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Incomplete Markets and Security Prices: Do Asset-Pricing Puzzles Result from Aggregation Problems?

Kris Jacobs*

Abstract

This paper investigates Euler equations involving security prices and household-level consumption data. It provides a useful complement to many existing studies of consumption-based asset pricing models that use a representative-agent framework, because the Euler equations under investigation hold even if markets are incomplete. It also provides a useful complement to simulation-based studies of market incompleteness. The empirical evidence indicates that the theory is rejected by the data along several dimensions. The results therefore indicate that some well-documented asset-pricing puzzles do not result from aggregation problems for the preferences under investigation.

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Abstract

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Introduction

The last two decades have witnessed an explosion in theoretical and empirical investigations of the relation between security prices and macroeconomic variables. An extensive literature has focused on representative-agent consumption-based asset pricing models, which attempt to explain stock and bond prices by analyzing the behaviour of a representative agent who maximizes expected lifetime utility. Early empirical investigations of these models conclude that various aspects of the model are strongly at odds with the data (e.g., see Grossman and Shiller (1981), Hansen and Singleton (1982, 1983), and Mehra and Prescott (1985)).

Two explanations for these empirical failures have been proposed. First, an extensive literature has investigated modifications and generalizations of the preferences of the representative agent. This approach has been successful in some dimensions. For instance, preferences exhibiting habit persistence have been used to construct models which are able to match some aspects of the data (e.g., see Constantinides (1990) and Campbell and Cochrane (1995)).

A second explanation has investigated the extent to which the poor empirical performance of consumption-based asset pricing models can be attributed to ancillary assumptions which underlie the representative-agent framework. Much of the motivation for studying the representative-agent model stems from the fact that, under a complete markets assumption, its predictions coincide with those of a competitive equilibrium in a decentralized economy. However, a complete markets structure involves some fairly strong assumptions concerning the nature of the information agents possess and the sophistication of insurance markets available to them. Several papers have rejected these assumptions statistically, thereby casting doubt on the implications of representative agent economies (e.g., see Attanasio and Davis (1997), Cochrane (1991), Mace (1991) and Hayashi, Altonji and Kotlikoff (1995)). Several recent studies, using theoretical arguments or simulation techniques, have concluded that deviations from market completeness may hold some promise to explain a variety of asset-pricing puzzles (e.g. see Constantinides and Duffie (1996) and Heaton and Lucas (1996)).

This paper provides statistical evidence on the importance of market incompleteness by directly analyzing the Euler equations for individual consumers, rather than those for the representative consumer. The paper uses conditional as well as unconditional information to conduct statistical inference, and therefore the papers by Hansen and Singleton (1982,1983) are the most interesting reference points in the representative agent literature. By comparing test results with results from the representative agent literature the economic importance of market completeness becomes clear, because, under market completeness, these test results should be similar. This analysis also provides a useful complement to simulation-based studies of market incompleteness, because the relations under investigation hold under fairly general conditions and make relatively few assumptions on issues which affect the result of simulation studies. In addition, theory is evaluated in a direct fashion as opposed to the more indirect criteria used by simulation studies.

The main purpose of the paper is to provide a detailed comparison of empirical tests and behavioral parameters obtained using household data with findings from the representative agent literature. To allow such comparisons, I focus on a standard time separable constant relative risk aversion (TS-CRRA) utility function. Using a TS-CRRA preference specification, time series studies have concluded that, whereas equilibrium restrictions pertaining to risky assets are sometimes supported by the data, this is almost never the case for restrictions pertaining to riskless assets. Moreover, the set of restrictions involving both assets is typically strongly rejected by the data. Here I investigate whether these stylized facts also hold when estimating Euler equations involving household-level data.

The paper concludes that some implications of the theory are rejected by the data. To some extent findings are similar to those of the representative agent literature, because the implications of the model pertaining to the riskless asset are strongly rejected for a large number of instrument sets. The implications of the model pertaining to the risky asset are also often rejected, but some instrument sets that yield rejections for the riskless asset do not yield rejections for the risky asset. Estimates of behavioral parameters are very robust, which is important because the CRRA parameter is intimately related to the price of risk. Estimates of the rate of relative risk aversion are in the concave region of the parameter space, and implied risk aversion is moderate.[1]

Besides the importance of the empirical results within the TS-CRRA framework, the results are indicative of the usefulness of analyzing decentralized economies in this way. Estimating Euler equations from panel data is complicated by econometric problems and data problems such as the presence of measurement error in the data. However, empirical results in this paper indicate that the analysis of nonlinear Euler equations using panel data is worthwhile. A search for appropriate preferences using household data should therefore provide a useful complement to the rich literature that uses the representative agent paradigm. Because the estimates obtained in this study rely on weaker assumptions, estimated behavioral parameters are more easily related to the preferences of individual agents. These estimates are therefore more appropriate for use in simulation exercises than estimates obtained using time-series data.

The paper proceeds as follows. Section I provides a detailed motivation for this study by discussing relevant theory and existing research. Section II discusses the data and the econometric framework. Section III presents and discusses the empirical results. Section IV concludes and outlines avenues for future research.

I. Motivation

Consider an economy populated by a large number of agents with identical preferences for consumption, but with different endowment streams. These agents do not have access to a complete market in contingent claims, but they have a riskless asset (a bond) and a risky asset (a stock) available to smooth their consumption. Given this market structure and a time-separable specification of preferences, each agent i maximizes expected lifetime utility

$$\underset{c_{i,t},b_{i,t+1},s_{i,t+1}}{Max} \qquad E_0 \sum_{t=0}^{\infty} \beta^t \ u(c_{i,t}) \tag{1}$$

subject to a sequence of budget constraints of the form

$$c_{i,t} \ + \ p_t s_{i,t+1} \ + \ q_t b_{i,t+1} \ = \ (p_t + d_t) s_{i,t} \ + \ b_{i,t} \tag{2}$$

where

$c_{i,t}$ is per capita consumption in period t;
$b_{i,t}$ represents per capita holdings of the riskless asset in period t;

$s_{i,t}$ represents per capita holdings of the risky asset in period t;
p_t is the price of the risky asset in period t;
d_t is the dividend on the risky asset in period t;
q_t is the (normalized) price of the riskless asset in period t;
ß is the discount factor;
u(.) is the per period utility function; and
E_t is the mathematical expectation conditional on information available at *t*.

This optimization problem yields the following first-order conditions:

$$\left[u'(c_{i,t}) - \lambda_{i,t}\right]c_{i,t} = 0 \tag{3}$$

$$\left[-\lambda_{i,t}q_t + \beta E_t\lambda_{i,t+1}\right]b_{i,t} = 0 \tag{4}$$

$$\left[-\lambda_{i,t}p_t + \beta E_t(p_{t+1} + d_{t+1})\lambda_{i,t+1}\right]s_{i,t} = 0 \tag{5}$$

where $\lambda_{i,t}$ is the Lagrange multiplier associated with the time *t* budget constraint. If we assume that all households consume strictly positive amounts and limit our sample to those households holding bonds and stocks, we can use (3), (4) and (5) to obtain

$$1 = \beta E_t \frac{1}{q_t}\frac{u'(c_{i,t+1})}{u'(c_{i,t})} \tag{6}$$

$$1 = \beta E_t\left(\frac{p_{t+1} + d_{t+1}}{p_t}\right)\frac{u'(c_{i,t+1})}{u'(c_{i,t})} \tag{7}$$

If agents have access to a complete market in contingent claims, the Euler equations (6) and (7) hold not only for individual consumers, but also for a representative consumer, with the aggregate marginal utility of consumption taking the place of the individual's marginal utility of consumption. Those Euler equations have received considerable interest in the empirical literature that relates equilibrium prices and consumption. Using a time separable constant relative risk aversion specification (TS-CRRA) the model has been investigated along several dimensions. Hansen and Singleton (1982, 1983, 1984) report statistical tests based on the orthogonality between the Euler equation errors in (6) and (7) and variables in the agent's information set. They reject the model statistically and in some cases obtain parameter estimates in the nonconcave region of the parameter space. They reject the Euler equation involving the riskless asset (6) more often than the one involving the risky asset (7). When considering both Euler equations jointly the model is strongly rejected by the data.[2]

In short, the empirical performance of the consumption-based asset pricing model using the TS-CRRA preference specification has not been a success. In response, the literature has investigated two modifications of this basic framework which are of particular interest here.[3] A first line of research has investigated alternative preference specifications.[4] In summary, this research strategy has achieved considerable success in improving the empirical performance of the TS-CRRA specification, but has not succeeded in explaining all aspects of the data. For instance, Kocherlakota (1996) argues convincingly that the equity premium puzzle is not explained by any of these alternative preferences.

The second modification to the basic framework addresses the importance of the complete markets assumption. The existence of a complete market in contingent claims allows agents with different endowment patterns to arrange their consumption profiles as advantageously as possible, giving rise to perfect correlation between agents' marginal utilities and identical correlations with market prices. The economy can therefore be studied by focusing on the Euler equation for the representative agent's problem because the correlation between the representative agent's marginal utility and prices is the same as the one between an individual's marginal utility and prices.

If agents do not have access to complete markets, marginal utilities will not be perfectly correlated, and the Euler equation for the representative agent will not necessarily have an obvious connection with the competitive equilibrium of an economy which consists of identical agents who all have preferences equal to those of the representative agent. This is problematic because the performance of consumption-based asset pricing models has been assessed not only by means of formal test statistics, but also in terms of implied values of behavioral parameters.

Casual observation suggests that this theoretically convenient structure of marginal utility may be hard to achieve with existing opportunities for risk sharing. Also, a number of recent studies show that the existence of a set of contingent claims markets can be statistically rejected (e.g., see Attanasio and Davis (1997), Cochrane (1991), Mace (1991) and Hayashi, Altonji and Kotlikoff (1995)). Therefore, an interesting second modification of the original consumption-based asset pricing model involves relaxing the assumption that agents have access to a complete market in contingent claims.

