

Catching Up with the Joneses: Heterogeneous Preferences and the Dynamics of Asset Prices

Yeung Lewis Chan

Hong Kong University of Science and Technology

Leonid Kogan

Massachusetts Institute of Technology

We analyze a general equilibrium exchange economy with a continuum of agents who have “catching up with the Joneses” preferences and differ only with respect to the curvature of their utility functions. While individual risk aversion does not change over time, dynamic redistribution of wealth among the agents leads to countercyclical time variation in the Sharpe ratio of stock returns. We show that both the conditional risk premium and the return volatility are negatively related to the level of stock prices. Therefore, our model exhibits many of the empirically observed properties of aggregate stock returns, for example, patterns of autocorrelation in returns, the “leverage effect” in return volatility, and long-horizon return predictability.

We thank Andrew Abel, John Campbell, George Chacko, Timothy Chue, Francisco Gomes, John Heaton, Alan Kraus, Jun Liu, Chau Minh, Raman Uppal, Luis Viceira, Jiang Wang, two anonymous referees, and the seminar participants at the City University of Hong Kong, Harvard University, Hong Kong University of Science and Technology, the London Business School, a Massachusetts Institute of Technology Ph.D. seminar, University of British Columbia, University of Texas at Austin, the Wharton School, the European Finance Association 2001 meetings, the National Bureau of Economic Research 2001 Summer Institute, and the 2000 Western Finance Association conference for their valuable comments. The editor John Cochrane provided extensive comments, which greatly improved the paper. Financial support from the DAG-HKUST (Chan) and the Rodney L. White Center for Financial Research (Kogan) is gratefully acknowledged.

[*Journal of Political Economy*, 2002, vol. 110, no. 6]
© 2002 by The University of Chicago. All rights reserved. 0022-3808/2002/11006-0003\$10.00

I. Introduction

Many classical dynamic models such as Lucas (1978) and Cox, Ingersoll, and Ross (1985) use the representative investor framework to study the determination of asset prices. This approach makes the computation of equilibrium elegantly simple and contributes a great deal to our understanding of how underlying economic structures such as preferences, endowments, and production technologies influence asset prices. As shown in a recent paper by Campbell and Cochrane (1999), many of the empirically observed features of stock prices can be reproduced within a model with a single representative agent whose utility function exhibits countercyclical variation in risk aversion, giving rise to a slowly varying, countercyclical risk premium in stock returns. In this paper we explore a specific economic mechanism leading to countercyclical variation in the conditional risk premium. We study an economy populated by heterogeneous agents whose individual risk aversion is constant over time but varies across the population. The aggregate risk premium in such an economy exhibits countercyclical variation due to endogenous changes in the cross-sectional distribution of wealth. Relatively risk-tolerant agents hold a higher proportion of their wealth in stocks. Therefore, a decline in the stock market reduces the fraction of aggregate wealth controlled by such agents and hence their contribution to the aggregate risk aversion. Thus the equilibrium risk premium rises as a result of a fall in stock prices.

We calibrate our model to match the basic unconditional moments of stock and bond returns and compare its conditional properties with historical evidence. We find that endogenous changes in conditional moments of returns due to preference heterogeneity are of sufficiently large magnitude to be economically significant. However, changes in expected stock returns in the model are still partially driven by time-varying interest rates, a result of the functional form of individual preferences assumed in our analysis. Thus, while heterogeneous risk preferences can give rise to many of the observed properties of asset returns, the simple structure of our model does not capture all the important quantitative features of the data.

A representative-agent model can be viewed as a reduced-form description of an outcome of the aggregation procedure in an economy populated by heterogeneous agents. Such models are silent about the precise nature of individual investor behavior and hence say nothing about disaggregated variables, such as individual asset holdings and consumption. Our model accounts for investor heterogeneity explicitly. Thus, in addition to relating aggregate consumption to asset prices, it generates implications for individual investor behavior, which can be used to evaluate the empirical plausibility of heterogeneous risk pref-

erences as an explanation of the salient features of the aggregate stock market behavior. In particular, we find that individual asset holdings in our model are comparable across the population, even though a significant degree of preference heterogeneity is necessary to capture the unconditional properties of asset returns. On the other hand, perfect risk sharing in our model implies sizable cross-sectional differences in individual consumption volatility. This offers a natural area for future extensions of our basic model that is distinct from simply improving its asset pricing implications.

In two related papers, Dumas (1989) and Wang (1996) consider economies in which agents differ in their risk aversion.¹ Dumas analyzes a two-person production economy with an exogenous stock return process and relies purely on numerical analysis. Wang considers a two-person exchange economy and is able to obtain closed-form expressions for certain bond prices for several specific combinations of individual risk aversion coefficients. Our work differs from theirs in three important aspects. First, while Dumas and Wang emphasize the dynamics and the term structure of interest rates, we focus mainly on the behavior of stock prices. Second, they consider time-separable, state-independent utility functions, whereas preferences in our model exhibit the “catching up with the Joneses” feature. As a result, the asymptotic cross-sectional distribution of wealth is not degenerate in our model, in contrast to the exchange economy in Wang’s paper, where a single type dominates the economy as aggregate wealth increases without bound.² This result is important since it allows us to discuss the average, long-run properties of asset prices. Finally, in contrast to their papers, we calibrate our model and assess its quantitative implications relative to historical data.

The rest of the paper is organized as follows. Section II describes the model. Section III characterizes the competitive equilibrium. Section IV examines the dynamics of stock returns. Section V presents a conclusion.

II. The Model

We consider a continuous-time, infinite-horizon exchange economy with complete financial markets and a single perishable consumption good.

¹ Other forms of heterogeneity have also been considered in the literature. For instance, Mankiw (1986) and Constantinides and Duffie (1996) argue that differences in investors’ noninsurable income process can help explain the equity premium puzzle of Mehra and Prescott (1985). See Brav, Constantinides, and Geczy (2002) for some related empirical evidence. In the context of portfolio insurance, Grossman and Zhou (1996) study a finite-horizon exchange economy with two types of agents.

² Dumas demonstrates that the cross-sectional wealth distribution in his model can be stationary under certain assumptions on model parameters. In our model the wealth distribution is always stationary.

There is only one source of uncertainty, and investors trade in financial securities to share risk.

Our model has two somewhat nonstandard elements. First, we assume that agents' preferences exhibit the "catching up with the Joneses" feature of Abel (1990, 1999). Specifically, we assume that individual utility is a power function of the ratio of individual consumption to the social standard of living. This form of preferences retains the property of the standard constant relative risk aversion (CRRA) utility function that individual risk aversion does not change over time. Second, we assume that there exists a continuum of investors who differ from each other with respect to the curvature of their utility functions.

The catching up with the Joneses feature of preferences guarantees the existence of a nondegenerate stationary cross-sectional distribution of wealth. It also allows the equilibrium interest rate to be relatively low even though the aggregate utility curvature is relatively high.³ Time variation in the Sharpe ratio of stock returns comes entirely from preference heterogeneity. Moreover, heterogeneity can give rise to countercyclical variation in return volatility, and we show that in otherwise similar homogeneous economies, volatility is procyclical.⁴

Aggregate endowment.—The aggregate endowment process Y_t is described by a geometric Brownian motion

$$dY_t = \mu Y_t dt + \sigma Y_t dB_t, \quad t \in [0, \infty), \quad (1)$$

where B_t is a standard Brownian motion. Both μ and σ are constants with $\mu > \sigma^2/2$ and $\sigma > 0$. Well-known properties of this process include its conditional lognormality and nonnegativity.

Capital markets.—There are two long-lived financial securities available for trading: a risky asset, *the stock*, and a locally riskless instrument. The stock price is denoted by P_t ; the instantaneous risk-free interest rate is denoted by r_t . There is a single share of the stock outstanding, which entitles its holder to the dividend stream Y_t . The bond is available in zero net supply.

Preferences and cross-sectional heterogeneity.—In this economy, all investors maximize expected utility of the form

$$E_0 \left[\int_0^{\infty} e^{-\rho t} U(C_t, X_t, \gamma) dt \right],$$

³ In a representative-agent model with a standard time-separable CRRA utility function, it is difficult to reconcile high values of the Sharpe ratio with low levels of the risk-free rate. This "risk-free rate puzzle" is discussed in Weil (1989).

