c, \tau_1, \ldots, \tau_n, \tau_m, \tau_z]'$ is the vector of factor loadings.

In this setting, we assume that innovations can be decomposed into two orthogonal, zero-mean shocks e_t and $\boldsymbol{\nu}_t$, which are jointly normal. A first element which is common to all is given by e_t. For example, in our setting, for a stochastic investment set à la Merton, this 'pure' exogenous shock could be related to the prevailing state of the world. The $(n+3)\times 1$ vector $\boldsymbol{\tau}$ represents the sensitivity of individual innovations to this common shock. The second component $\boldsymbol{\nu}_t$ is the specific element in consumption growth, net returns and taste shock growth innovations. It represents purely idiosyncratic elements to the innovations process, which are unaffected by the common factor. The conditional covariance of $\boldsymbol{\epsilon}_t$ is then given by:

$$\begin{aligned} \boldsymbol{\Sigma}_{t-1} &\equiv E_{t-1}(\boldsymbol{\epsilon}_t\boldsymbol{\epsilon}_t') \\ &= \tau s_{t-1}^2 \tau' + \boldsymbol{\Omega}. \end{aligned} \tag{3.4}$$

We further restrict the scedastic structure of the process $\boldsymbol{\epsilon}_t$ by assuming that:

$$\begin{aligned} \boldsymbol{\Omega} &\equiv E_{t-1}(\boldsymbol{\nu}_t\boldsymbol{\nu}_t') = E(\boldsymbol{\nu}_t\boldsymbol{\nu}_t') \\ &= diag[\omega_c^2, \omega_1^2, \ldots, \omega_n^2, \omega_m^2, \omega_z^2], \quad and, \\ s_t^2 &\equiv E_{t-1}(e_t^2) \\ &= (1-\delta_1-\delta_2) + \delta_1 e_{t-1}^2 + \delta_2 s_{t-1}^2 \\ E(e_t^2) &= 1. \end{aligned} \tag{3.5}$$

We suppose that the multivariate conditional heteroscedasticity in $\boldsymbol{\epsilon}_t$ stems from a univariate GARCH(1,1) process found in the common factor e_t, which has unconditional variance set equal to one[7]. As usual, the conditional heteroscedastic case is obtained from δ_1 and $\delta_2 \in (0,1)$ with $(\delta_1+\delta_2) < 1$, while conditional homoscedasticity is obtained when $\delta_1 = \delta_2 = 0$. The specific innovations $\boldsymbol{\nu}_t$ are distributed with a constant variance $\boldsymbol{\Omega}$, which is diagonal. Hence, any covariances between elements of the innovations included in $\boldsymbol{\epsilon}_t$ is exclusively accounted for by the presence of

[7]This is a standard procedure in factorial analysis to establish the scale of the common factor.

the common factor e_t. Under these assumptions, the equity premia (3.2) is obtained as:

$$r^e_{i,t} = -\frac{1}{2}(\tau_i^2 s_{t-1}^2 + \omega_i^2) + \rho\left(\frac{1-\alpha}{1-\rho}\right)\tau_i\tau_c s_{t-1}^2 + \left(\frac{\alpha-\rho}{1-\rho}\right)\tau_i\tau_m s_{t-1}^2 - \left(\frac{1-\alpha}{1-\rho}\right)\lambda\tau_i\tau_z s_{t-1}^2 + \epsilon_{i,t}, \quad (3.6)$$

for $i = 1, \ldots, n, m$.

Although the theoretical foundations for the presence of conditional heteroscedasticity in asset pricing models may not be clearly defined [Backus and Gregory (1993)], the relevance of their contribution to the pricing of productive assets has been well documented [Bollerslev et al. (1992)]. In particular, GARCH structures seem well adapted in order to reproduce the alternating periods of volatility and smoothness found in post-war US returns data.