Recently an interesting literature has developed which addresses the quantitative importance of deviations from market completeness by means of simulation techniques. Simulations for economies with complete markets are compared to economies where agents do not have access to complete markets, but have certain assets available to insure themselves. Whereas early studies (e.g. Telmer (1993), Lucas (1994) and Rios-Rull (1994)) conclude that economies with market incompleteness have similar outcomes as those with complete markets, Heaton and Lucas (1996) find that some asset-pricing puzzles can be resolved when taking transactions costs into account. (See also Luttmer (1996) on this issue). Constantinides and Duffie (1996), using a theoretical argument, show that market incompleteness can resolve some asset-pricing puzzles if shocks to the income processes are sufficiently persistent.

This paper investigates the quantitative importance of incomplete markets by studying the Euler equations (6) and (7) directly. By investigating such restrictions at the disaggregate level, a search for appropriate preference specifications can be conducted which is a useful complement to investigations using time-series data, on one hand, and to simulation-based inference, on the other hand. The use of time-series data has some advantages compared to disaggregate data, such as less dramatic measurement error problems and the availability of long time series. However, the interpretation of estimated parameter values is subject to a set of ancillary assumptions regarding the validity of aggregation. Compared to simulation-based inference, the techniques in this paper obviously face numerous econometric and data constraints, but the results are less sensitive to a variety of assumptions which turn out to critically affect simulation, such as the persistence of idiosyncratic shocks to income and the net supply of bonds. (See Constantinides and Duffie (1996), Kocherlakota (1996) and especially Heaton and Lucas (1996) for the importance of these assumptions for simulation studies).

In this paper I use data from the Panel Study on Income Dynamics (PSID) to investigate Euler equations at the disaggregate level. I investigate (6) and (7) using a constant relative risk aversion specification

$$u(c_{i,t}) = \frac{1}{\gamma} c_{i,t}^{\gamma} \tag{8}$$

where $1-\gamma$ is the coefficient of relative risk aversion. I obtain estimates of the behavioral parameters and tests of the model by exploiting the fact that the econometric errors associated with Euler equations (6) and (7) should be orthogonal to variables in the agents' information sets.

This research is related in part to the literature on the permanent income hypothesis and liquidity constraints (see Attanasio and Browning (1995), Deaton (1992), Hall and Mishkin (1982), Runkle (1991) and Zeldes (1989)). Studies of the permanent income hypothesis that use panel data essentially test the orthogonality between the error associated with (6) and variables in the household's information set. This paper provides a more general analysis of these market structures. First, I estimate and test not only the Euler equation involving a riskless asset, but also the Euler equation involving a risky asset, as well as both Euler equations jointly. These tests are motivated by stylized facts in the time-series literature. Whereas Hansen and Singleton (1982, 1983, 1984) find strong evidence against the model when investigating the Euler equation involving the riskless asset and the Euler equations for the riskless and risky assets jointly, the Euler equation associated with the risky asset is often not rejected by the data. Other studies investigating different aspects of the data have confirmed that the Euler equation involving the riskless asset is very strongly at odds with the data (e.g., see Weil (1989) and Cochrane and Hansen (1992)). Second, a vast literature suggests that preferences are often conditional on demographic variables such as age. I investigate the extent to which including such demographics in the Euler equation improves the fit of the model. Third, I investigate in detail to what extent the inclusion in the sample of households who are not at interior positions affects estimation and testing. To the extent that studies mentioned above have addressed this issue, they have used different selection criteria from the ones used in this paper. Fourth, I use different test statistics compared to many existing studies. Most importantly, previous studies investigate a linearized version of the Euler equations. For instance, Attanasio and Weber (1993, 1995) investigate aggregation using a linearization of (6). They find that incorrect aggregation severely affects estimation and test results in that context. I estimate the Euler equations (6) and (7) using nonlinear estimation, because linearization may yield implausible parameter estimates.

Besides the literature on the permanent income hypothesis, there are three other studies which are related to this paper. Interesting studies by Mankiw and Zeldes (1991) and Brav and

Geczy (1996) use panel data to study the equity premium puzzle. The investigation by Mankiw and Zeldes also uses the PSID but stresses the moments of the Euler equation errors and does not investigate the relation to variables in the information set. Moreover, their results do not rely on formal statistical procedures and stress the properties of per capita consumption as opposed to consumption at the household level. Brav and Geczy (1996) use the Consumer Expenditure Survey (CES) and extend the analysis of Mankiw and Zeldes in several ways. The critical difference with my investigation is that they work with per capita consumption. Therefore, the implications of the model they investigate are not generally valid under incomplete markets.[5]

One study that directly addresses nonlinearities, the properties of household consumption, and the importance of demographics is Altug and Miller (1990). Altug and Miller estimate the nonlinear Euler equation (7) for a nonseparable specification and use demographics as preference shifters. However, they do so under the maintained assumption of market completeness. They cannot reject the implications of (7). The problem with this result is that whereas Altug and Miller do not reject market completeness, later studies have attributed this finding to their testing strategy and instrument selection (e.g., see Attanasio and Davis (1997), Cochrane (1991), Mace (1991) and Hayashi, Altonji and Kotlikoff (1995)). If market completeness does not hold, Altug and Miller's nonrejection of restrictions implied by Euler equations is difficult to interpret. In any case, an investigation of Euler equations under alternative assumptions seems worthwhile.

II. Data and Estimation

The empirical investigation uses data from the Panel Study of Income Dynamics (PSID) for the period 1974-1987. The PSID has been used extensively in existing studies of life-cycle optimization (e.g., see Hall and Mishkin (1982), Hotz, Kydland and Sedlacek (1988), Mankiw and Zeldes (1990, 1991), Runkle (1991) and Zeldes (1989)). The PSID has certain disadvantages, such as the fact that it does not contain a satisfactory measure of total consumption. Therefore, I follow existing studies that use the PSID by using household food consumption as the consumption measure. The construction of household food consumption and data selection issues are discussed in Appendix I.[6]

In the PSID, the household is the unit of observation and the only consumption measure available is household consumption. Consequently, the fact that preferences are defined at the level of the individual complicates empirical testing. I solve this problem by including an exponential function of household size in periods *t* and *t+1* in preferences (see below). A related issue is that a vast literature suggests that preferences are often conditional on demographic variables such as age. Therefore, I analyze the Euler equations with and without an exponential function of such variables included as preference shifters. The Euler equations including preference shifters are given by

$$1 = \beta E_t \frac{1}{q_t}\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1} \exp\left[f_1 fs_{i,t+1} + f_2 fs_{i,t}\right] \exp\left[d \;\, demo_{i,t+1}\right] \tag{9}$$

$$1 = \beta E_t \left(\frac{p_{t+1}+d_{t+1}}{p_t}\right)\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1} \exp\left[f_1 fs_{i,t+1} + f_2 fs_{i,t}\right] \exp\left[d \;\, demo_{i,t+1}\right] \tag{10}$$

where $fs_{i,t}$ stands for family size in period *t*;
$demo_{i,t}$ stands for a vector of preference shifters at time *t*; and
f_1, f_2 are scalar parameters and *d* is a vector of parameters.

Parameter estimates and test statistics are obtained by exploiting the orthogonality between the Euler equation errors and variables in the agent's information set using a Generalized Method of Moments (GMM) framework (see Hansen (1982)). The framework is similar to the one used in Hansen and Singleton (1982) in a representative agent context, but the panel aspect of the data generates some additional difficulties. Appendix II discusses the estimation of the Euler equations including preference shifters, but the case without preference shifters is obviously included as a special case. It must be noted that the estimation framework is very general. For instance, it allows for the panel to be unbalanced.

In the GMM framework, the choice of instruments becomes a crucial issue because it can critically affect estimation and test results.[7] Results are reported for several instrument sets. Most of these instrument sets are fairly small, because the small time dimension of the dataset *(T=12)* limits the number of instruments in case one wants to construct covariance matrices in a general nonparametric way. Family size in periods *t+1* and *t* is included in every instrument set. The first instrument set used further contains a constant, the lagged riskless rate of return and the unemployment rates for the household head's occupation lagged once interacted with the age of the household head. The second instrument set reported on is larger: besides family size and lagged family size it includes a constant, the lagged interest rate and stock market return, the occupational unemployment rate for the household head, this unemployment rate interacted with his/her age and the unemployment rate interacted with his/her education. A third instrument set is meant to address the importance of demographics in Euler equations. It contains the instruments in the second instrument set plus the age of the household head.

An important motivation for using the PSID to analyze the issues outlined in Section I is that the PSID allows me to construct samples of households who are at interior solutions. This allows me to investigate the extent to which tests of Euler equations are affected by including households in the sample for whom this Euler equation does not necessarily hold. Moreover, comparison of restricted and unrestricted samples can illustrate the extent to which tests of Euler equations using time-series data are affected by including households who are at corners. To identify households at interior solutions, I use a 1984 question from the PSID which asks households for their holdings of liquid assets and stocks. This question is the same as that used by Mankiw and Zeldes (1991) to analyze aspects of the equity premium puzzle. The question allows me to construct four samples of interest: (i) a sample including all households that satisfy the selection criteria; (ii) a sample including only households in (i) who have nonzero holdings of the relevant asset; and (iii) and (iv) samples including only households in (i) with holdings of the relevant asset larger than $1,000 or $10,000, respectively. This question is discussed in more detail in Appendix I.

The construction of returns on stock and bond markets is crucial to the analysis. To match returns with the time dimension of consumption, I construct yearly returns as the average of twelve returns on one-year investments which expire at the end of every month of the year. This construction is motivated by the interpretation of consumption as yearly totals (flows) and not stocks at one point in time. The bond returns are returns on rolling over three-month treasury bills and are obtained from Moody’s. The stock returns are returns on the Standard and Poor’s 500 composite.

III. Empirical Results

The discussion of the empirical results intends to address several questions. First, which theoretical implications are statistically rejected? A second issue of interest are the estimates of behavioral parameters.[8] Third, should Euler equations be estimated conditional on demographic variables? In answering this question, I analyze the impact of demographic variables on estimates of behavioral parameters, as well as their impact on test statistics. Fourth, does the inclusion of households who are at corners yield misleading conclusions when using formal test statistics or when estimating behavioral parameters?