⁴ The procyclical behavior of volatility in this context means that a high level of the price-dividend ratio or a large increase in stock prices is associated with higher levels of volatility. Alternatively, changes in volatility are positively correlated with stock returns.

where

$$U(C_t, X_t; \gamma) = \frac{1}{1 - \gamma} \left(\frac{C_t}{X_t} \right)^{1 - \gamma}. \quad (2)$$

The term C_t is the consumption rate at time t , and X_t is a state variable treated as exogenous by individual investors, which will be given an interpretation of the standard of living in the economy. The time discount rate ρ is common to all investors. The only agent-specific feature of preferences is the curvature parameter γ , which measures individual risk aversion with respect to consumption gambles. Equivalently, γ can be interpreted as the individual risk aversion coefficient with respect to wealth gambles, just as with the standard CRRA utility function. Because the utility function is homothetic in consumption and individuals treat the process X_t as exogenous, the indirect utility function over wealth is also homothetic, of the form $[1/(1 - \gamma)]W_t^{1 - \gamma}h(X_t, \cdot)$, where the multiplier $h(X_t, \cdot)$ depends also on the current investment opportunity set. The only distinction from the standard CRRA case is the dependence of h on X_t . Thus the relative risk aversion coefficient with respect to wealth gambles is also equal to γ and does not change over time. While such a dual interpretation of γ is possible at an individual level, it does not hold in the aggregate since the utility function of the representative agent is derived from individual preferences and is not homothetic in general (unless all agents in the economy have identical preferences). Thus the “ratio” functional form of preferences in (2) is particularly convenient for isolating the effects of preference heterogeneity. Any kind of time variation in the aggregate risk aversion must be due to the differences in γ across investors.

The specification in (2) implies that the utility of the investor is influenced not only directly by her own consumption but also indirectly by the standard of living of others. Abel (1990, 1999) refers to preferences of this type as “catching up with the Joneses”: a higher standard of living X_t provides a complementary effect on current consumption.⁵

⁵ This type of preferences is often referred to as “external habit formation.” Various specifications of representative-agent models with habit formation have been analyzed in the literature. Major contributions in the continuous-time setting include Ryder and Heal (1973), Sundaresan (1989), Constantinides (1990), Detemple and Zapatero (1991), Hindy and Huang (1992, 1993), and Hindy, Huang, and Zhu (1997). Abel (1990, 1999), Gali (1994), and Campbell and Cochrane (1999) consider discrete-time models. Bakshi and Chen (1996) develop a related model in which agents derive utility directly from their social status, measured by their wealth relative to the social wealth index. On the empirical side, Ferson and Constantinides (1991), Heaton (1995), and Campbell and Cochrane (1999) confront such models with historical data and find that they overcome many of the shortcomings of standard models with time-separable, state-independent preferences.

Formally, complementarity of the standard of living and individual consumption requires that

$$\frac{\partial U_c(C_t, X_t; \gamma)}{\partial X_t} = (\gamma - 1)C_t^{-\gamma}X_t^{\gamma-2} \geq 0. \quad (3)$$

Thus we restrict our analysis to $\gamma \geq 1$. We allow for a continuum or a finite collection of preference types, defined over $\gamma \in [1, \infty)$.

Our specification of preferences differs from Abel's in the definition of the process X_t . We define X_t as a weighted geometric average of past realizations of the aggregate endowment process⁶

$$x_t = x_0 e^{-\lambda t} + \lambda \int_0^t e^{-\lambda(t-s)} y_s ds, \quad (4)$$

where $x_t \equiv \ln(X_t)$ and $y_t \equiv \ln(Y_t)$. Abel allows X_t to depend on the agent's own consumption. More important, he restricts the history dependence in X_t to a single lag in a discrete-time model. Our use of an infinite moving average in (4) reduces variability of the expected growth rate of the marginal utility of consumption, lowering the volatility and increasing the persistence of the interest rate in equilibrium.

Definition (4) justifies the interpretation of X_t as the standard of living. One can see that the parameter λ governs the degree of history dependence in X_t . When $\lambda \gg \sigma^2$, $x_t \approx y_t$; that is, the standard of living tracks closely the most recent realizations of the aggregate endowment. On the other hand, if $\lambda \approx 0$, then X_t is influenced heavily by the past history.

It is convenient to describe the state of the economy in terms of the variable $\omega_t \equiv y_t - x_t$. Since ω_t measures aggregate consumption relative to the standard of living, $\omega_t = \ln(Y_t/X_t)$, we call it *relative (log) consumption*. Naturally, a high (low) relative consumption value is interpreted as a good (bad) state of the economy. Given the lognormal specification of the aggregate endowment process, relative consumption is conditionally normally distributed and follows a linear mean-reverting process

$$d\omega_t = -\lambda(\omega_t - \bar{\omega})dt + \sigma dB_t, \quad (5)$$

⁶ In equilibrium of our exchange economy, there is no distinction between the aggregate endowment and the aggregate consumption, as a result of market clearing in the goods markets. Hence, one can equivalently think of X_t as a weighted average of past realizations of the aggregate consumption. In other contexts, however, the two definitions are not equivalent. It may be convenient to define the standard of living in terms of income of other agents in the economy, as opposed to their consumption, since such a definition circumvents the externality problems that otherwise drive a wedge between the competitive equilibrium and the solution of the central planner's problem. However, formal analysis of these two alternative modeling approaches is beyond the scope of this paper.

with the long-run mean and standard deviation given by

$$\bar{\omega} \equiv \lim_{t \rightarrow \infty} E_0[\omega_t | \omega_0] = \frac{\mu - (\sigma^2/2)}{\lambda},$$

$$\sigma[\omega] \equiv \left[\lim_{t \rightarrow \infty} \text{Var}_0(\omega_t | \omega_0) \right]^{1/2} = \frac{\sigma}{\sqrt{2\lambda}}.$$

The behavior of relative consumption reflects the slow-moving nature of the standard of living process. Aggregate endowment shocks get incorporated into the relative consumption variable instantaneously and then decay exponentially at rate λ , as the standard of living process slowly adapts to the new level of endowment. Higher values of λ imply lower persistence and lower steady-state variance of relative consumption.

III. The Competitive Equilibrium

In this section we analyze the general properties of the competitive equilibrium in the heterogeneous-agent economy. We solve the model in three steps, as is standard in the literature (e.g., Karatzas, Lehoczky, and Shreve 1990; Wang 1996). First, we analyze the social planner’s problem in order to obtain the optimal consumption sharing rule. Then we construct an Arrow-Debreu economy to support the optimal allocation found in the planner’s problem. Finally, we implement the Arrow-Debreu equilibrium as a sequential-trade economy.

The social planner’s problem.—The social planner distributes the aggregate endowment among the consumers so that the resulting allocation is Pareto optimal. We assume without loss of generality that there is only one investor of each type, and $f(\gamma)$ is the social weight attached by the planner to type γ .⁷ Given the distribution of social weights $f(\gamma)$, the objective of the social planner is

$$\sup_{\{C_t(Y_t, X_t; \gamma)\}} E_0 \left[\int_0^\infty e^{-\rho t} \left\{ \int_1^\infty f(\gamma) \frac{1}{1-\gamma} \left[\frac{C_t(Y_t, X_t; \gamma)}{X_t} \right]^{1-\gamma} d\gamma \right\} dt \right]$$

subject to the resource constraint

$$\int_1^\infty \frac{C_t(Y_t, X_t; \gamma)}{X_t} d\gamma \leq \frac{Y_t}{X_t} \quad \forall t \in [0, \infty). \tag{6}$$

Since there is no intertemporal transfer of resources, this optimization

⁷ For technical reasons, it is convenient to assume that the distribution $f(\gamma)$ has a compact support.

reduces to a static problem. At each point in time and in each state of the economy, the planner solves

$$\sup_{\{C_t(Y_b, X_b; \gamma)\}} \int_1^\infty f(\gamma) \frac{1}{1-\gamma} \left[\frac{C_t(Y_b, X_b; \gamma)}{X_t} \right]^{1-\gamma} d\gamma$$

subject to the resource constraint (6). The following lemma summarizes the optimal sharing rule.