For empirical implementation, the common factor GARCH process has often been considered as a useful alternative to large-scale multivariate GARCH processes [Engle, Ng and Rothschild (1990), Ng, Engle and Rothschild (1992)]. The latent factor GARCH process and the particular parametrization which we use, can be seen as a useful variant of observable factor GARCH processes [Diebold and Nerlove (1989), King, Sentana and Wadhwani (1994), Harvey, Ruiz and Sentana (1992)]. In our case, the main advantage of this approach is that it allows us to recover the covariance of shocks and returns $\sigma_{iz,t}$, without having to specify a law of motion for the unobservable taste shocks z_t. Finally, note that common factor heteroscedasticity obtains whether taste shocks influence preferences or not (i.e. even if $\lambda = 0$), and whether or not the common factor influences taste shocks innovations (i.e. even if $\tau_z = 0$).

3.2 Identification

The vector of parameters $\boldsymbol{\theta}$ includes (i) the coefficients of the consumption growth ARMAX process (ϕ_0, $\phi_{c,j}$, and ϕ_i, j where $i = 1, \ldots, n, m$), (ii) the parameters of the scedastic structure ($\boldsymbol{\tau}$,

$\mathbf{\Omega}$, δ_1, and δ_2), (iii) and the coefficients describing the preferences (α, ρ, and λ). We now discuss the identification of each parameter in turn.

First, the parameters of the ARMAX process (3.1) are clearly exactly identified. Similarly, under conditional heteroscedasticity, the parameters δ_1 and δ_2 are exactly identified from the GARCH process (3.5). Also, note that ω_z^2 does not appear anywhere in (3.6) under the block diagonality of $\mathbf{\Omega}$. For this reason, the relevant model to be estimated can be reduced the $(n+2)\times 1$ system (3.1) and (3.6), with scedastic functions given by (3.5), where we redefine $\boldsymbol{\epsilon}_t = [\epsilon_{c,t}, \epsilon_{1,t}, \ldots, \epsilon_{n,t}, \epsilon_{m,t}]'$, with $\boldsymbol{\tau}, \mathbf{\Omega}$ redefined in analogous fashion. Them, the parameters τ_i and ω_i, for $i = c, 1, \ldots, n, m$ are identified up to a column sign change, from the $(n+3)\times(n+2)/2$ measurable unconditional second moments, i.e. $\mathbf{\Sigma} = \boldsymbol{\tau} s^2 \boldsymbol{\tau} + \mathbf{\Omega}$. This is a necessary and sufficient condition for identification, since $s^2 = 1$ and $\mathbf{\Omega}$ is diagonal [Joreskog (1979)].

Moreover, when τ_z is normalized to unity, we can identify λ. Clearly this normalization affects the magnitude of the estimated λ, but not the t-statistic of the null that $\lambda = 0$, which represents a test that taste shocks affect direct utility, and thereby the equity premium. Also, the point estimates and the t-statistics of the coefficient of relative risk aversion α and of the elasticity of inter-temporal substitution $1/\rho$ are not altered by the normalization $\tau_z = 1$ and the scaling of the common factor $s^2 = 1$ as well as by the fact that $\boldsymbol{\tau}$ is identified up to a column sign change.

Finally, the structural parameters α, ρ and λ are over-identified under the normalizations discussed above. To see this, note that an unrestricted reduced form (URF) can be obtained, in which net individual net returns, as well as the market net return are regressed on a constant $(\mu_1, \ldots, \mu_n, \mu_m)$ and conditional covariance s_{t-1}^2:

$$r_{i,t}^e = \mu_i + \xi_i s_{t-1}^2 + \epsilon_{i,t}, \qquad i = 1, \ldots, n, m \tag{3.7}$$

which is estimated jointly with consumption growth process (3.1) and scedastic structure (3.5), with $\boldsymbol{\xi} = 0$ and $\boldsymbol{\delta} = 0$ imposed for the conditional homoscedastic model. This URF forms the basis for a LR test of the over-identifying restrictions imposed by the model, which is performed below. In fact, for the conditional homoscedastic (heteroscedastic) case there is respectively (i) n $(2n+1)$ over-identifying restrictions for separable preferences without taste shocks, (ii) $n-1$ $(2n)$ over-identifying restrictions for separable preferences with taste shocks, as well as for non-separable preferences without taste shocks, and finally (iii) $n-2$ $(2n-1)$ over-identifying restrictions for non-separable preferences with taste shocks.