Summarizing my results at the outset, the evidence supports two main conclusions. First, test statistics provide a considerable amount of evidence against certain implications of the consumption-based asset-pricing model. I limit my investigation to instrument sets that are highly correlated with the observables in the Euler equation (asset returns and consumption growth). However, some instruments, such as lagged consumption growth, are excluded to avoid the most serious measurement error problems. For the instruments that I investigate, I find that the Euler equation associated with the riskless asset is rejected by the data for a very large number of instrument sets. However, in the case of the Euler equation associated with the risky asset the evidence is more mixed, with certain instrument sets yielding a statistical rejection and others a statistical nonrejection. When considering both Euler equations jointly, the evidence against the model is typically also quite strong. A second conclusion is that estimates of behavioral parameters are very robust. Estimates of the discount rate are intuitively plausible, and estimates of the rate of relative risk aversion are in the concave region of the parameter space and indicate relatively moderate risk aversion. This finding confirms results from the representative agent literature when similar orthogonality conditions are used.[9]

In Tables I through VII, I present results using three different instrument sets.[10] The results in Tables I-III are obtained using the first instrument set. The results in Tables IV-V are obtained using the second instrument set. The results in Tables VI-VII are obtained using the third instrument set. Results for the first two instrument sets are meant to support the main conclusions. Results for the third instrument set address the importance of demographics in Euler equations.

Tables I, IV and VI contain results for the Euler equation associated with the riskless asset. Tables II, V and VII contain results associated with the Euler equation for the risky asset. Table III contains results obtained by considering both Euler equations jointly. In each table, column 1 contains results for the largest sample, which includes households who are at corners. Column 2 contains results obtained with a sample that only includes households which report nonzero holdings of the asset(s) under investigation. Columns 3 and 4 contain results for households which report holdings of the asset(s) under investigation larger than $1,000 or $10,000, respectively.

Every table contains point estimates and standard errors for the behavioral parameters. Estimates of parameters that capture the importance of family size and preference shifters are omitted to save space. The tables further include the test statistic associated with the overidentifying restrictions and the significance level associated with this statistic, which can be obtained by noting that the test statistic is asymptotically distributed as a Chi-square statistic with degrees of freedom equal to the number of overidentifying conditions. To clarify how this significance level is obtained, the number of instruments used in each table and the number of overidentifying conditions are also listed. Every table also includes the total number of households included *H*, the sample size *N* and the number of iterations on the covariance matrix required to obtain the results that are listed.

Tables IA, IB about here

Table I contains results for the Euler equation associated with the riskless asset obtained with five instruments. Table IA contains estimates and test statistics obtained using the covariance matrix (AII-8) and the potentially more powerful test statistics obtained using covariance matrix (AII-10). Table IB contains results obtained using the covariance matrix (AII-9), which does not allow contemporaneous correlation between the Euler equations of different households at a point in time.

All of these results are obtained using the one-round GMM estimator in (AII-5). Standard errors are computed using (AII-7) and test statistics are computed using (AII-6).[11] First consider estimates of the behavioral parameters in Table IA. The estimate of the rate of time preference β is between 0.905 and 0.968, values which are widely considered to be intuitively plausible. Also, the estimate of the rate of relative risk aversion $1-\gamma$ is between 0.541 and 1.238. These values are in the concave region of the parameter space and, moreover, indicate moderate risk aversion. Except for the estimate of the coefficient of relative risk aversion in column 4, all parameters are also estimated relatively precisely when using conventional significance levels.

Interestingly, comparison of column 1 with columns 2, 3 and 4 indicates that the inclusion of households at corners in the sample does not significantly bias the estimates of behavioral parameters. Inspection of the test statistics in Table IA shows that the test statistics are highest in column 1. However tempting to interpret this as more evidence against the sample with household at corners, the results merely indicate that at the 5 percent level the theory is rejected by the data, even when excluding households at corners. Notice that, as expected, the tests computed using covariance matrix (AII-10) are more powerful than those computed using covariance matrix (AII-8). Finally, consider the test results in Table IB. Test statistics are dramatically higher than those in Table IA. The data therefore indicate that there is substantial positive correlation between Euler equation errors of different households at a point in time. By neglecting this correlation, one would conclude that the evidence against the model is far more dramatic than indicated in Table IA.

Tables IIA, IIB about here

Table II contains results of estimation of the Euler equation associated with the risky asset, obtained with five instruments. The results in Tables IIA and IIB are obtained using the one-round GMM estimator in (AII-5), using the covariance matrices in (AII-8), (AII-10) and (AII-9).[12] The behavioral parameters are significantly estimated in most cases, and just as in Table I the estimates are quite robust across columns. Compared to Table I, the estimates of the parameter of relative risk aversion are larger and the estimates of β are significantly smaller. This finding is similar to findings in several papers in the representative agent literature. Kocherlakota (1996) provides intuition for this finding in the case where only unconditional information is used.

As anticipated, the test statistics obtained using (AII-10) are higher than those obtained using (AII-8), but they still yield several nonrejections at the 5 percent level. At the 1 percent level, the theory is not rejected for any sample, even for the more powerful test statistics. So whereas the theory is strongly rejected for the Euler equation involving the riskless asset in Table

I, Table II indicates that it is frequently not rejected when testing the Euler equation involving the risky asset. This finding is representative for a large number of instrument sets that I investigate: the Euler equation involving the riskless asset is usually strongly rejected, whereas the one involving the risky asset is rejected for some instrument sets and not for others. These findings are also similar to those of studies in the representative agent literature that have exploited similar restrictions (e.g., see Hansen and Singleton (1983)). Parameter estimates obtained here are also relatively similar to those studies. However, parameter estimates obtained here are more robust and parameters are more precisely estimated than in those studies.

Tables IIIA, IIIB about here

Representative agent studies find that the theory gets little support from the data when testing both Euler equations jointly. Table IIIA confirms that in several cases the theory is rejected at conventional significance levels even when allowing for market incompleteness. Estimated values of behavioral parameters are usually in between the point estimates in Tables I and II. Just as in Tables I and II, estimated parameter values in column 1 are not very different from those in columns 2, 3, and 4. Table IIIB indicates that accounting for contemporaneous correlation between households' Euler equation errors is even more crucial here than in the one-equation cases in Tables I and II. Without taking these correlation patterns into account, all samples would yield very dramatic rejections.

Tables IVA, IVB, VA, VB about here

The results in Tables IV-V, obtained with an instrument set with eight instruments, are indicative of the robustness of the results in Tables I and II. With regard to the estimated parameter values, the results are remarkably robust. Estimates of the parameter of relative risk aversion are larger in Table V than in Table IV and estimates of β lower. However, the test statistics indicate differences from the statistical evidence documented in Tables I and II. Inspecting test statistics obtained with the covariance matrix (AII-10) in Tables IVA and VA, it can be seen that the Euler equation associated with the risky asset is now rejected as well as the Euler equation associated with the riskless asset.[13]

Tables VI, VII about here

Finally, Tables VI and VII are meant to illustrate the importance of including preference shifters in the Euler equation. Tables VI and VII use the same instrument set used to generate Tables IV and V, except that the age of the household head, which is now also a regressor, is also included in the instrument set. Therefore the total number of instruments is now nine, but the number of overidentifying conditions is four, the same as in Tables IV and V.

The results in Tables VI and VII show that including the preference shifter does not dramatically affect estimates of behavioral parameters. When including the preference shifter, the statistical tests also indicate some nonrejections at conventional significance levels for cases where Tables IVA and VA indicate rejection. This seems to indicate that the data support the inclusion of demographics in the Euler equation. Overall this analysis of the importance of demographics is rather favourable to the use of general equilibrium models to explain asset prices: whereas the evidence suggests that these models omit relevant variables (the demographics), omitting these demographics does not bias estimates of behavioral parameters, and therefore may not critically affect the implications of the model.

6. Conclusion

This paper tests Euler equations involving riskless and risky assets using household-level data from the PSID. The Euler equations under investigation are implied by theory for a variety of economic environments. One of the few assumptions underlying these Euler equations is that households have a risky and a riskless asset at their disposal in seeking to smooth consumption over time. No assumptions have to be made about the precise nature of the interaction between individuals, the nature of other available markets, or the factors that may limit a household's ability to smooth consumption. Whereas empirical testing of these Euler equations faces serious limitations in terms of data availability, this investigation should prove a useful complement to a large research project which investigates general equilibrium relationships between asset prices and aggregate consumption by using a representative-agent construction. Whereas representative agent models are readily testable and face less severe data problems, empirical rejections may indicate that the ancillary assumption of market completeness is too strong. The results in this paper are also a useful complement to a growing literature that investigates the importance of market incompleteness by means of simulation. Whereas the approach in this paper is subject to data limitations and econometric difficulties, the implications of the model that are tested are relatively robust with respect to certain assumptions that critically affect the results of simulation-based studies, such as the persistence of idiosyncratic income shocks or the net supply of bonds.

A robust conclusion of this paper is that for the preference specification under consideration in this paper, Euler equations at the household level are not supported by the data in all dimensions, even for households at interior solutions. Therefore, investigations of market structures other than a complete contingent claims market may not be successful when adopting the preferences under consideration in this paper. It must be noted that whereas not all implications of the theory are supported, the results suggest that in certain cases it receives support from the data in certain dimensions. For example, the Euler equations pertaining to the risky asset are not rejected for a large number of instrument sets. Moreover, estimation yields robust estimates of the behavioral parameters and the data indicate moderate levels of risk aversion.

The results allow several other conclusions. They indicate that a more detailed investigation of the presence of demographic variables is warranted. Whereas including demographics in the Euler equation yields lower test statistics, it does not affect estimates of behavioral parameters. Behavioral parameters relevant for asset pricing are estimated using panel data, under fairly general assumptions. To the best of my knowledge, this is the first study that uses panel data to estimate of the discount rate under weak assumptions. Also, available estimates of parameters such as the rate of relative risk aversion are new, because existing estimates were obtained under radically different assumptions.

These results suggest a number of extensions. First, inspection of the results raises questions about the reliability of the test statistics. It may be inappropriate to rely on the asymptotic properties of these test statistics. In particular, it is possible that several of the nonrejections obtained in Tables I through VII are due to the lack of power of the tests because of the small time dimension of the dataset. Given the importance of these test statistics, it would be desirable to evaluate their small-sample performance. To investigate this further, a detailed Monte Carlo study of the performance of the test statistics within the context of the present model may be informative. Repeating the tests in this paper for datasets with a longer time dimension might also prove interesting.