LEMMA 1. The optimal consumption sharing rule is given by

$$C_t^*(Y_b, X_b; \gamma) = c_t^*(\omega_b; \gamma) Y_t \quad (7)$$

and

$$c_t^*(\omega_b; \gamma) = f(\gamma)^{1/\gamma} \exp \left[-\frac{1}{\gamma} z(\omega_t) - \omega_t \right], \quad (8)$$

where $z(\omega_t)$ is the logarithm of the shadow price of the resource constraint (6) and is characterized by

$$\int_1^\infty f(\gamma)^{1/\gamma} \exp \left[-\frac{1}{\gamma} z(\omega_t) - \omega_t \right] d\gamma = 1. \quad (9)$$

Lemma 1 shows that individual consumption, as a fraction of the aggregate endowment, is a function of relative consumption ω_b , which is a stationary state variable. Thus consumption (and hence wealth) of all investors grows at the same average rate, and no single agent dominates the economy in the long run. In contrast, a heterogeneous economy in which agents have standard time-separable CRRA preferences with the same time discount rate is eventually dominated by the least risk averse agent, as shown in Wang (1996). This difference between the two models is due to the catching up with the Joneses feature of preferences. In Wang's exchange economy, at high levels of consumption, the marginal utility of investors with low values of γ is relatively high. Thus they are allocated a larger fraction of the aggregate endowment. This is not the case in our economy because high levels of consumption are associated with high levels of the social standard of living X_b , which has a larger impact on the marginal utility of investors with high values of γ . Therefore, the catching up with the Joneses feature has an equalizing effect on marginal utilities of agents with different curvature parameters. As a result, the shares of the aggregate endowment allocated to individual agents remain stationary over time and depend on the ratio of the aggregate endowment to the standard of living.

The Arrow-Debreu economy.—It is well known that the Pareto-optimal allocation (7)–(9) can be supported as an equilibrium allocation in a particular Arrow-Debreu economy (e.g., Duffie and Huang 1985). In

this economy, agents can trade in primitive state-contingent claims, which pay off a unit of consumption in a particular state of the economy and zero otherwise. Let $\xi_{t,s}$ denote the stochastic discount factor in such an economy. Then the price of an arbitrary payoff stream $\{F_s, s \in [t, \infty)\}$ at time t is given by $E_t[\int_t^\infty \xi_{t,s} F_s ds]$. In equilibrium, $\xi_{t,s}$ can be expressed in terms of the shadow price of the resource constraint in the social planner's problem:

$$\xi_{t,s} = \exp[-\rho(s-t) - z_t + z_s + x_t - x_s], \quad t \leq s. \quad (10)$$

The sequential-trade economy.—Given the Arrow-Debreu equilibrium, a sequential-trade equilibrium can be constructed in which investors trade continuously in a small number of long-lived securities. Duffie and Huang (1985) provide a general analysis of such an implementation problem. Their results can be extended to our setting using arguments similar to those in Wang (1996, lemma 3).⁸

Prices of long-lived assets in equilibrium are determined by the prices of primitive Arrow-Debreu claims. In particular, the stock price satisfies

$$P_t = E_t\left[\int_t^\infty \xi_{t,s} Y_s ds\right] = E_t\left[\int_t^\infty \exp[-\rho(s-t) - z_t + z_s + x_t - x_s] Y_s ds\right], \quad (11)$$

and the instantaneous interest rate is given by

$$\begin{aligned} r_t &= \lim_{\Delta t \searrow 0} \frac{E_t[\xi_{t,t+\Delta t} - 1]}{\Delta t} \\ &= \lim_{\Delta t \searrow 0} \frac{E_t[\exp(-\rho\Delta t - z_t + z_{t+\Delta t} + x_t - x_{t+\Delta t}) - 1]}{\Delta t}. \end{aligned} \quad (12)$$

IV. Asset Prices

In this section we analyze the dynamics of asset prices. We point out qualitative and quantitative differences in the behavior of stock returns in heterogeneous and homogeneous economies and argue that these

⁸ To use the results in Duffie and Huang (1985), one needs to establish that the financial markets are dynamically complete. In our economy there is only one source of uncertainty; hence to ensure dynamic completeness, the volatility of stock returns must be positive almost surely. For economies populated with identical agents with $\gamma \geq 1$, this follows from the fact that the price-dividend ratio is nondecreasing in relative consumption, which implies that $\sigma_{R,t} \geq \sigma$ (see the Appendix). A general result for heterogeneous economies is difficult to establish, although our numerical simulations confirm that the volatility of returns is strictly positive. However, dynamic completeness is easy to guarantee by introducing continuously resettled financial contracts with unit volatility and an endogenously determined rate of return. See Karatzas et al. (1990) for a formal construction.

differences can be understood in terms of the evolution of the cross-sectional distribution of wealth over time.

A. *Theoretical Characterization*

While the general expression for the stock price is provided by (11), a more explicit characterization would facilitate further qualitative analysis. The following lemma provides a characterization of the stock price.

LEMMA 2. The equilibrium price-dividend ratio is given by

$$\begin{aligned} \frac{P_t}{Y_t} &= p(\omega_t) \\ &\equiv \exp[-z(\omega_t) - \omega_t] E \left[\int_t^\infty \exp[-\rho(s-t) + z(\omega_s) + \omega_s] ds \mid \omega_t \right]. \quad (13) \end{aligned}$$

The expression (13) shows that the price-dividend ratio P_t/Y_t depends only on relative consumption ω_t . The price-dividend ratio summarizes the conditional expectations of future discount rates and dividend growth rates. Under our specification of the aggregate endowment process, future dividend growth is independent of the current state of the economy. Thus the price-dividend ratio depends only on the distribution of future discount rates. The higher the future discount rates, the lower the price-dividend ratio.

To relate (13) to standard results, consider as an example a representative-agent economy with logarithmic preferences. When there is only one type with $\gamma = 1$, (9) becomes $\exp[-z(\omega_t) - \omega_t] = 1$, and therefore $z(\omega_t) = -\omega_t$. As a result, the price-dividend ratio is constant:

$$\frac{P_t}{Y_t} = E_t \left[\int_t^\infty e^{-\rho(s-t)} ds \right] = \frac{1}{\rho},$$

which is the well-known solution.

In our complete-market economy, the stochastic discount factor $\xi_{t,s}$ in (10) is uniquely determined in equilibrium and can be used to analyze the conditional moments of asset returns (see, e.g., Duffie 1996, sec. 6D). The key property of our model is the countercyclical behavior of the Sharpe ratio of stock returns in equilibrium. This property is important since it leads to empirically plausible patterns of predictability in stock returns, as documented below. Preference heterogeneity pro-

vides an intuitive economic mechanism for generating such counter-cyclical behavior of the Sharpe ratio.⁹

LEMMA 3. If the economy is populated by more than a single type of agents, the instantaneous Sharpe ratio of stock returns is a monotonically decreasing function of relative consumption. It is given by

$$\frac{\mu_{R,t} - r_t}{\sigma_{R,t}} = -\sigma z'(\omega_t), \quad (14)$$

where $z(\omega_t)$ is the logarithm of the shadow price of the resource constraint characterized by (9), and $\mu_{R,t}$ and $\sigma_{R,t}$ denote the instantaneous mean and volatility of stock returns.

The result of lemma 3 can be seen as an outcome of the endogenous redistribution of wealth in the economy. Agents with relatively low risk aversion coefficients hold a higher proportion of their wealth in stocks. Therefore, a decline in the stock market reduces the fraction of aggregate wealth controlled by such agents. To induce the agents to hold the entire stock market in the aggregate, the equilibrium compensation for risk (the Sharpe ratio) must rise.

The following lemma provides expressions for the risk-free rate and the mean and volatility of stock returns.

LEMMA 4. The instantaneous interest rate r_t is given by

$$r_t = \rho + \lambda(\omega_t - \bar{\omega})z'(\omega_t) + \lambda\omega_t - \frac{1}{2}\sigma^2 z''(\omega_t) - \frac{1}{2}\sigma^2 [z'(\omega_t)]^2. \quad (15)$$

The conditional moments of stock returns are given by

$$\sigma_{R,t} = \sigma \left[1 + \frac{p'(\omega_t)}{p(\omega_t)} \right] \quad (16)$$

and

$$\mu_{R,t} = r_t - \sigma z'(\omega_t) \sigma_{R,t}. \quad (17)$$

B. Simulation Results

In this subsection we quantify the effects of preference heterogeneity. We calibrate our model using several unconditional moments of historical asset returns and then investigate the dynamics of conditional moments. We also highlight the impact of heterogeneity by comparing heterogeneous and homogeneous economies.

⁹ The Sharpe ratio of stock returns in our model is proportional to the curvature of the utility function of the representative agent. In the context of a one-period Arrow-Debreu economy populated by CRRA utility agents who differ in their risk aversion, Benninga and Mayshar (1997) show that such a curvature is decreasing in the level of the aggregate endowment. Lemma 3 is mathematically equivalent to their result.