3.3 Estimation Procedure

The estimation strategy we follow evolves around the construction of the log-likelihood function, based on the state-space representation of the common factor e_t. The steps we follow are:

1- The lag structure (p_c, p_i, where $i = 1, \ldots, n, m$) of the ARMAX process (3.1) is determined so that no detectable serial correlation is found in unanticipated consumption growth. To do so, the process (3.1) is estimated by Ordinary Least Squares (OLS) for several lag lengths. Then, a Heteroscedasticity-Robust Gauss Newton Regression (HRGNR) procedure is used to test for any remaining serial correlation. This approach allows for the possibility of conditional heteroscedasticity of unknown form [Davidson and MacKinnon (1993)]. The relevant lag structure is used in the next steps.

2- The Kalman filter is applied. Taking the common factor as the state, it is straightforward to derive the updating equations:

$$
\begin{aligned}
e_{t|t} &\equiv E_t(e_t) \\
&= s^2_{t|t}\boldsymbol{\tau}'\boldsymbol{\Sigma}^{-1}_{t|t-1}\boldsymbol{\epsilon}_{t|t}, \\
s^2_{t|t} &\equiv E_t(e^2_t) \\
&= s^2_{t|t-1} - s^2_{t|t-1}\boldsymbol{\tau}'\boldsymbol{\Sigma}^{-1}_{t|t-1}\boldsymbol{\tau}s^2_{t|t-1},
\end{aligned}
\tag{3.8}
$$

where,

$$
\begin{aligned}
\boldsymbol{\epsilon}_{t|t} &\equiv E_t(\boldsymbol{\epsilon}_t) \\
&= \begin{bmatrix} \Delta c_t - \phi_0 - \sum_{j=1}^{p_c}\phi_{c,j}\Delta c_{t-j} - \sum_{i=1}^{n,m}\sum_{j=1}^{p_i}\phi_{i,j}r^e_{i,t-j} \\ r^e_{i,t} + \frac{1}{2}(\tau_i^2 s^2_{t|t-1} + \omega_i^2) - \rho\left(\frac{1-\alpha}{1-\rho}\right)\tau_i\tau_c s^2_{t|t-1} - \left(\frac{\alpha-\rho}{1-\rho}\right)\tau_i\tau_m s^2_{t|t-1} + \left(\frac{1-\alpha}{1-\rho}\right)\lambda\tau_i s^2_{t|t-1} \end{bmatrix},
\end{aligned}
$$

for $i = 1, \ldots n, m$, and where,

$$
\begin{aligned}
\boldsymbol{\Sigma}_{t|t-1} &\equiv E_{t-1}(\boldsymbol{\epsilon}_t\boldsymbol{\epsilon}'_t) \\
&= \boldsymbol{\tau}s^2_{t|t-1}\boldsymbol{\tau}' + \boldsymbol{\Omega} \\
s^2_{t|t-1} &\equiv E_{t-1}(e^2_t) \\
&= (1-\delta_1-\delta_2) + \delta_1(e^2_{t-1|t-1} + s^2_{t-1|t-1}) + \delta_2 s^2_{t-1|t-2}.
\end{aligned}
$$