Another natural extension of this paper is the search for a preference specification that implies Euler equations that are not rejected by the data (at least for households at interior solutions). There is an extensive literature which conducts such a search by using the Euler equations for the representative agent. It seems worthwhile to investigate those specifications at the household level and verify whether their success or lack thereof in tests of representative-agent models is confirmed by tests of household Euler equations. This suggests that tests similar to those conducted here may be instructive for highly nonlinear specifications involving time-nonseparabilities, nonexpected utility, and first-order risk aversion. Preferences based on habit formation have enjoyed some success, and it will be particularly interesting to assess their performance at the household level.

Another potentially interesting extension concerns the investigation of restrictions implied by the model other than the restrictions investigated here. In particular, tests involving Euler equation error moments using data at the household level may prove interesting. In existing tests of Euler equations using time-series data such tests typically yield dramatic rejections, and imply values for behavioral parameters other than those obtained using tests of orthogonality conditions.

This work on alternative preference specifications may also prove useful for a growing literature which analyzes asset pricing by simulating general equilibrium models. It seems particularly interesting to use estimates of behavioral parameters in such exercises which can be easily related to the preferences of individual agents populating the economies under consideration. Estimates such as those obtained in this paper seem to be good candidates.

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Table IA
Estimation and test results for the Euler equation associated with the riskless asset
Results obtained using instrument set one

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{1}{q_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma - 1$. Results for f_1 and f_2 are not reported. Instrument set one includes five instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once and the unemployment rate for the household head's occupation lagged once interacted with the age of the household head. Given that there are four parameters to be estimated and five instruments, test statistics have one degree of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Two different test statistics are constructed that differ in the construction of the variance-covariance matrix used in the computations. Both test statistics allow for contemporaneous correlation between households' Euler equation errors. Test statistic 1 constructs the variance-covariance matrix using the raw sample orthogonality conditions. Test statistic 2 constructs the variance-covariance matrix using demeaned sample orthogonality conditions. The use of test statistic 2 therefore leads to a more powerful test than the use of test statistic 1. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.923 (0.042)	0.905 (0.079)	0.934 (0.044)	0.968 (0.056)
$\gamma - 1$ (Standard Deviation)	-1.030 (0.313)	-1.238 (0.516)	-1.115 (0.392)	-0.541 (0.995)
Number of Instruments Degrees of Freedom	5 1	5 1	5 1	5 1
Test statistic 1 (Significance Level)	7.227 (0.007)	5.745 (0.016)	6.223 (0.012)	6.632 (0.010)
Test statistic 2 (Significance Level)	18.128 (0.000)	11.020 (0.001)	12.929 (0.000)	14.838 (0.000)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	2452 14691	1465 9464	428 2961

Table IB
Estimation and test results for the Euler equation associated with the riskless asset
Results obtained using instrument set one
No contemporaneous correlation in covariance matrix

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta(\frac{c_{i,t+1}}{c_{i,t}})^{\gamma-1} (\frac{1}{q_t}) \exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set one includes five instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once and the unemployment rate for the household head's occupation lagged once interacted with the age of the household head. Given that there are four parameters to be estimated and five instruments, test statistics have one degree of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.923 (0.027)	0.905 (0.063)	0.934 (0.033)	0.968 (0.073)
$\gamma-1$ (Standard Deviation)	-1.030 (0.194)	-1.238 (0.406)	-1.115 (0.274)	-0.541 (1.309)
Number of Instruments Degrees of Freedom	5 1	5 1	5 1	5 1
Test statistic (Significance Level)	77.981 (0.000)	41.713 (0.000)	36.543 (0.000)	80.098 (0.000)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	2452 14691	1465 9464	428 2961

Table IIA
Estimation and test results for the Euler equation associated with the risky asset
Results obtained using instrument set one

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{p_{t+1}+d_{t+1}}{p_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set one includes five instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once and the unemployment rate for the household head's occupation lagged once interacted with the age of the household head. Given that there are four parameters to be estimated and five instruments, test statistics have one degree of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Two different test statistics are constructed that differ in the construction of the variance-covariance matrix used in the computations. Both test statistics allow for contemporaneous correlation between households' Euler equation errors. Test statistic 1 constructs the variance-covariance matrix using the raw sample orthogonality conditions. Test statistic 2 constructs the variance-covariance matrix using demeaned sample orthogonality conditions. The use of test statistic 2 therefore leads to a more powerful test than the use of test statistic 1. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.784 (0.161)	0.681 (0.201)	0.699 (0.228)	0.800 (0.130)
$\gamma-1$ (Standard Deviation)	-1.516 (0.733)	-2.231 (0.854)	-2.262 (1.082)	-1.742 (1.014)
Number of Instruments Degrees of Freedom	5 1	5 1	5 1	5 1
Test statistic 1 (Significance Level)	3.012 (0.082)	2.929 (0.087)	2.594 (0.107)	1.909 (0.167)
Test statistic 2 (Significance Level)	4.022 (0.044)	3.876 (0.048)	3.308 (0.068)	2.275 (0.131)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	770 5197	495 3448	198 1465

Table IIB
Estimation and test results for the Euler equation associated with the risky asset
Results obtained using instrument set one
No contemporaneous correlation in covariance matrix

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{p_{t+1}+d_{t+1}}{p_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set one includes five instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once and the unemployment rate for the household head's occupation lagged once interacted with the age of the household head. Given that there are four parameters to be estimated and five instruments, test statistics have one degree of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.784 (0.056)	0.681 (0.121)	0.699 (0.222)	0.800 (0.154)
$\gamma-1$ (Standard Deviation)	-1.516 (0.287)	-2.231 (0.584)	-2.262 (1.120)	-1.742 (1.152)
Number of Instruments Degrees of Freedom	5 1	5 1	5 1	5 1
Test statistic (Significance Level)	151.527 (0.000)	12.934 (0.000)	9.034 (0.002)	8.873 (0.002)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	770 5197	495 3448	198 1465

Table IIIA
Estimation and test results for both Euler equations estimated jointly
Results obtained using instrument set one

Estimation and test results obtained by GMM estimation of the Euler equations

$$1 = \beta(\frac{c_{i,t+1}}{c_{i,t}})^{\gamma-1} (\frac{1}{q_t}) \exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

$$1 = \beta(\frac{c_{i,t+1}}{c_{i,t}})^{\gamma-1} (\frac{p_{t+1}+d_{t+1}}{p_t}) \exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set one includes five instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once and the unemployment rate for the household head's occupation lagged once interacted with the age of the household head. Given that there are four parameters to be estimated and five instruments per equation, test statistics have six degrees of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Two different test statistics are constructed that differ in the construction of the variance-covariance matrix used in the computations. Both test statistics allow for contemporaneous correlation between households' Euler equation errors. Test statistic 1 constructs the variance-covariance matrix using the raw sample orthogonality conditions. Test statistic 2 constructs the variance-covariance matrix using demeaned sample orthogonality conditions. The use of test statistic 2 therefore leads to a more powerful test than the use of test statistic 1. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.833 (0.138)	0.764 (0.140)	0.723 (0.190)	0.894 (0.069)
$\gamma-1$ (Standard Deviation)	-1.393 (0.670)	-1.941 (0.659)	-2.323 (0.882)	-0.826 (0.438)
Number of Instruments Degrees of Freedom	5 6	5 6	5 6	5 6
Test statistic 1 (Significance Level)	9.029 (0.171)	11.479 (0.074)	31.711 (0.000)	9.724 (0.136)
Test statistic 2 (Significance Level)	15.844 (0.014)	14.370 (0.025)	34.897 (0.000)	29.539 (0.000)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	740 5029	413 2990	103 769

Table IIIB
Estimation and test results for the Euler equation associated with the riskless asset
Results obtained using instrument set one
No contemporaneous correlation in covariance matrix

Estimation and test results obtained by GMM estimation of the Euler equations

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{1}{q_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{p_{t+1}+d_{t+1}}{p_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set one includes five instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once and the unemployment rate for the household head's occupation lagged once interacted with the age of the household head. Given that there are four parameters to be estimated and five instruments per equation, test statistics have one degree of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.833 (0.048)	0.764 (0.097)	0.723 (0.193)	0.894 (0.095)
$\gamma-1$ (Standard Deviation)	-1.393 (0.260)	-1.941 (0.498)	-2.323 (0.966)	-0.826 (0.931)
Number of Instruments Degrees of Freedom	5 6	5 6	5 6	5 6
Test statistic (Significance Level)	3999.605 (0.000)	921.965 (0.000)	432.539 (0.000)	179.860 (0.000)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	740 5029	413 2990	103 769

Table IVA
Estimation and test results for the Euler equation associated with the riskless asset
Results obtained using instrument set two

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{1}{q_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set two includes eight instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once, the risky rate of return lagged once, the unemployment rate for the household head's occupation lagged once, this unemployment rate lagged once interacted with age of the household head, and this unemployment rate lagged once interacted with education of the household head. Given that there are four parameters to be estimated and eight instruments, test statistics have four degrees of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Two different test statistics are constructed that differ in the construction of the variance-covariance matrix used in the computations. Both test statistics allow for contemporaneous correlation between households' Euler equation errors. Test statistic 1 constructs the variance-covariance matrix using the raw sample orthogonality conditions. Test statistic 2 constructs the variance-covariance matrix using demeaned sample orthogonality conditions. The use of test statistic 2 therefore leads to a more powerful test than the use of test statistic 1. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.939 (0.030)	0.897 (0.065)	0.972 (0.012)	0.981 (0.010)
$\gamma-1$ (Standard Deviation)	-0.908 (0.235)	-1.288 (0.400)	-0.685 (0.172)	-0.057 (0.088)
Number of Instruments Degrees of Freedom	8 4	8 4	8 4	8 4
Test statistic 1 (Significance Level)	8.210 (0.084)	9.521 (0.049)	9.494 (0.049)	22.970 (0.000)
Test statistic 2 (Significance Level)	26.483 (0.000)	55.404 (0.000)	38.621 (0.000)	40.310 (0.000)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	2452 14691	1465 9464	428 2961