TABLE 1
PARAMETERS OF THE HETEROGENEOUS AND THE HOMOGENEOUS MODELS

PARAMETER	VARIABLE	MODEL	
		Heterogeneous	Homogeneous
Mean consumption growth (%)	μ	1.80	1.80
Standard deviation of consumption growth (%)	σ	4.02	4.02
Degree of history dependence in X_t (%)	λ	5.87	4.00
Subjective discount factor (%)	ρ	5.21	5.30
Risk aversion coefficient	γ	...	8.14
Cross section of utility weights	a_1	3.53	...
	a_2	.030	...

Calibration.—In choosing model parameters, we use historical returns of the Standard & Poor's 500 index, commercial paper returns, and per capita consumption over the 1889–1994 period. All returns and consumption data are real. We focus on the century-long sample as opposed to the postwar sample. We do this for two reasons. First, the postwar sample presents a much tougher target for calibration because of the relatively low volatility of consumption and the risk-free rate and the relatively high Sharpe ratio of stock returns. As a result, our choice of individual preferences and the cross-sectional distribution of agent types assumed below do not allow us to match the unconditional moments of the data with high accuracy. This makes it difficult to interpret the implications of the model for the conditional properties of returns. Second, historical periods such as the Great Depression cannot be ruled out *ex ante*; therefore, omitting them from the sample might misrepresent the average properties of asset returns. Thus we opt for using the century-long sample in our calibration, acknowledging that the basic form of our model has difficulty in matching the moments of the postwar sample period.

We choose the mean and standard deviation of the endowment process, μ and σ , to match the corresponding values of per capita aggregate consumption. As in the data, we average the consumption level over every year. We assume that the cross-sectional distribution of weights in the objective of the social planner is described by

$$f(\gamma) = (\gamma - 1) \exp(-a_1\gamma - a_2\gamma^2). \quad (18)$$

We choose parameters a_1 and a_2 together with the time discount rate ρ and the persistence parameter λ to match closely the first two moments of excess returns on stocks and the risk-free rate. Table 1 summarizes our parameter choices, and figure 1 plots the utility weights in (18). A summary of the implied unconditional moments of the model is pre-

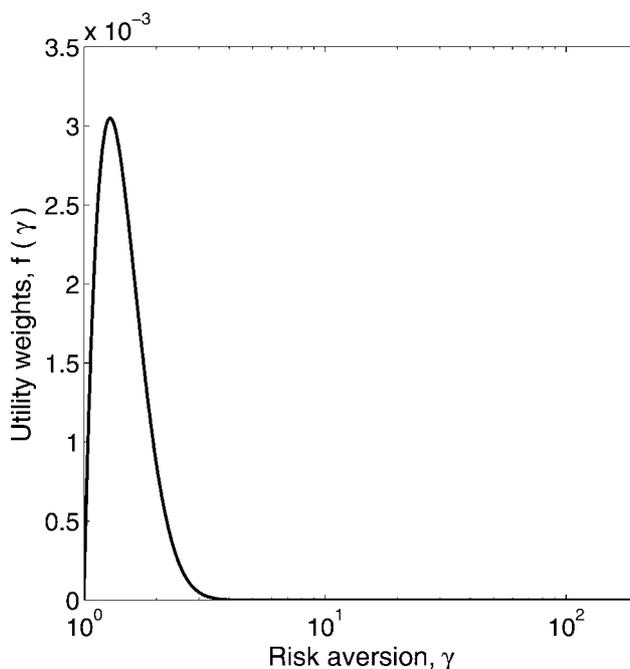


FIG. 1.—Utility weights. Utility weights $f(\gamma)$ in the objective of the social planner are plotted as a function of individual risk aversion.

sented in table 2.¹⁰ By construction, the model reproduces the first two moments of stock and bond returns. It also gives rise to a highly persistent risk-free rate because the state variable, relative consumption, is slow moving. This is an improvement over the one-lag discrete-time model of Abel (1990), in which the risk-free rate is highly volatile and has low persistence. The average price-dividend ratio in the model is comparable to that in historical data, but the long-run standard deviation of the ratio is higher than empirically observed.

For comparison, we also calibrate a model with a single type of agents.

¹⁰ The real risk-free rate is not directly observable, and only ex post real returns can be constructed from the data. The standard deviation of ex post returns on commercial paper overstates the actual volatility of the risk-free rate because of unanticipated inflation. For the same reason, realized real returns on bonds are less persistent than the expected real rate of return. Campbell, Lo, and MacKinlay (1997, p. 329) argue that historical volatility of the ex ante real rate of return on short-term bonds is close to 3 percent, which is consistent with the results in Siegel (1992). This is the number we use in our calibration. We estimate the historical autocorrelation coefficient on the basis of both nominal returns on commercial paper and the ex post real returns. Ex post returns are less persistent than nominal returns.

TABLE 2
MOMENTS OF SIMULATED AND HISTORICAL DATA

STATISTIC	DATA	MODEL	
		Heterogeneous	Homogeneous
$E[\Delta c]^*$	1.72	1.72	1.72
$\sigma[\Delta c]^*$	3.28	3.28	3.28
$E[r_B]^*$	1.83	1.83	1.83
$\sigma[r_B]^*$	3.0	2.90	4.02
$\rho_1[r_B]$	.85	.96	.97
$E[r_S - r_B]^*$	4.18	4.18	4.18
$\sigma[r_S - r_B]^*$	17.74	17.79	17.70
$E[r_S - r_B]/\sigma[r_S - r_B]^*$	.24	.24	.24
$\exp(E[p - y])$	22.48	28.76	27.21
$\sigma[p - y]$	.28	.51	.49
$\bar{\omega}$	...	.32	.47
$\sigma[\omega]$	...	.12	.14

NOTE.—The historical moments are based on the 1889–1994 sample period (Campbell et al. [1997, table 8.1] report the first two moments of stock and bond returns). All returns are defined at an annual frequency. Consumption is averaged over every year, and the price-dividend ratio is defined at the end of the year. Whenever possible, moments of the model are computed by integrating with respect to the long-run stationary distribution of the model. In the remaining cases, moments are estimated on the basis of 50,000 years of simulated data. All returns are annual percentages. The term Δc is log consumption growth; $r_B = \int_0^1 r_B dt$ is log bond return; $r_S = \int_0^1 \mu_{st} - \frac{1}{2}\sigma_{st}^2 dt$ is log stock return; $p - y$ is the log price-dividend ratio; and $\rho_1[r_B]$ denotes the first-order autocorrelation coefficient of the interest rate process. The data column shows the estimate of this coefficient for *nominal* annual commercial paper returns between 1989 and 1994. The ex post real interest rate autocorrelation is .52. This estimate is biased downward because of unanticipated inflation.

* Denotes the moments that model parameters were chosen to match.

The homogeneous model is not capable of simultaneously reproducing the same four unconditional moments of returns. Therefore, we set the parameters with an objective of minimizing the volatility of the risk-free rate, while matching closely the remaining three of the four moments. Parameter values and the key properties of the homogeneous model are summarized in tables 1 and 2. Overall, the performance of the homogeneous model is comparable to that of the heterogeneous model in terms of replicating the unconditional moments of stock and bond returns, except that the interest rate volatility is relatively high.

Conditional moments of returns.—The key to understanding the properties of stock returns in the model is the relation between conditional moments of returns and relative consumption. Figure 2 shows that the price-dividend ratio is a monotonically increasing function of relative consumption. This is intuitive given the countercyclical behavior of expected stock returns, as shown below. Thus conditional moments of returns can be equivalently stated in terms of the level of stock prices.