Note that $s^2_{t|t-1}$ incorporates a correction term ($s^2_{t-1/t-1}$) in the usual GARCH(1,1) process to reflect the uncertainty of the common factor estimates [Harvey et al. (1992)]. For given values of the parameters $\boldsymbol{\theta}$, the formulae (3.8) are evaluated for $t = (p+1), \ldots, T$ — where $p = \max(p_c, p_i)$ and $e_{p|p} = 0$, $s^2_{p|p} = s^2_{p+1|p} = 1$ are initialized from the unconditional moments. As is well known, under conditional homoscedasticity ($\delta_1 = \delta_2 = 0$), the Kalman filter is optimal, that is, it produces the best (in the conditional mean square error sense) estimates of the unknown common factor $e_{t|t}$. Under conditional heteroscedasticity ($\delta_1 \neq 0$ and/or $\delta_2 \neq 0$), then the Kalman filter is quasi-optimal because it relies on the conditional Gaussian assumption, although this assumption is not satisfied [Harvey et al. (1992)].

3- The approximate log-likelihood of the sample (ignoring the constant term) is constructed from the Kalman filter by regarding the distribution of the unanticipated components as being conditionally Gaussian. This yields:

$$\mathcal{L}(\boldsymbol{\epsilon}, \boldsymbol{\theta}) = -\frac{1}{2} \sum_{t=p+1}^{T} \log \mid \boldsymbol{\Sigma}_{t|t-1} \mid -\frac{1}{2} \sum_{t=p+1}^{T} \boldsymbol{\epsilon}'_{t|t} \boldsymbol{\Sigma}_{t|t-1}^{-1} \boldsymbol{\epsilon}_{t|t}, \tag{3.9}$$

Then, equation (3.9) is maximized over the parameters $\boldsymbol{\theta}$ by using the simplex and the BHHH algorithms. Steps 2 and 3 are performed for several starting values for $\boldsymbol{\theta}$. In particular, we used many starting values (i) that are between 0.5 and 10.0 for ρ and α, (ii) that are between -10.0 and 10.0 for λ, and (iii) that are between 0.05 and 0.99 for δ_1 and δ_2 (when conditional heteroscedasticity is allowed). Finally, the starting values for the parameters ($\phi_{c,j}$ and $\phi_{i,j}$) of the consumption growth ARMAX process are those obtained by OLS (step 1).

4 Results

4.1 Data

The data we use is an update of the data set used by Epstein and Zin (1991) and Jorion and Giovannini (1993). It is composed of US monthly stock returns for the period 1959:4 to 1992:7. The net returns are for the 4 of the 5 major industry groups, i.e primary (1), transportation (2), trade (3) and finance/services (4), with net market rate given by the value-weighted returns. Following

Epstein and Zin (1991) and Jorion and Giovannini (1993), we omit the manufacturing group from estimation to avoid near-perfect collinearity between individual net returns and the market net return. The net risk-free rate is proxied by the rate on 1-month US T-Bills. All net returns are expressed in real terms, using the consumption deflator. Real per-capita expenditures on non-durables and services are used for the consumption measure. Descriptive statistics are presented in Table 1.

The dichotomy between the smooth consumption growth series and the volatile net returns stands out clearly from the ranges and covariance figures. For separable preferences without taste shocks, the impact on predicted equity premia takes the form of high coefficients of relative risk aversion required to offset the low consumption covariances. Indeed, heuristic individual estimates for the coefficients of relative risk aversion – i.e. $\hat{\alpha} = [E(r^e_{i,t}) + .5\sigma_{ii}]\sigma^{-1}_{i,c}$ – from the descriptive statistics in Table 1, range from 248 for trade returns to 460 for transportation. When most studies evaluate reasonable coefficients of relative risk aversion to be less than ten, the simple separable pricing model with homoscedastic errors implies relative Arrow-Pratt indices which clearly appear unrealistic.