Table IVB
Estimation and test results for the Euler equation associated with the riskless asset
Results obtained using instrument set two
No contemporaneous correlation in covariance matrix

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta(\frac{c_{i,t+1}}{c_{i,t}})^{\gamma-1} (\frac{1}{q_t}) \exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set two includes eight instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once, the risky rate of return lagged once, the unemployment rate for the household head's occupation lagged once, this unemployment rate lagged once interacted with age of the household head, and this unemployment rate lagged once interacted with education of the household head. Given that there are four parameters to be estimated and eight instruments, test statistics have four degrees of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.939 (0.019)	0.897 (0.066)	0.972 (0.010)	0.968 (0.073)
$\gamma-1$ (Standard Deviation)	-0.908 (0.155)	-1.288 (0.412)	-0.685 (0.140)	-0.057 (0.029)
Number of Instruments Degrees of Freedom	8 4	8 4	8 4	5 1
Test statistic (Significance Level)	118.608 (0.000)	45.331 (0.000)	141.411 (0.000)	1560.268 (0.000)
Iterations on Covariance Matrix	1	1	1	
H N	3555 18813	1465 9465	428 2961	428 2961

Table VA
Estimation and test results for the Euler equation associated with the risky asset
Results obtained using instrument set two

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 \;=\; \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{p_{t+1}+d_{t+1}}{p_t}\right)\exp[f_1 fs_{i,t+1} \;+\; f_2 fs_{i,t}] \;+\; e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set two includes eight instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once, the risky rate of return lagged once, the unemployment rate for the household head's occupation lagged once, this unemployment rate lagged once interacted with age of the household head, and this unemployment rate lagged once interacted with education of the household head. Given that there are four parameters to be estimated and eight instruments, test statistics have four degrees of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Two different test statistics are constructed that differ in the construction of the variance-covariance matrix used in the computations. Both test statistics allow for contemporaneous correlation between households' Euler equation errors. Test statistic 1 constructs the variance-covariance matrix using the raw sample orthogonality conditions. Test statistic 2 constructs the variance-covariance matrix using demeaned sample orthogonality conditions. The use of test statistic 2 therefore leads to a more powerful test than the use of test statistic 1. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.780 (0.135)	0.682 (0.197)	0.813 (0.261)	0.916 (0.022)
$\gamma-1$ (Standard Deviation)	-1.535 (0.590)	-2.218 (0.843)	-1.621 (1.563)	-0.121 (0.494)
Number of Instruments Degrees of Freedom	8 4	8 4	8 4	8 4
Test statistic 1 (Significance Level)	6.752 (0.149)	5.848 (0.210)	6.377 (0.172)	4.804 (0.308)
Test statistic 2 (Significance Level)	16.701 (0.002)	11.411 (0.002)	13.808 (0.007)	5.768 (0.217)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	770 5197	495 3448	198 1465

Table VB
Estimation and test results for the Euler equation associated with the risky asset
Results obtained using instrument set two
No contemporaneous correlation in covariance matrix

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{1}{q_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set two includes eight instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once, the risky rate of return lagged once, the unemployment rate for the household head's occupation lagged once, this unemployment rate lagged once interacted with age of the household head, and this unemployment rate lagged once interacted with education of the household head. Given that there are four parameters to be estimated and eight instruments, test statistics have four degrees of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.780 (0.046)	0.682 (0.118)	0.813 (0.117)	0.916 (0.008)
$\gamma-1$ (Standard Deviation)	-1.535 (0.233)	-2.218 (0.572)	-1.621 (0.765)	-0.121 (0.170)
Number of Instruments Degrees of Freedom	8 4	8 4	8 4	8 4
Test statistic (Significance Level)	204.913 (0.000)	28.479 (0.000)	47.974 (0.000)	295.465 (0.000)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	770 5197	495 3448	198 1465

Table VI
Estimation and test results for the Euler equation associated with the riskless asset
Results obtained using instrument set three
Demographics included in Euler equation

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta(\frac{c_{i,t+1}}{c_{i,t}})^{\gamma-1} \ (\frac{1}{q_t}) \ \exp[f_1 fs_{i,t} + f_2 fs_{i,t}] \ \exp[d \ demo_{i,t+1}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma - 1$. Results for f_1, f_2 and d are not reported. Instrument set three includes nine instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once, the risky rate of return lagged once, the age of the household head, the unemployment rate for the household head's occupation lagged once, this unemployment rate lagged once interacted with age of the household head, and this unemployment rate lagged once interacted with education of the household head. Given that there are five parameters to be estimated and nine instruments, test statistics have four degrees of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Two different test statistics are constructed that differ in the construction of the variance-covariance matrix used in the computations. Both test statistics allow for contemporaneous correlation between households' Euler equation errors. Test statistic 1 constructs the variance-covariance matrix using the raw sample orthogonality conditions. Test statistic 2 constructs the variance-covariance matrix using demeaned sample orthogonality conditions. The use of test statistic 2 therefore leads to a more powerful test than the use of test statistic 1. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.979 (0.028)	0.989 (0.031)	1.013 (0.029)	1.013 (0.018)
$\gamma - 1$ (Standard Deviation)	-0.964 (0.257)	-1.022 (0.298)	-1.143 (0.329)	-0.280 (0.270)
Number of Instruments Degrees of Freedom	9 4	9 4	9 4	9 4
Test statistic 1 (Significance Level)	7.218 (0.124)	6.566 (0.160)	5.899 (0.206)	8.767 (0.067)
Test statistic 2 (Significance Level)	17.186 (0.001)	14.470 (0.005)	11.627 (0.020)	32.590 (0.000)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	2452 14691	1465 9464	428 2961

Table VII
Estimation and test results for the Euler equation associated with the risky asset
Results obtained using instrument set three
Demographics included in Euler equation

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 \;=\; \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1} \left(\frac{p_{t+1}+d_{t+1}}{p_t}\right) \exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] \exp[d\; demo_{i,t+1}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1, f_2 and d are not reported. Instrument set three includes nine instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once, the risky rate of return lagged once, the age of the household head, the unemployment rate for the household head's occupation lagged once, this unemployment rate lagged once interacted with age of the household head, and this unemployment rate lagged once interacted with education of the household head. Given that there are five parameters to be estimated and nine instruments, test statistics have four degrees of freedom. Test statistics are computed according to lemma 4.1 in Hansen (1982). Two different test statistics are constructed that differ in the construction of the variance-covariance matrix used in the computations. Both test statistics allow for contemporaneous correlation between households' Euler equation errors. Test statistic 1 constructs the variance-covariance matrix using the raw sample orthogonality conditions. Test statistic 2 constructs the variance-covariance matrix using demeaned sample orthogonality conditions. The use of test statistic 2 therefore leads to a more powerful test than the use of test statistic 1. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.847 (0.115)	0.713 (0.180)	0.782 (0.224)	0.962 (0.107)
$\gamma-1$ (Standard Deviation)	-1.472 (0.539)	-2.537 (0.815)	-2.374 (0.329)	-1.338 (1.122)
Number of Instruments Degrees of Freedom	9 4	9 4	9 4	9 4
Test statistic 1 (Significance Level)	4.312 (0.365)	5.413 (0.247)	6.873 (0.142)	4.143 (0.386)
Test statistic 2 (Significance Level)	6.825 (0.145)	9.855 (0.042)	16.051 (0.002)	6.318 (0.176)
Iterations on Covariance Matrix	1	1	1	1
H N	3555 18813	770 5197	495 3448	198 1465

Appendix I: Data Selection

This appendix describes the data selection procedure for the Panel Study of Income Dynamics (PSID) data used in the empirical analysis. I use data from the PSID for the years 1974 to 1987. The data is taken from the 1987 respondent and non-respondent files of the PSID and includes all data on families headed by a male, including single males. Observations on individuals in the poverty subsample are included in the sample if they fulfil the selection criteria.

The central issue is the construction of the consumption measure. The most important problem is that the PSID allows only the construction of a measure of food consumption. I therefore follow the existing literature by using food consumption as the consumption measure. Another problem is that this food consumption measure is defined at the household level, and the theory is at the level of an individual agent. As explained in Section II, the latter problem is solved by working with household consumption and including a function of family size in the Euler equation. All consumption measures in the PSID are in nominal terms. They are converted to real terms by deflating by the food consumption price index, which is obtained from the Economic Report of the President.

The measure of consumption is constructed by aggregating i) money spent on food in restaurants; ii) money spent on food in the home which is not purchased with food stamps; and iii) the monetary value of food obtained through food stamps. The expenditure information on food in and outside the house in interview year $t+1$ is interpreted as referring to year t. Other authors have assumed that expenditure on food consumed in the home and restaurants in year t is a weighted average of the responses from interview year $t+1$ and interview year t, usually with the respective weights being .75 and .25. It must be noted that this construction of the consumption measure interprets the relevant PSID questions as referring to a flow variable, as opposed to a stock at a point in time. The reason that different studies have not treated this information in a consistent way is that the questions asked are not without ambiguity (See Altug and Miller (1990), Hall and Mishkin (1982), Mankiw and Zeldes (1990,1991), Runkle (1991) and Zeldes (1989) on this issue). Stock and bond returns are constructed to match the construction of the consumption series.

For each Euler equation, results are reported for four different samples. A first sample is the same regardless of the Euler equation under investigation and includes all observations for which the following data selection criteria are satisfied:

i) the household head has to be between 25 and 60 years of age.

ii) yearly hours worked by the household head have to be between 100 and 4160.

iii) total real food consumption in 1987 dollars has to be less than $12,000 per person and more than $720 per person and total real family food consumption has to be less than $30,000.

vii) there can be no missing data on the demographic information used in the estimation exercises. The different demographic variables used as regressors are: age of the head, age of the head squared, family size in period *t*, family size in period *t-1*, dummies indicating whether the head is married or not in periods *t* and *t-1*, and the race of the head. Also, the educational achievement of the household head is used as a selection criterion because it is used in the construction of the instrument set. It must be noted that some estimation exercises using these demographics are not reported in the paper.