The main effect of preference heterogeneity can be seen in the behavior of the Sharpe ratio of returns. As we have established in lemma 3, the Sharpe ratio in a heterogeneous economy is countercyclical,

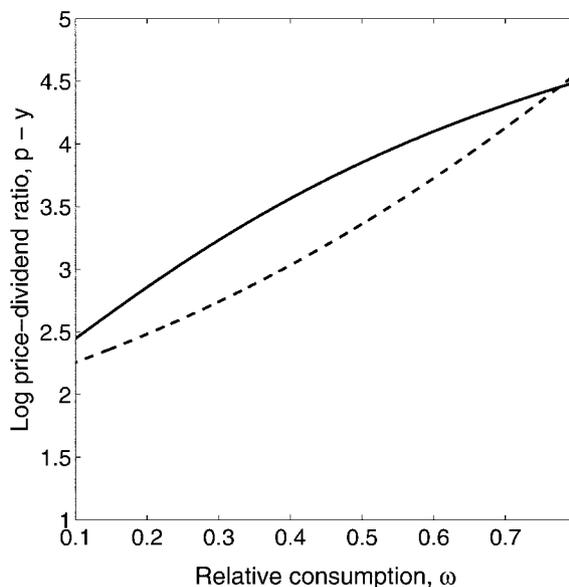


FIG. 2.—Price-dividend ratio. The logarithm of the price-dividend ratio, $p - y$, is plotted as a function of relative consumption. The solid line corresponds to the heterogeneous model, and the broken line corresponds to the homogeneous model.

whereas it is constant in economies populated by a single type of agents.¹¹ The negative relation between the Sharpe ratio and relative consumption is shown in figure 3*a*. The Sharpe ratio varies significantly over time. The long-run standard deviation of the Sharpe ratio in the heterogeneous model is 0.06, and its long-run mean is 0.32. As we have argued above, the countercyclical behavior of the Sharpe ratio is driven by the endogenous redistribution of wealth in the economy. Figure 4 illustrates the cross-sectional distribution of wealth implied by our choice of model parameters and the utility weights in (18). We plot the wealth distribution for three different values of relative consumption: $\bar{\omega} - \sigma[\omega]$, $\bar{\omega}$, and $\bar{\omega} + \sigma[\omega]$, representing a below-average, the average, and an above-average state of the economy. In each case the distribution has a similar shape. A decline in relative consumption shifts the mass of the wealth distribution toward the types with higher risk aversion, increasing the Sharpe ratio.

Figure 3*b* presents the conditional volatility of returns as a function

¹¹ Ferson and Harvey (1991) and Harvey (1991) provide empirical evidence on countercyclical variation in the market price of risk and expected returns. These moments are negatively related to the price-dividend ratio and are higher during business cycle troughs than during peaks.

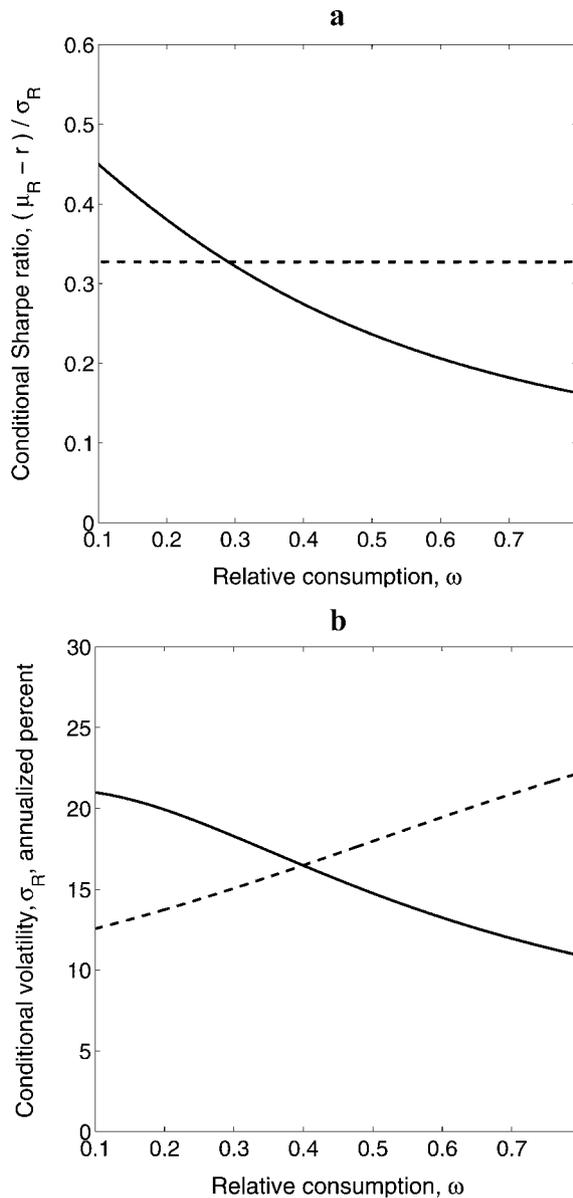


FIG. 3.—Conditional moments of stock returns. *a*, The instantaneous Sharpe ratio and, *b*, conditional volatility of stock returns are plotted as functions of relative consumption. The solid line corresponds to the heterogeneous model, and the broken line corresponds to the homogeneous model.

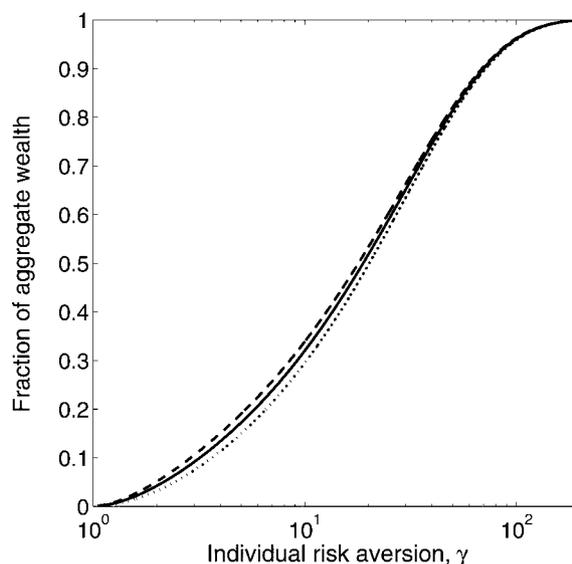


FIG. 4.—Cross-sectional distribution of wealth. For every value of γ (horizontal axis), the line shows the fraction of the aggregate wealth controlled by individuals with risk aversion less than or equal to γ . The dotted, solid, and broken lines correspond to three values of relative consumption, $\bar{\omega} - \sigma[\omega]$, $\bar{\omega}$, and $\bar{\omega} + \sigma[\omega]$, respectively.

of relative consumption. Again, the effect of preference heterogeneity is clear. While the conditional volatility in any homogeneous economy is procyclical (this general result is established in the Appendix), a heterogeneous economy can exhibit a countercyclical pattern in volatility. This effect requires a sufficient degree of preference heterogeneity and depends on the shape of the cross-sectional wealth distribution.¹² Intuition for why preference heterogeneity can change the pattern of conditional volatility is provided by the following observation. While the conditional volatility increases with relative consumption in homogeneous economies, it also appears to rise with the risk aversion parameter *across* the homogeneous economies. We illustrate this in figure 5 by plotting the conditional volatility of returns in homogeneous economies with different values of the risk aversion parameter, holding other parameters fixed at their calibrated values shown in table 1. A fall in relative consumption leads to two effects. If the aggregate risk aversion remained

¹² If one assumes that most of the agents in the economy have risk aversion coefficients close to one, it is possible to show with asymptotic analysis that the countercyclical pattern in conditional volatility arises if the cross-sectional dispersion of risk aversion coefficients is sufficiently high relative to the “average” risk aversion. See Chan and Kogan (2000) for formal derivations.

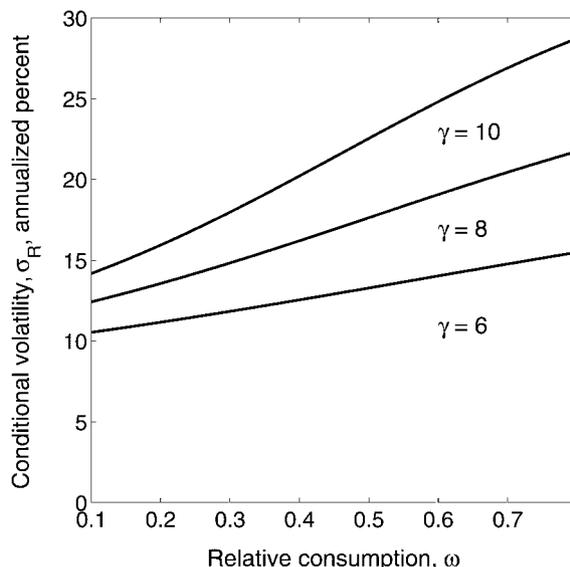


FIG. 5.—Conditional volatility of returns in homogeneous economies. The conditional volatility of stock returns is plotted as a function of relative consumption in three homogeneous economies. These economies differ only with respect to the risk aversion parameter γ , which takes values of 6, 8, and 10. All other model parameters are fixed at their calibrated values: $\rho = 5.30$ percent and $\lambda = 4.02$ percent.

constant, the direct effect would be a decline in conditional volatility. However, since the wealth distribution shifts toward more risk averse agents, the indirect effect is an increase in conditional volatility. The second effect dominates when the degree of cross-sectional heterogeneity is sufficiently high. Thus the countercyclical variation in conditional volatility in the heterogeneous economy can be informally attributed to an effective shift across homogeneous economies with different levels of aggregate risk aversion.