4.2 Conditional Homoscedasticity

Applying the HRGNR procedure indicates that the relevant structure for the consumption growth process (3.1) is $p_c = p_i = 4$, and $\phi_{i,j} = 0$, $i = 1, \ldots, 4$, i.e. the consumption growth is regressed on a constant, four own lags and four lags of the market excess return. Given this structure, we maximized the LLF (3.9), imposing $\delta_1 = \delta_2 = 0$, under conditional homoscedasticity. For briefness, Table 2 reports only the estimated structural parameters α, ρ and λ, which are central to the specification of preferences and allow us to statistically replicate the conditional first moments of equity premia as well as an unrestricted linearization[8]. The first and second columns correspond to preferences without taste shocks ($\lambda = 0$): first the separable case ($\alpha = \rho$), followed by non-separable preferences ($\alpha \neq \rho$). Columns 3 and 4 are obtained in similar order, by relaxing the restriction of no taste shocks ($\lambda \neq 0$). Note finally that standard errors are given in parentheses, while the P-values for the relevant tests are reported in square brackets.

The LR results in Table 2 reveal that for all four restricted reduced forms, the over-identifying restrictions are not rejected at the 5% level. This implies that the cross-equations restrictions implied by the representative agent model effectively allow us to replicate the conditional first moments of equity premia better than an unrestricted linearization. Yet, some differences in the performance of each individual model stand out clearly.

Hence, the separable preferences without taste shocks involve an estimate of the coefficient of relative risk aversion of over 224. This is in line with the heuristic estimates presented in Section 4.1. Also, this is of the same order of magnitude as some of the estimates found by Grossman et al. (1987). Moreover, the point estimate clearly stands outside the usually accepted range $0 < \alpha < 10$. This is consistent with earlier findings that separable preferences without taste shocks do not account for the equity premium puzzle.

In contrast, the non-separable preferences without taste shocks produce reasonable estimates of the coefficient of relative risk aversion and of the elasticity of inter-temporal substitution. Also, point estimates are roughly of the same order of magnitude as those obtained by Epstein and Zin (1991), and Jorion and Giovannini (1993). In particular, Epstein and Zin (1991) find GMM estimates of $0.4 < \hat{\alpha} < 1.4$, and $2.4 < \hat{\rho} < 4.8$, while Jorion and Giovannini (1993) obtain $5.4 <$

[8]All other results concerning the consumption growth, URF and scedastic parameters are available from the authors upon request.

$\hat{\alpha} < 11.9$ and $3.7 < \hat{\rho} < 11.9$ using ML estimation. However, the LR test [P-value] for the null that $\alpha = \rho$ is 1.64 [0.20], so that separable preferences without taste shocks cannot be rejected at the 5 or 10% levels, when tested against non-separable preferences without taste shocks, as also found by Jorion and Giovannini (1993). Yet, as we just mentioned, the separable preferences without taste shocks do not appear to be an appropriate parametrization as well.

Introducing taste shocks on the other hand reveal that λ is significant at the 5% level for the separable case. More importantly, we observe a dramatic reduction in the point estimate for the coefficient of relative risk aversion whose estimate is now below 3.0. This is obtained through the negative covariance between taste shocks and asset returns which yield $\lambda\sigma_{iz} = \lambda\tau_i < 0$. This means that the contribution of taste shocks to the equity premia is positive. In other words, their presence supplement the consumption risk; a high degree of risk aversion is no longer necessary to inflate the low covariance between consumption growth and asset net returns in order to reproduce the high historical value of equity premia, the presence of preference risks justifies the large compensation demanded by the agent to hold the risky assets.

Finally, non-separable preferences with taste shocks also yield reasonable estimates of the coefficient of relative risk aversion and of the elasticity of inter-temporal substitution. Again, taste shocks significantly affect the equity premia, with λ being significant at the 10% level. However, when the null of separable preferences is tested against non-separability, we obtain a LR statistic of 0.10 [0.75], which again points in favor of separable preferences.

Overall, these results reveal that separable with taste shocks perform better in accounting for the equity premium puzzle. In fact, the presence of taste shocks yields realistic estimates of the structural preference parameters, and and is statistically preferable to the alternative specifications of the representative agent model.

4.3 Conditional Heteroscedasticity

Given the appropriate lag length introduced above for the consumption growth process, the model is re-estimated allowing this time for conditional heteroscedasticity ($\boldsymbol{\delta} \neq 0$). Table 3 reports the preference parameter estimates (α, ρ, λ), supplemented with the GARCH(1,1) parameters $\boldsymbol{\delta}$.