This first sample has 18813 observations. For all Euler equations under investigation, estimation and test results are reported for three other samples, which are meant to include only households with strictly positive holdings of the relevant assets. The samples are created by including only households who state that they have nonzero holdings of the relevant asset, or holdings larger than $1,000 or $10,000. To select these households, a series of 1984 questions from the PSID are used. These questions essentially ask households whether they have positive holdings of a relatively riskless and/or a risky asset at that time. Specifically, for the riskless asset the questions (questions # V10917 through # V10921) ask:

i) "Do you (or anyone else in your family living there) have any money in checking or savings accounts, money market funds, certificates of deposit, government savings bonds, or Treasury bills, including IRA's?"

ii) if affirmative answer to i)

"If you added up all such accounts for all of your family living there, about how much would they amount to right now?"

iii) if no answer to ii)

"Would it amount to $10,000 or more?" and dependent on this answer "$1,000 or more?" or "$100,000 or more?"

For the risky asset the questions (questions # V10912 through # V10916) are:

i) "Do you (or anyone in your family living there) have any shares of stock in publicly held corporations, mutual funds, or investment trusts, including stocks in IRAs?"

ii) if affirmative answer to i)

"If you sold all that and paid off everything you owed on it, how much would you have?"

iii) if no answer to ii)

"Would it amount to $10,000 or more?" and dependent on this answer "$1,000 or more?" or "$100,000 or more?"

The main purpose of using these questions is a comparison of estimation and test results between the sample that only includes households at interior conditions and the sample that also includes households at corner solutions. The analysis of the samples that only include households with asset holdings larger than $1,000 or $10,000 is interesting from two perspectives. First, these samples are less likely to contain classification errors (households at corner solutions), and therefore it is interesting to compare them to the sample that also includes households at corner solutions. Also, a comparison of estimation and test results between the different samples with positive asset holdings can indicate whether they have different characteristics. It must be noted that the questions listed above also allow construction of a sample of households with asset holdings larger than $100,000. However, this sample is not used in the analysis because it is too small to allow a formal statistical analysis.

It must also be noted that the selection criterion used in this paper is potentially problematic. The most important problem is that for every year that a household is included in the sample, it is classified as an assetholder or a non-assetholder on the basis of this 1984 question. This may obviously give rise to misclassifications. Also, a potential problem with the interpretation of the results is that the difference between the second and the first sample for the analysis of a given Euler equation is not necessarily totally made up by households who are non-assetholders in 1984. A household may simply not be present in the sample in 1984, yet be an assetholder in every other year. For a more detailed discussion of the 1984 PSID question see Mankiw and Zeldes (1990,1991).

Appendix II: Estimation and test procedures

This appendix discusses estimation of the Euler equations using the Generalized Method of Moments (GMM) framework (see Hansen (1982)).[14] The framework is similar to the one used in Hansen and Singleton (1982) in a representative agent context, but the panel aspect of the data generates some additional difficulties. To illustrate the generality of the results obtained in this manner, such as the framework's ability to allow for unbalanced panels, the estimators and test statistics are discussed here in some detail. Euler equations (9) and (10) are repeated here for convenience, lagged once, as

$$1 \;=\; \beta E_{t-1}\frac{1}{q_{t-1}}\left(\frac{c_{i,t}}{c_{i,t-1}}\right)^{\gamma-1}\exp\left[f_1 fs_{i,t} \;+\; f_2 fs_{i,t-1}\right]\exp\left[d\;demo_{i,t}\right] \qquad \text{(AII-1)}$$

$$1 \;=\; \beta E_{t-1}\left(\frac{p_t+d_t}{p_{t-1}}\right)\left(\frac{c_{i,t}}{c_{i,t-1}}\right)^{\gamma-1}\exp\left[f_1 fs_{i,t}+f_2 fs_{i,t-1}\right]\exp\left[d\;demo_{i,t}\right] \qquad \text{(AII-2)}$$

where $fs_{i,t}$ stands for family size in period t;
$demo_{i,t}$ stands for a vector of preference shifters at time t; and
f_1,f_2 are scalar parameters and d is a vector of parameters.

Because of a number of econometric complications the discussion of the estimation procedure is rather lengthy. To limit its length, only the one-equation case is discussed. The estimation techniques used for estimating both Euler equations jointly are a straightforward extension of the techniques used for one equation. The empirical results for both Euler equations jointly allow for contemporaneous correlation between the Euler equation errors for the risky and riskless assets when computing the covariance matrix of the orthogonality conditions.

Consider the error associated with the Euler equation (AII-1) or (AII-2) and for simplicity label it $e_{i,t}$, where t is the time index and i is the household index. Theory specifies $E_{t-1}e_{i,t} = 0$. Consider a maximum of T observations on H households. Consider M instruments per household $z^1_{i,t-1},\ldots,z^n_{i,t-1},\ldots,z^M_{i,t-1}$. Then consider $v^n_{i,t}=e_{i,t}z^n_{i,t-1}$. Using the law of iterated expectations we know that $E v_{i,t}^{n}=0$, for all n and i. Theory therefore specifies a total of MxH orthogonality conditions. One can in principle simply use these MxH orthogonality conditions to estimate the parameters by GMM. This strategy seems interesting, given that GMM allows for potential heteroskedasticity and correlation patterns for Euler errors of different households at a point in time or across time. However, the dimension of the GMM covariance matrix of the orthogonality conditions is MxH when using this strategy. This is problematic given that we have a maximum of T observations per household, and H is much larger than T. Each element of the covariance matrix is therefore the sum of T outer products, and the covariance matrix will have rank $T < MxH$. Since the inverse of this covariance matrix is used in the test statistics GMM tests will be hard to interpret.

In principle, this problem can be addressed by imposing enough restrictions when computing the covariance matrix to ensure that it has full rank. However, given the enormous difference between MxH and T in the problem under study, these restrictions would have to be quite stringent. This is problematic because a priori one would expect certain heteroskedasticity and correlation patterns to be critically important, and restrictions needed to make the matrix full rank would precisely restrict those patterns.

For these reasons, I take another approach to solving the dimensionality problem, which allows for general heteroskedasticity and correlation patterns. Noting that the panel is unbalanced, denote the number of households in the sample at time t as H_t. Consider the M orthogonality conditions $E\overline{v_t^{n}}, n=1,...,M$, where $\overline{v_t^{n}} = (1/H_t) \sum_{i=1}^{H_t} v_{i,t}^{n}$. For these M orthogonality restrictions estimation and testing by GMM then becomes possible with very general and unrestricted covariance matrices as long as $M < T$.

The GMM estimator simply exploits the fact that if the theory is correct $(1/T) \sum_{t=1}^{T} \overline{v_t^{n}}$ should be close to zero. Define the $Mx1$ vector $\overline{v_t} = (\overline{v_t^{1}},...,\overline{v_t^{M}})'$ and consider the estimate of the *MxM* covariance matrix

$$\hat{\Omega} = (1/T)\sum_{t=1}^{T} \overline{\hat{v}_t}\ \overline{\hat{v}_t}^{\prime}, \tag{AII-3}$$

The construction of this covariance matrix is critically important to determine the model's empirical performance. For now, we just note that $\overline{\hat{v}_t^{\,n}}$, the estimate of $\overline{v_t^{\,n}}$, has been constructed by obtaining estimates $\hat{e}_{it}$ using the nonlinear two stage least squares (NL2SLS) estimator, which is a consistent estimator in this context. Before we discuss this issue in more detail, we first focus on an important problem with applying GMM in the context of the empirical exercise in this paper. Denote the *(Kx1)* parameter vector by ϕ. In most empirical applications in the literature, GMM estimates $\hat{\phi}$ for the *K* parameters are then obtained by minimizing

$$J_T = \left[(1/T)\sum_{t=1}^{T} \overline{v_t}(\phi)^{\prime}\right] \hat{\Omega}^{-1} \left[(1/T)\sum_{t=1}^{T} \overline{v_t}(\phi)\right], \tag{AII-4}$$

The covariance matrix of $T^{1/2}(\hat{\phi}-\phi)$ can be computed as $(\hat{H}^{\prime}\hat{\Omega}^{-1}\hat{H})^{-1}$, where $\hat{H}$ is a consistent estimate of the *MxK* matrix $H = E[\delta\overline{v_t}/\delta\phi^{\prime}]$. A test statistic is obtained by computing $T\, J_T$, evaluated at the optimum $\hat{\phi}$. This statistic is asymptotically distributed as χ^2_{M-K}, provided that $\hat{\Omega}$ is a consistent estimate of the covariance matrix (see Hansen (1982)). The inverse of this covariance matrix is often referred to as the optimal weighting matrix. GMM estimates obtained by minimization of J_T in (AII-4) are often referred to as two-round estimates. If desired, one can use parameters obtained in this way to construct estimates $\hat{e}_{it}$, which can be used to construct a new $\hat{\Omega}$ and will lead to new estimates $\hat{\phi}$. This procedure can be iterated at will to produce 3, 4, 5,.., *x* round estimates. However, asymptotic properties of estimates obtained in that way and assorted *J*-statistics are the same as for the two-round case.

For the empirical exercise conducted in this paper, it is critically important to take into account contemporaneous correlation between households when computing the covariance matrix. However, when performing two-round estimation with the inverse of that covariance matrix as the weighting matrix, we generally do not obtain satisfactory results. The objective function seems to be poorly behaved, and in many cases the parameter estimates do not converge. To resolve this, I obtain parameter estimates and construct test statistics based on a one-round GMM estimator. These test statistics are based on Hansen's lemma 4.1 (1982, p. 1049). The more conventional two-round estimators are based on Hansen's lemma 4.2 (1982, p. 1049). Consider minimizing

$$J_T = [(1/T) \sum_{t=1}^{T} \overline{v}_t(\phi)'] \; W \; [(1/T)\sum_{t=1}^{T} \overline{v}_t(\phi)] \tag{AII-5}$$

for an arbitrary *MxM* weighting matrix *W*. From Hansen (1982) we know that

$$m_T = T \; [(1/T) \sum_{t=1}^{T} \overline{\hat{v}_t'} \;] \; \hat{Q}^{-} \; [(1/T)\sum_{t=1}^{T} \overline{\hat{v}_t} \;] \tag{AII-6}$$

is distributed χ^2_{M-K}, where $\hat{Q} = \hat{P}\hat{\Omega}\hat{P}'$ and $\hat{P} = I - \hat{H}(\hat{H}'W\hat{H})^{-1}\hat{H}'W$. Note that all matrices in (AII-6) are evaluated at $\hat{\phi}$, the value of the parameters that minimizes (AII-5). Also note that the notation $\hat{Q}^{-}$ stands for the generalized inverse of $\hat{Q}$. The matrix $\hat{Q}$ has dimension *MxM* but rank *M-K*. The reason for this is the structure of the matrix $\hat{P}$. Note that in contrast the matrix $\hat{\Omega}$ used in (AII-4) does have full rank *M* (see Newey (1985)).