Predictability of stock returns.—To analyze the patterns of predictability in stock returns, we simulate 50,000 years of returns and compute the population values of several commonly used statistics. In our analysis we focus on excess stock returns to isolate the effect of the time-varying expected return from the impact of the time-varying interest rate. We compare the properties of the model with the corresponding empirical estimates. To emphasize the effect of preference heterogeneity, we also present the statistics for the homogeneous model calibrated to the same set of unconditional moments of returns as for the heterogeneous model.

Panels A and B of table 3 show that excess stock returns in the het-

TABLE 3
AUTOCORRELATIONS AND CROSS CORRELATIONS OF SIMULATED AND HISTORICAL DATA

	LAG j (Years)				
	1	2	3	5	7
A. $(r_s - r_B)_t (r_s - r_B)_{t+j}$					
Data	.03	-.21	.13	-.16	.13
Heterogeneous model	-.02	-.02	-.02	-.02	-.02
Homogeneous model	.01	.01	.00	.00	.01
B. $\sum_{i=1}^j \rho[(r_s - r_B)_t (r_s - r_B)_{t-i}]$					
Data	.03	-.18	-.05	-.28	-.15
Heterogeneous model	-.02	-.04	-.06	-.08	-.10
Homogeneous model	.01	.01	.02	.02	.03
C. $(p - y)_t (r_s - r_B)_{t+j}$					
Data	-.18	-.27	-.08	-.21	-.05
Heterogeneous model	-.07	-.06	-.06	-.06	-.06
Homogeneous model	.02	.01	.02	.01	.01
D. $(p - y)_t | r_s - r_B |_{t+j}$					
Data	-.20	-.06	-.06	-.18	-.12
Heterogeneous model	-.14	-.13	-.11	-.11	-.11
Homogeneous model	.15	.13	.13	.13	.13

NOTE.—All returns are annual. For each statistic, we report a historical estimate and the corresponding population moments of the heterogeneous model and the homogeneous model, estimated on the basis of 50,000 years of simulated data.

erogeneous model exhibit univariate mean reversion. In panel B, individual autocorrelations are aggregated into partial sums to cope with the fact that individual coefficients are poorly measured. The resulting coefficients are negative in sign, as in historical data. This negative autocorrelation in the model is due to the countercyclical behavior of the Sharpe ratio and conditional volatility of excess returns, which implies that a decline in stock prices leads to an increase in expected excess returns. In contrast, the homogeneous model produces slightly positive autocorrelation coefficients. The reason is that the Sharpe ratio of stock returns is constant in the homogeneous model and conditional volatility is procyclical; therefore, expected excess returns are procyclical as well.

In the heterogeneous model, the price-dividend ratio forecasts excess stock returns with a negative sign, as shown in panel C of table 3 and in table 4. While the sign of this relation is consistent with empirical observations, the explanatory power of the price-dividend ratio in long-horizon predictive regressions is smaller than in the data. However, if we were to estimate the same relations for stock returns, as opposed to returns in excess of the risk-free rate, the slopes and the R^2 's would increase approximately by a factor of four and 10, respectively, matching closely the corresponding empirical numbers. This suggests that the

TABLE 4
LONG-HORIZON REGRESSIONS

HORIZON (Years)	MODEL					
	DATA		Heterogeneous		Homogeneous	
	Coefficient	R^2	Coefficient	R^2	Coefficient	R^2
1	-.12	.04	-.03	.01	.01	.00
2	-.30	.10	-.05	.01	.01	.00
3	-.35	.11	-.07	.01	.02	.00
5	-.64	.23	-.09	.02	.02	.00
7	-.73	.25	-.11	.02	.03	.00

NOTE.—Log excess stock returns are regressed on the log price-dividend ratio. The table reports the slope coefficients of the regressions and the R^2 's for historical data, the heterogeneous model, and the homogeneous model. Historical estimates are based on the 1889–1994 sample. Statistics for the models are estimated on the basis of 50,000 years of simulated data.

reason for the relatively small magnitude of the effects in table 4 is that stock returns are partly predictable because of the changes in the risk-free rate. One can further see this through a decomposition of the instantaneous expected stock return as a sum of the risk-free rate and the risk premium (expected excess return). Figure 6 shows that the countercyclical nature of expected returns in our heterogeneous model is due partly to the varying risk premium and partly to the varying interest rate. This is an advance over the homogeneous model, in which the conditional risk premium is procyclical, and therefore the negative relation between the price-dividend ratio and returns is driven entirely by the dynamics of interest rates. Thus it is preference heterogeneity that generates negative variation in the risk premium. However, a significant fraction of stock return predictability in the heterogeneous model is still due to time variation in the risk-free rate, which is a feature of our preference specification (2). In particular, the long-run standard deviation of the risk-free rate is 2.9 percent, compared to 1.7 percent for the risk premium. This explains the magnitude of the R^2 's in the predictive regressions in table 4. Subtracting the risk-free rate from stock returns significantly reduces the variance of the remaining predictable component of returns.

Panel D of table 3 shows that the price-dividend ratio forecasts volatility of returns for many years ahead. In particular, a decline in stock prices predicts an increase in volatility. This is intuitive in light of the behavior of the instantaneous conditional volatility of returns (see fig. 3*b*). This pattern of cross correlations between the price-dividend ratio and the absolute value of returns is similar to the one observed empirically and is consistent with the well-known “leverage effect” (e.g., Black 1976; Schwert 1989; Campbell and Hentschel 1992). For comparison, the homogeneous model generates a counterfactual positive relation

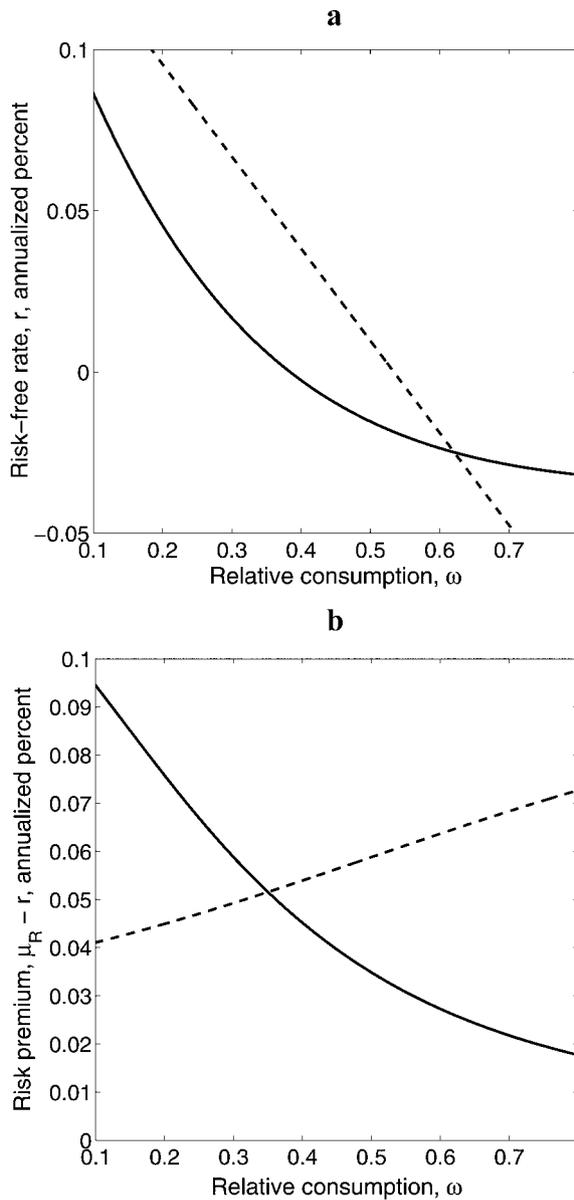


FIG. 6.—Risk-free rate and the risk premium. *a*, The risk-free rate r and *b*, the conditional risk premium $\mu_R - r$ are plotted as functions of relative consumption. The solid line corresponds to the heterogeneous model, and the broken line corresponds to the homogeneous model.

between the level of prices and future volatility of returns, demonstrating that the negative relation must be due to preference heterogeneity.