Table 3 shows that, as expected the estimates $\delta_1, \delta_2 \in (0,1)$, with $(\delta_1 + \delta_2) < 1$. Both estimates are significant at the 5% level, under all four preference specifications. Also, a joint test of exclusion reveal that the inclusion of time-varying second moments is warranted. Finally, we find no evidence suggesting that the GARCH(1,1) process is inadequate from the artificial regression results, in which squared residuals are regressed on their own lagged values, for lags up to 12.

On the other hand, the addition of the GARCH specification does not significantly alter the results for the structural parameter estimates, and therefore, does not modify the conclusions already obtained under conditional homoscedasticity. Indeed, over-identifying tests still point in favor of the restricted reduced form, with parameter estimates remaining virtually unchanged, although we note a modest increase in precision.

Once again, separable preferences without taste shocks lead to unrealistic estimates for the coefficient of relative risk aversion, while allowing for non-separability produces reasonable estimates of the preference parameters. However, the LR test for the null that $\alpha = \rho$ is 2.30 [0.13], so that separability is not rejected at the 10% level. The inclusion of taste shocks in separable preferences significantly improves the explanatory power of the model and implies an estimate which is consistent with common beliefs about risk aversion. Similarly, non-separable preferences with taste shocks yield to realistic estimates of the preference parameters, but the null of separability is not rejected, with a LR statistic of 0.62 [0.43].

To summarize, we find that separable preferences with taste shocks appear to be the most promising specification in accounting for the equity premium puzzle. More specifically, the model is statistically preferable to the alternative specifications. Also it produces lower estimates of disinclination toward risk because the presence of taste shocks reduces the weight placed on consumption risk in explaining the equity premia, by justifying it as taste risks which must be compensated as well. This result also holds when conditional heteroscedasticity is allowed, which suggests that time-varying second moments do not by their own provide the answer to the high observed equity premia.

5 Conclusion

The objective of this paper has been to study the impact of taste shocks for equilibrium excess returns, allowing for time- and state-non-separabilities of preferences. The estimation of the resulting Euler equations was carried out by assuming a joint log normal process for consumption, taste shocks and returns, using the corresponding linearized representation of equity premia. We parametrized the model through latent variables techniques, by specifying the innovations process to be a linear combination of a common component and an idiosyncratic term. The common factor can be conditionally homoscedastic or heteroscedastic, while the specific term is always conditionally homoscedastic. This translated into a particularly parsimonious conditional heteroscedastic structure, as well as eliminating the need to specify an arbitrary law of motion for taste shocks.

Our results point toward several elements. First, the null of state- and time-separable preferences is not rejected, whether taste shocks and/or conditional heteroscedasticity are allowed or not. While the presence of GARCH processes is not rejected and produces a modest increase in precision, it does not substantially alter point estimates of the structural parameters. Therefore, time-varying equity premia obtained through conditional heteroscedastic second moments does not provide the answer to the high observed equity premia, regardless of the separability of preferences. Furthermore, the hypothesis of sensitivity of preferences to taste shocks cannot be rejected for either separable or non-separable case, independently of the scedastic structure. Perhaps more importantly, we also observe that, under separable preferences, taste shocks provide for a dramatic reduction in the estimate for the coefficient of relative risk aversion, by shifting weight away from consumption risk. This provides a partial answer for the equity premium puzzle.

Indeed, since we deliberately remained agnostic about the causes of the taste shocks, a natural extension would be to investigate their sources. Hence, for instance, since both separable and non-separable preferences assume iso-elastic preferences toward risk, a potential for improvement could be in exploring other parameterizations for risk aversion. Another alternative extension would be to analyze whether the separable preferences with taste shocks can also resolve the risk-free rate puzzle (i.e. the observed interest rate is excessively low). This procedure would however force us to estimate a fourth preference parameter, the subjective discount rate, and to specify an arbitrary law of motion for taste shocks. Since little theoretical or experimental guidance about the nature of taste shocks is available, this procedure clearly encompasses numerous challenges.