The covariance matrix of $T^{1/2}(\hat{\phi} - \phi)$ can be computed as

$$(\hat{H}'W\hat{H})^{-1}(\hat{H}'W\hat{\Omega}W\hat{H})(\hat{H}'W\hat{H})'^{-1} \tag{AII-7}$$

Note that (AII-7) reduces to $(\hat{H}'\hat{\Omega}^{-1}\hat{H})^{-1}$ for $W = \hat{\Omega}^{-1}$, the optimal weighting matrix.

In principle one can perform the optimization problem in (AII-5) for any choice of weighting matrix *W*. However, the weighting matrix should differ considerably from the inverse of the covariance matrix for the optimization problem to be well defined. Also, common sense suggests to construct it using the same instruments as used in the orthogonality conditions. We have H_t households in the sample at time t. The total sample size N then equals $\sum_{t=1}^{T} H_t$. For a given *1xM* vector of instruments $z_{i,t}=(z_{i,t}^{1},...,z_{i,t}^{M})$ define $Z_t=(1/H_t)(z_{1,t}^{\prime},...,z_{I_t,t}^{\prime})^{\prime}$. I use the inverse of $\sum_{t=1}^{T} Z_t^{\prime}Z_t$ as the weighting matrix W. This choice of W effectively reduces the minimization in (AII-5) to NL2SLS. If the data displayed homoskedasticity, were uncorrelated over time and uncorrelated over households, this choice of W would equal the inverse of the covariance matrix $\hat{\Omega}$ (up to a constant). The purpose of the computations in (AII-6) and (AII-7) is to correct for deviations of these assumptions in the data when computing test statistics and standard errors.

Another important issue that has to be discussed is the computation of the covariance matrix $\hat{\Omega}$ used in (AII-6) and (AII-7). Consider once again the covariance matrix given by (AII-3)

$$\hat{\Omega}=(1/T)\sum_{t=1}^{T} \overline{\hat{v}}_t \, \overline{\hat{v}}_t^{\prime} \tag{AII-8}$$

In accordance with rational expectations this covariance matrix does not allow for Euler errors to be correlated over time for a household. The computation of $\hat{\Omega}$ in (AII-8) does however allow for heteroskedasticity of unknown form, and it allows Euler errors of different households at time t to be arbitrarily correlated.[15] This is important because the rational expectations framework does not restrict these correlations. Their exact error structure will depend on the structure of the market underlying the data, and markets with more extensive risk sharing will exhibit a higher positive correlation. In the extreme, complete markets will lead to perfect risk sharing and perfect correlation. To assess the importance of this type of pattern in the data, I compare test results obtained using (AII-8) with test results obtained using

$$\hat{\Omega}=(1/T)\sum_{t=1}^{T} \left(\sum_{i=1}^{H_t} \hat{v}_{i,t}\hat{v}_{i,t}^{\prime}\right) \tag{AII-9}$$

where $v_{i,t}$ is the *Mx1* vector $(1/H_t)(v^1_{i,t},\ldots,v^M_{i,t})'$. The covariance matrix in (AII-9) allows for arbitrary heteroskedasticity but restricts Euler equation errors to be uncorrelated. The difference between the test statistics based on (AII-8) and (AII-9) will therefore be indicative of the importance of contemporaneous correlation between different households' Euler equation errors. An additional advantage of studying results obtained with (AII-9) is that with this covariance matrix the objective function in (AII-4) is very well behaved. Therefore, we can compute the two-round *J*-statistics in (AII-4) as well as the one-round statistics in (AII-6). The empirical results below indicate that in this case these statistics show little difference for a given sample. This is reassuring when interpreting the one-round statistics obtained with covariance matrix (AII-8). In this case the minimization of (AII-4) (the more conventional two-round case) is problematic, as mentioned above.

A last issue regarding the computation of the covariance matrix (AII-8) is that an alternative is also presented in the empirical results. Even though we are dealing with a panel data problem, by summing over the orthogonality conditions we have effectively reduced our problem to a GMM framework with *T=12* observations. Typically for such sample sizes power is low. I have therefore constructed an alternative for (AII-8) to be used in (AII-6) and (AII-7) which is potentially more powerful. Consider

$$\hat{\Omega} = (1/T)\sum_{t=1}^{T}\left(\overline{\hat{v}}_t - ((1/T)\sum_{t=1}^{T}\overline{\hat{v}}_t)\right)\left(\overline{\hat{v}}_t - ((1/T)\sum_{t=1}^{T}\overline{\hat{v}}_t)\right)' \qquad \text{(AII-10)}$$

The intuition behind (AII-10) is clear. Under the null, we have $(1/T)\sum_{t=1}^{T}\overline{v}_t = 0$ and $\hat{\Omega}$ in (AII-10) is identical to $\hat{\Omega}$ in (AII-8). However, under the alternative (AII-10) will lead to a smaller covariance matrix than (AII-8) and therefore to a more powerful test statistic. It turns out that in many cases this small sample correction makes a difference in the samples under investigation.

Appendix III: GMM estimation with iteration on the weighting matrix

Table AI
Estimation and test results for the Euler equation associated with the riskless asset
Results obtained using instrument set one
Results obtained by iterating on the GMM weighting matrix

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{1}{q_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set one includes five instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once and the unemployment rate for the household head's occupation lagged once interacted with the age of the household head. Given that there are four parameters to be estimated and five instruments, test statistics have one degree of freedom. Test statistics are computed according to lemma 4.2 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.923 (0.029)	0.908 (0.065)	0.932 (0.038)	0.972 (0.061)
$\gamma-1$ (Standard Deviation)	-1.063 (0.200)	-1.253 (0.413)	-1.180 (0.288)	-0.516 (1.160)
Number of Instruments Degrees of Freedom	5 1	5 1	5 1	5 1
Test statistic (Significance Level)	71.640 (0.000)	40.164 (0.000)	31.336 (0.000)	87.241 (0.000)
Iterations on Covariance Matrix	4	4	4	4
H N	3555 18813	2452 14691	1465 9464	428 2961

Table AII
Estimation and test results for the Euler equation associated with the risky asset
Results obtained using instrument set one
Results obtained by iterating on the GMM weighting matrix

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 \; = \; \beta(\frac{c_{i,t+1}}{c_{i,t}})^{\gamma-1} \; (\frac{p_{t+1}+d_{t+1}}{p_t}) \; \exp[f_1 fs_{i,t+1} \; + \; f_2 fs_{i,t}] \; + \; e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set one includes five instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once and the unemployment rate for the household head's occupation lagged once interacted with the age of the household head. Given that there are four parameters to be estimated and five instruments, test statistics have one degree of freedom. Test statistics are computed according to lemma 4.2 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.787 (0.064)	0.657 (0.135)	0.650 (0.243)	0.659 (0.155)
$\gamma-1$ (Standard Deviation)	-1.615 (0.302)	-2.445 (0.599)	-2.626 (1.083)	-2.824 (0.809)
Number of Instruments Degrees of Freedom	5 1	5 1	5 1	5 1
Test statistic (Significance Level)	121.004 (0.000)	9.014 (0.002)	4.919 (0.026)	1.426 (0.232)
Iterations on Covariance Matrix	7	5	6	8
H N	3555 18813	770 5197	495 3448	198 1465

Table AIII
Estimation and test results for the Euler equation associated with the riskless asset
Results obtained using instrument set two
Results obtained by iterating on the GMM weighting matrix

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1}\left(\frac{1}{q_t}\right)\exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, q_t is the (normalized) price of the riskless asset in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma - 1$. Results for f_1 and f_2 are not reported. Instrument set two includes eight instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once, the risky rate of return lagged once, the unemployment rate for the household head's occupation lagged once, this unemployment rate lagged once interacted with the age of the household head, and this unemployment rate lagged once interacted with the education of the household head. Given that there are four parameters to be estimated and eight instruments, test statistics have four degrees of freedom. Test statistics are computed according to lemma 4.2 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.937 (0.020)	0.899 (0.065)	0.961 (0.015)	0.982 (0.002)
$\gamma - 1$ (Standard Deviation)	-0.941 (0.160)	-1.282 (0.406)	-0.817 (0.175)	-0.112 (0.040)
Number of Instruments Degrees of Freedom	8 4	8 4	8 4	8 4
Test statistic (Significance Level)	105.80 (0.000)	44.038 (0.000)	95.646 (0.000)	858.480 (0.000)
Iterations on Covariance Matrix	5	3	4	9
H N	3555 18813	2452 14691	1465 9464	428 2961

Table AIV
Estimation and test results for the Euler equation associated with the risky asset
Results obtained using instrument set two
Results obtained by iterating on the GMM weighting matrix

Estimation and test results obtained by GMM estimation of the Euler equation

$$1 = \beta\left(\frac{c_{i,t+1}}{c_{i,t}}\right)^{\gamma-1} \left(\frac{p_{t+1}+d_{t+1}}{p_t}\right) \exp[f_1 fs_{i,t+1} + f_2 fs_{i,t}] + e_{i,t+1}$$

where $c_{i,t}$ is consumption of household i at date t, p_t is the price of the risky asset in period t, d_t is the dividend in period t, $fs_{i,t}$ is the size of household i in period t and $e_{i,t+1}$ is an econometric error term. Point estimates and standard deviations are presented for parameters β and $\gamma-1$. Results for f_1 and f_2 are not reported. Instrument set two includes eight instruments: family size in periods t+1 and t, a constant, the riskless rate of return lagged once, the risky rate of return lagged once, the unemployment rate for the household head's occupation lagged once, this unemployment rate lagged once interacted with the age of the household head, and this unemployment rate lagged once interacted with the education of the household head. Given that there are four parameters to be estimated and eight instruments, test statistics have four degrees of freedom. Test statistics are computed according to lemma 4.2 in Hansen (1982). Test statistics do not allow for contemporaneous correlation between households' Euler equation errors. Column 1 contains results obtained using all households in the sample. Columns 2,3 and 4 contain results obtained using increasingly stringent asset holding criteria. For each column, H denotes the number of households included in the sample and N denotes the number of observations included in the sample.