Wealth distribution and individual policies.—In addition to evaluating the implications of our model for asset prices, one can judge the plausibility of its economic mechanism on the basis of the properties of individual investor behavior required to produce sizable variation in conditional moments of stock returns. In particular, since time variation in the aggregate risk premium in our model is driven entirely by heterogeneity in individual risk exposure and resulting changes in the cross-sectional wealth distribution, we quantify the cross-sectional distribution of asset holdings within the model. To further assess the effect of risk sharing among heterogeneous agents, we also discuss the properties of individual consumption processes.

Individual portfolio policies can be conveniently summarized by individual exposure to the aggregate market risk. As one would expect, less risk averse agents invest a higher fraction of their wealth in risky assets. We illustrate the cross-sectional dispersion in individual risk exposure in figure 7. Specifically, we compute the instantaneous betas of individual wealth processes with respect to the aggregate stock market and plot the cross-sectional distribution of such betas. While figure 4 shows that individual risk aversion coefficients vary widely across the population, according to figure 7, most of the time more than 90 percent of total wealth is controlled by individuals with risk exposure between 0.88 and 1.2. Thus the magnitude of the cross-sectional dispersion in individual risk exposure within the model does not seem excessive, and leverage ratios for most individuals are relatively low. The intuition behind this finding can be understood by considering the equilibrium consumption policies of individuals with high values of γ . In the limit in which risk aversion approaches infinity, lemma 1 shows that the consumption policy of such agents is proportional to the standard of living process, scaled appropriately to satisfy the individual budget constraint. Owing to the catching up with the Joneses feature of preferences, high- γ agents are reluctant to substitute their *relative* consumption over time; therefore, their consumption closely tracks the economywide standard of living. Thus the wealth process of a high- γ agent is approximately proportional to the present discounted value of a financial asset with cash flows equal to the standard of living X_t . The process X_t is in turn a moving average of the aggregate endowment and has similar long-run behavior. Hence, the wealth process of high- γ individuals is close to the (scaled) value of the claim on aggregate endowment, and its market beta is close to one.

According to figure 4, a significant fraction of the total wealth in the economy is controlled by agents with relatively high risk aversion, ex-

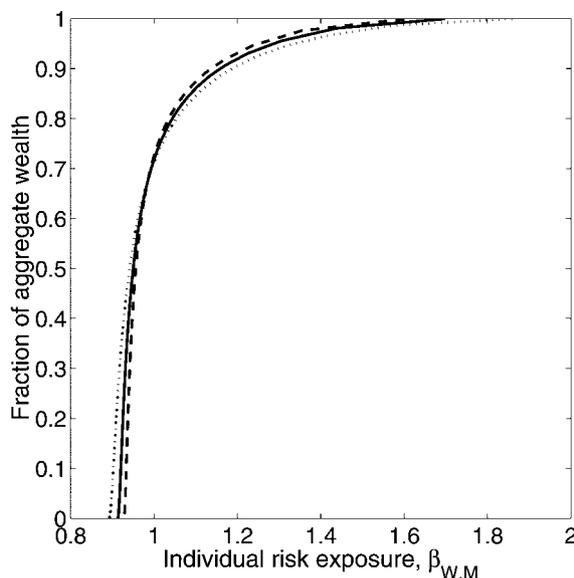


FIG. 7.—Individual risk exposure. Risk exposure is summarized by the instantaneous market beta of the individual wealth process, $\beta_{W,M}$. For every value of the individual market beta (horizontal axis), the graph shows the fraction of the aggregate wealth controlled by individuals with risk exposure less than or equal to $\beta_{W,M}$. The dotted, solid, and broken lines correspond to three values of the aggregate state (relative consumption), $\bar{\omega} - \sigma[\omega]$, $\bar{\omega}$, and $\bar{\omega} + \sigma[\omega]$, respectively.

plaining the concentration of individual risk exposure around one in figure 4.

The argument above also explains why the consumption of high- γ agents has relatively low instantaneous volatility. The reason is that it closely tracks the process for the standard of living X_p , which is locally deterministic. Market clearing implies that the agents with low values of the curvature parameter must absorb a larger portion of the aggregate endowment volatility. To quantify the implications of risk sharing in our model economy for individual consumption processes, we plot the cross-sectional distribution of instantaneous consumption volatility in figure 8. Approximately 75 percent of the aggregate wealth is controlled by agents with consumption volatility below the volatility of the aggregate endowment. However, 10 percent of the aggregate wealth belongs to agents with consumption volatility at least two and a half times higher than that of the aggregate. Although empirically the time-series properties of individual consumption are difficult to measure precisely, the fact that our model implies a substantial degree of dispersion in volatility

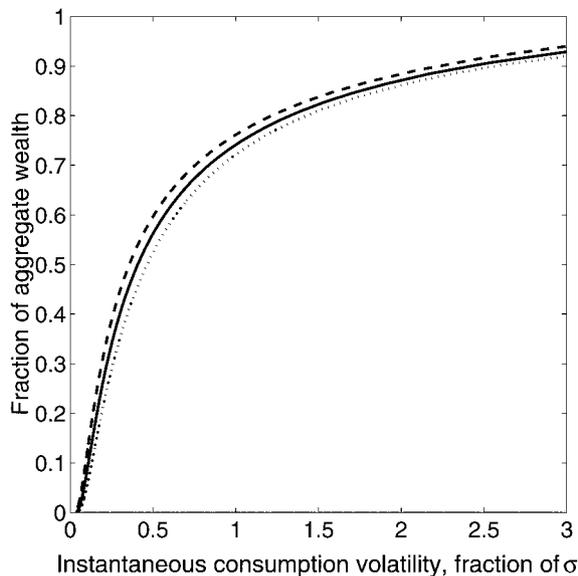


FIG. 8.—Individual consumption volatility. For every value of the instantaneous volatility of the individual consumption process (horizontal axis, measured as a fraction of the volatility of the aggregate endowment σ), the graph shows the fraction of the aggregate wealth controlled by individuals with consumption volatility less than or equal to that value. The dotted, solid, and broken lines correspond to three values of the aggregate state (relative consumption), $\bar{\omega} - \sigma[\omega]$, $\bar{\omega}$, and $\bar{\omega} + \sigma[\omega]$, respectively.

of individual consumption across the population could be viewed as one of its limitations. The basic model of this paper could be extended in a number of directions with the objective of improving its cross-sectional implications. Heterogeneity in individual risk exposure could arise not only from differences in risk aversion but also from differences in beliefs, access to capital markets, idiosyncratic uninsurable risk, and so forth.¹³ Incorporating these additional dimensions of heterogeneity could help produce realistic cross-sectional features of individual policies. Generalizing the framework of this paper while retaining its tractability poses a challenge for future research.

V. Conclusion

Representative-agent models identify economic mechanisms that generate empirically observed features of asset prices. One such mechanism

¹³ Several papers make progress along these dimensions (e.g., Detemple and Murthy 1994; Constantinides and Duffie 1996; Heaton and Lucas 1996; Basak and Cuoco 1998, 2000; Storesletten, Telmer, and Yaron 2001).

is countercyclical variation in the aggregate risk aversion and the market price of risk, as shown by Campbell and Cochrane (1999). This effect arises in our model as a result of heterogeneity in risk preferences among the agents. In a heterogeneous economy, moves in the stock market trigger changes in the cross-sectional distribution of wealth, which we show to cause countercyclical variation in the conditional risk premium and volatility of stock returns.

While endogenous changes in aggregate risk aversion contribute with the right sign to the pattern of time variation in expected returns and volatility, a nontrivial fraction of expected return variation in our model is still due to changes in the risk-free rate. This property of the model is explained by our choice of the specific functional form of preferences. Thus we cannot argue that the observed empirical properties of stock returns should be attributed to heterogeneous risk preferences alone. Nevertheless, the ability of our heterogeneous-agent model to replicate various qualitative features of aggregate stock returns is encouraging. It suggests that many salient features of the data can arise naturally as a result of interaction between rational investors with different risk preferences.