A Descriptive statistics

Table 1: Descriptive statistics.

series	mean (e-02)	max	min	covariance (e-02)					
Δc_t	0.16	0.016	-0.011	0.2e-02	0.2e-02	0.1e-02	0.3e-02	0.2e-02	0.21e-02
$r^e_{1,t}$	0.48	0.22	-0.24		0.28	0.12	0.16	0.19	0.18
$r^e_{2,t}$	0.39	0.15	-0.12			0.14	0.15	0.16	0.14
$r^e_{3,t}$	0.59	0.25	-0.29				0.31	0.23	0.21
$r^e_{4,t}$	0.48	0.19	-0.21					0.24	0.20
$r^e_{m,t}$	0.44	0.16	-0.22						0.19

Note: Industry groups primary (1), transportation (2), trade (3) finance/services (4), market (m).

B Estimation Results

Table 2: Estimated preference parameters, homoscedastic case.

	Separable	Non-separable	Separable & taste shocks	Non-separable & taste shocks
LLF	8242.94	8243.76	8245.27	8245.32
OIR	4	3	3	2
LR	8.50	6.86	3.84	3.74
	[0.075]	[0.077]	[0.28]	[0.154]
α	224.73	0.43	2.90	3.35
	(135.59)	(0.98)	(0.75)	(8.06)
ρ		1.35		3.07
		(2.86)		(9.68)
λ			-0.11	-0.10
			(0.05)	(0.06)

Note: Standard errors in parentheses, marginal significance [P-value] in square brackets. LLF: Log likelihood function. OIR: Number of over-identifying restrictions. LR: Likelihood ratio test ($LLF_{URF} = 8247.19$).

Table 3: Estimated preference and GARCH(1,1) parameters, cond. heteroscedastic case.

	Separable	Non-separable	Separable & taste shocks	Non-separable & taste shocks
LLF	8247.34	8248.49	8250.70	8251.01
OIR	9	8	8	7
LR	15.94	13.64	9.22	8.60
	[0.068]	[0.092]	[0.32]	[0.28]
α	288.1	0.41	1.43	3.62
	(151.3)	(1.03)	(0.48)	(7.09)
ρ		1.25		2.60
		(2.75)		(8.82)
λ			-0.15	-0.11
			(0.05)	(0.05)
δ_1	0.68e-01	0.68e-01	0.68e-01	0.68e-01
	(0.33e-01)	(0.33e-01)	(0.33e-01)	(0.33e-01)
δ_2	0.84	0.84	0.84	0.84
	(0.78e-01)	(0.78e-01)	(0.78e-01)	(0.78e-01)
LR	8.80	9.46	10.86	11.38
	[0.12e-01]	[0.88e-02]	[0.44e-02]	[0.34e-02]
$q = 4$	0.61	0.61	0.61	0.61
	[0.55]	[0.55]	[0.55]	[0.55]
$q = 8$	0.49	0.49	0.49	0.49
	[0.81]	[0.81]	[0.81]	[0.81]
$q = 12$	0.95	0.95	0.95	0.95
	[0.49]	[0.49]	[0.49]	[0.49]

Note: Standard errors in parentheses, marginal significance [P-value] in square brackets. LLF: Log likelihood function. OIR: Number of over-identifying restrictions. LR: Likelihood ratio test ($LLF_{URF} = 8255.31$). $q = 4, 8, 12$: F-test for joint exclusion of $b_3 = \ldots = b_q = 0$ in conditional heteroscedasticity test equation: $\boldsymbol{\epsilon}_{t|t}^2 = \boldsymbol{a} + \sum_{j=1}^{q} b_j \boldsymbol{\epsilon}_{t-j|t-j}^2 + res_t$.

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