	All Households	Asset Holdings > 0	Asset Holdings > 1000	Asset holdings > 10000
β (Standard Deviation)	0.792 (0.050)	0.702 (0.120)	0.793 (0.159)	0.932 (0.020)
$\gamma-1$ (Standard Deviation)	-1.598 (0.237)	-2.239 (0.558)	-1.881 (0.885)	-0.575 (0.369)
Number of Instruments Degrees of Freedom	8 4	8 4	8 4	8 4
Test statistic (Significance Level)	176.344 (0.000)	26.703 (0.000)	31.234 (0.000)	122.316 (0.000)
Iterations on Covariance Matrix	14	4	5	11
H N	3555 18813	770 5197	495 3448	198 1465

Footnotes

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1. As an anonymous referee pointed out, estimates of behavioral parameters based on orthogonality conditions are not meaningful if the orthogonality conditions are rejected by the data. Parameters estimated in this study may inspire some confidence, because they are very robust across estimation exercises, including those where the theory is not rejected by the data.

2. This paper constructs tests similar to those of Hansen and Singleton, which can be interpreted as testing whether agents ignore valuable predictive information. The model has also been found strongly at odds with the data along other dimensions. When exploiting only unconditional information the model restrictions point towards implausibly large values of the parameter of relative risk aversion (e.g., see Mehra and Prescott (1985) and certain results in Hansen and Singleton (1983) and Grossman, Melino and Shiller (1987)). Hansen and Jagannathan (1991) investigate yet other implications of the model which also point to large estimates of this parameter (see also Cochrane and Hansen (1992), Cecchetti, Lam and Mark (1994)

and Burnside (1994)).

3. The literature contains various other attempts to deal with these problems besides those addressed here (e.g. see Grossman, Melino and Shiller (1987) and Heaton (1993) on the issue of time aggregation).

4. Mankiw, Rotemberg and Summers (1985) investigate nonseparability between consumption and leisure; Dunn and Singleton (1986) examine time-nonseparabilities; and Eichenbaum, Hansen and Singleton (1988) estimate models with time-nonseparabilities and nonseparability between consumption and leisure. Epstein and Zin (1989, 1991) and Weil (1990) introduce nonexpected utility preferences, and Epstein and Zin (1989) investigate a first-order risk aversion specification. A particular form of time-nonseparability, called habit formation, has been fairly successful in matching the moments of the data (e.g., see Abel (1990), Campbell and Cochrane (1995), Cochrane and Hansen (1992), Constantinides (1990) and Detemple and Zapatero (1991)).

5. Mankiw and Zeldes (1991) and Brav and Geczy (1996) proceed by constructing yearly averages of the per capita consumption of stockholders and nonstockholders. They use these averages to perform a calibration which examines the extent to which the inclusion of non-stockholders in the sample biases estimates of behavioral parameters. One can think of this procedure as correcting for the presence of households at corner positions, while aggregating those households who end up at an interior position (using a market completeness argument or the aggregation techniques of Grossman and Shiller (1982)). Mankiw and Zeldes find that the bias is considerable but that the high rate of relative risk aversion implied by the stockholder sample is still high. Interestingly, Brav and Geczy (1996) obtain a more moderate value for the

rate of relative risk aversion. While these studies use panel data, after performing aggregation they can more usefully be thought of as time-series studies, because the performance of the model is determined by the properties of aggregate consumption. In my study, the performance of the model is determined by the time-series properties of household consumption. In the PSID, the properties of per capita consumption and individual household consumption are quite different, which leads one to expect differences between my results and those of Mankiw and Zeldes (1991) and Brav and Geczy (1996).

6. The use of food as a measure of total consumption is obviously problematic (e.g. see Attanasio and Weber (1995)). One could justify this by invoking additive separability between food and other consumption. However, for the purposes of testing consumption-based asset pricing models additional motivation is appropriate. The work of Shiller (1982) and Hansen and Jagannathan (1991) has indicated that the problem with the empirical performance of asset-pricing models can be summarized in terms of the insufficient variability of consumption. It seems that food consumption would be one of the consumption categories that is relatively smooth as compared to total consumption. To the extent that this is correct, it makes sense to think of the tests in this paper as being excessively strong. Failure to reject in this paper would probably lead to failure to reject when using total consumption variability. Whereas the tests under consideration in this paper are harder to relate to consumption variability than the ones in Shiller (1982) and Hansen and Jagannathan (1991), intuition suggests that for most tests the performance of the model is intimately related to the variability of consumption.

7. Instruments affect test results because the GMM estimator used in this study exploits orthogonality between the Euler equation error and the instruments which are in the agent’s information set. Therefore,

test statistics and estimated parameter values are the result of an optimization problem which is defined by the choice of instrument set. The choice of instruments may also be important to mitigate problems due to the presence of measurement error. It is well known that in linear environments measurement error problems can be addressed by appropriate choice of instruments (for a discussion in the context of linearized Euler equations see Runkle (1991)). In nonlinear environments, this problem is harder to handle. Note that the instruments used in this paper would go a long way toward solving the problem in a linear environment. However, for the model under consideration this is an outstanding issue which is not resolved in this paper.

8. As explained in Section I, these issues are motivated by findings in the representative agent literature. Empirical studies that use time-series data have shown that the Euler equation involving the riskless asset is more often rejected than the one involving the risky asset. When considering both Euler equations jointly the evidence against the model is usually very strong. Using a variety of criteria, several studies in the representative agent literature find very large estimates of the rate of relative risk aversion. It must be noted that when using criteria similar to the ones in this paper, estimates of the rate of relative risk aversion are not very large but sometimes in the nonconcave region of the parameter space.

9. For instance, see Hansen and Singleton (1983). These low estimates of the parameter of relative risk aversion contrast with others that are obtained in the representative agent literature. When using only unconditional information in the representative agent literature, parameter estimates are often intuitively implausible. In particular, for the TS-CRRA utility function, one obtains implausibly large values of the parameter of relative risk aversion (e.g. see Mehra and Prescott (1985) and certain results in Hansen and Singleton (1983) and Grossman, Melino and Shiller (1987)). Those results can be interpreted as performing

an analysis similar to the one in this paper, but with only a constant instrument (see Kocherlakota (1996) for an in depth exploration of these empirical results). The techniques advocated by Hansen and Jagannathan (1992), which stress different aspects of the data, also point to relatively large values of the parameter of relative risk aversion.

10. The computer programs used to obtain the results in Tables I-VII are written in FORTRAN. In all cases the Davidson-Fletcher-Powell (DFP) optimization algorithm is implemented using the GQOPT package contained in the IMSL statistical library. In all cases analytical derivatives are used in the optimization procedures. Ideally, one would like to present results for as many instrument sets with good instruments as possible, so that the reader can conclude for herself how much evidence against the model is provided. This strategy is followed in representative agent studies that exploit conditional information (e.g. see Hansen and Singleton (1982, 1983)). Given the space taken up by reporting on one instrument set for the empirical exercise in this paper, this is not possible here. I can only report on a small number of instrument sets. Different instrument sets with similar correlation patterns with the observables typically have very different power properties. The empirical results below report on instrument sets with different power properties, which attempt to "summarize" the power properties of the wide range of instrument sets I investigated.

11. For the covariance matrices used in Table IA, computation of an x-round, $x > 1$ GMM estimate does not yield satisfactory results. However, for the covariance matrix used in Table IB, such estimation is feasible. The results of this exercise are listed in Table AI of Appendix III. Comparison of this table with Table IB shows only small differences in parameter estimates and test statistics. The table also shows that the estimates converge relatively quickly over GMM rounds. This is reassuring when interpreting Table IA,

because these one-round GMM estimates are not often used in the literature. The fact that in cases where *x*-round *(x > 1)* estimation is feasible, the results are comparable to one-round estimation, is indicative of the potential value of one-round estimation in general.

12. Table AII in Appendix III shows that when using the *x*-round *(x > 1)* GMM estimator for covariance matrix (AII-9), the estimates are similar to those in Table IIB obtained using the one-round estimator. The test statistics are smaller in each column, and significantly smaller in column 4. This significant difference for the column 4 results has to be interpreted with caution, as the results in columns 4 (the smallest sample) are usually not as well behaved as those in columns 1,2 and 3.

13. Tables IVB and VB indicate that Euler errors are positively correlated across households, and that ignoring this correlation biases test statistics. Tables AIII and AIV in Appendix III again indicate that the *x*-round results *(x > 1)* are rather close to the results obtained in Tables IVB and VB, respectively.

14. Several authors have convincingly argued that the estimation of Euler equations for rational expectations models may be subject to problems when using panel data (e.g. see Altug and Labadie (1994), Altug and Miller (1990), Chamberlain (1984) and Runkle (1991)). Problems may arise because the underlying econometrics assume the existence of observations on a large number of time periods for each household. Available datasets such as the PSID typically contain only a limited number of observations on each household. It must be noted that whereas this criticism may be valid, the importance of this problem can only be addressed by means of a Monte Carlo analysis.

15. Even though rational expectations preclude nonzero correlation over time for a given household, I check for its impact on test statistics. It is important to verify its importance because panel data are very likely affected by measurement error. This measurement error could lead to serial correlation. See the appendix in Runkle (1991) for this argument in the context of estimation of linearizations of (9). Notice that the covariance matrix in (AII-8) also does not allow for correlation of the Euler error of household i at time t with the Euler error of household j at time $t+x$, $x \neq 0$. The correlation of these errors over time is found to be quantitatively a lot less important than contemporaneous correlation.