Appendix

Proof of Lemma 1

Let

$$c_t(Y_t, X_t; \gamma) \equiv \frac{C_t(Y_t, X_t; \gamma)}{Y_t}.$$

The sharing rule in (7) and (8) is simply the first-order condition for consumption in the social planner’s static optimization problem:

$$\begin{aligned} & \sup_{c_t(Y_t, X_t; \gamma)} \int_1^\infty f(b) \frac{1}{1-\gamma} \left[c_t(Y_t, X_t; \gamma) \frac{Y_t}{X_t} \right]^{1-\gamma} d\gamma \\ & \text{subject to } \int_1^\infty c_t(Y_t, X_t; \gamma) \frac{Y_t}{X_t} d\gamma = \frac{Y_t}{X_t} \\ & \Leftrightarrow \inf_{Z_t \geq 0} \sup_{c_t(Y_t, X_t; \gamma)} \int_1^\infty f(\gamma) \frac{1}{1-\gamma} [c_t(Y_t, X_t; \gamma)]^{1-\gamma} e^{(1-\gamma)\omega_t} d\gamma \\ & \quad - Z_t \cdot \frac{Y_t}{X_t} \cdot \left[\int_1^\infty c_t(Y_t, X_t; \gamma) d\gamma - 1 \right], \end{aligned}$$

where Z_t is the Lagrange multiplier (shadow price) of the constraint. Thus

$$c_t^*(Y_t, X_t; \gamma) = f(\gamma)^{1/\gamma} \exp\left(-\frac{1}{\gamma} z_t - \omega_t\right),$$

$$\int_1^\infty f(\gamma)^{1/\gamma} \exp\left(-\frac{1}{\gamma} z_t\right) d\gamma = e^{\omega_t}, \quad (\text{A1})$$

where $z_t \equiv \ln Z_t$. The resource constraint (A1) establishes a mapping between z_t and ω_t . The inverse of this mapping, $z(\omega_t)$, defines the logarithm of the shadow price, z_t , as a function of relative consumption ω_t . Thus consumption policy is a function of ω_t , $c_t^*(Y_t, X_t; \gamma) = c_t^*(\omega_t; \gamma)$. Q.E.D.

Proof of Lemma 2

Given the general expression for the stock price,

$$P_t = E_t \left[\int_t^\infty \exp[-\rho(s-t) - z_t + z_s + x_t - x_s] Y_s ds \right],$$

$$\frac{P_t}{Y_t} = \exp(x_t - z_t - y_t) E_t \left[\int_t^\infty \exp[-\rho(s-t) + z_s + y_s - x_s] ds \right]$$

$$= \exp[-z(\omega_t) - \omega_t] E \left[\int_t^\infty \exp[-\rho(s-t) + z(\omega_s) + \omega_s] ds \mid \omega_t \right].$$

The price-dividend ratio is well defined. Since $f(\gamma)$ has compact support, the function $z(\omega)$ is asymptotically linear as $|\omega| \rightarrow \infty$, and therefore the expectation of $\exp[z(\omega_t)]$ is finite. Q.E.D.

Proof of Lemma 3

In equilibrium, the instantaneous Sharpe ratio is equal to the absolute value of the volatility of the stochastic discount factor (e.g., Duffie 1996, sec. 6D), $|\sigma_s| = -\sigma z'(\omega_t)$. To show that the aggregate curvature parameter is negatively related to relative consumption, it is sufficient to establish that $z''(\omega_t) > 0$. Differentiating (9) twice with respect to ω_t yields

$$\int_1^\infty f(\gamma)^{1/\gamma} \exp\left[-\frac{1}{\gamma} z(\omega_t) - \omega_t\right] \left\{ \frac{z''(\omega_t)}{\gamma} - \left[\frac{z'(\omega_t)}{\gamma} + 1 \right]^2 \right\} d\gamma = 0.$$

If there are at least two types of agents in the economy,

$$\int_1^\infty f(\gamma)^{1/\gamma} \exp\left[-\frac{1}{\gamma} z(\omega_t) - \omega_t\right] \left[\frac{z'(\omega_t)}{\gamma} + 1 \right]^2 d\gamma > 0,$$

and the previous equality implies $z''(\omega_t) > 0$. Q.E.D.

Properties of the Model with Homogeneous Preferences

We establish some general properties of the stock price and return volatility in homogeneous economies. Abel (1999) derives explicit expressions for conditional moments of returns in a discrete-time economy under the assumption that the standard of living depends on a single lag of the aggregate consumption process. The conditional moments of returns in his model are constant. As we demonstrate below, this is not the case in a model with a slowly varying standard of living.

The next lemma shows that the price-dividend ratio in homogeneous economies is a monotone, convex function of relative consumption.

LEMMA 5. In a homogeneous economy with catching up with the Joneses preferences, the following properties hold: (a) The price-dividend ratio is increasing in the state variable ω_t for $\gamma > 1$. Formally,

$$\left. \begin{aligned} \frac{d(P_t/Y_t)}{d\omega_t} &> 0 & \gamma > 1 \\ &= 0 & \gamma = 1. \end{aligned} \right\}$$

(b) The price-dividend ratio is a convex function of ω_t for $\gamma > 1$.

Proof. Part a: With homogeneous agents, from the definition of $z(\omega_t)$ we immediately have $z(\omega_t) = -\gamma\omega_t$. To simplify the notation, define $\bar{P} \equiv P/Y$. Then the price function in (13) becomes

$$\begin{aligned} \bar{P} &= e^{(\gamma-1)\omega} E_0 \left[\int_0^\infty \exp[-\rho t + (1-\gamma)\omega_t] dt \mid \omega_0 = \omega \right] \\ &= e^{(\gamma-1)\omega} \left\{ \int_0^\infty \exp \left[-\rho t + (1-\gamma)E_0[\omega_t] + \frac{(1-\gamma)^2}{2} \text{Var}_0(\omega_t) \right] dt \right\} \\ &= e^{(\gamma-1)\omega} \cdot \int_0^\infty \kappa_t \exp[(1-\gamma)e^{-\lambda t}\omega] dt, \end{aligned}$$

where

$$\kappa_t \equiv \exp \left\{ -\rho t + \left[(1-\gamma)(1-e^{-\lambda t})\bar{\omega} + \frac{\sigma^2(1-\gamma)^2}{4\lambda}(1-e^{-2\lambda t}) \right] \right\} > 0.$$

Differentiating with respect to ω and rearranging terms, we obtain

$$\frac{d\bar{P}}{d\omega} = (\gamma-1)(\bar{P} - \bar{P}_1), \tag{A2}$$

where

$$\bar{P}_1 \equiv e^{(\gamma-1)\omega} \cdot \int_0^\infty \kappa_t \exp[(1-\gamma)e^{-\lambda t}\omega] e^{-\lambda t} dt.$$

It is obvious that $\bar{P} > \bar{P}_1$. Thus we have established part a.

Part b: Differentiating (A2) again with respect to ω gives

$$\frac{d^2\bar{P}}{d\omega^2} = (\gamma-1) \left(\frac{d\bar{P}}{d\omega} \right) + (\gamma-1) \left[\frac{d\bar{P}}{d\omega} - (\gamma-1)\bar{P} \right] + (\gamma-1)^2 \bar{P}_2,$$

where

$$\bar{P}_2 \equiv e^{(\gamma-1)\omega} \cdot \int_0^\infty \kappa_t \exp[(1-\gamma)e^{-\lambda t}\omega] e^{-2\lambda t} dt.$$

Again, it is obvious that $\bar{P} > \bar{P}_1 > \bar{P}_2$. Using (A2) and rearranging terms, we get

$$\begin{aligned} \frac{d^2 \bar{P}}{d\omega^2} &= 2(\gamma-1)^2(\bar{P}-\bar{P}_1) - (\gamma-1)^2(\bar{P}-\bar{P}_2) \\ &= (\gamma-1)^2(\bar{P}+\bar{P}_2-2\bar{P}_1). \end{aligned}$$

Thus, to complete the proof, it remains to show that $\bar{P}+\bar{P}_2-2\bar{P}_1 > 0$. But,

$$\begin{aligned} \bar{P}+\bar{P}_2-2\bar{P}_1 &= e^{(\gamma-1)\omega} \cdot \int_0^\infty \kappa_t \exp[(1-\gamma)e^{-\lambda t}\omega](1+e^{-2\lambda t}-2e^{-\lambda t}) dt \\ &= e^{(\gamma-1)\omega} \cdot \int_0^\infty \kappa_t \exp[(1-\gamma)e^{-\lambda t}\omega](1-e^{-\lambda t})^2 dt. \end{aligned}$$

Since all the terms involved are positive, we have $\bar{P}+\bar{P}_2-2\bar{P}_1 > 0$. This completes the proof. Q.E.D.

We can gain more intuition behind lemma 5 by examining the marginal utility process. Formally, the marginal utility of the representative investor follows

$$\frac{dU_c}{U_c} = \left[\lambda(\gamma-1)\omega_t - \gamma\mu + \frac{\sigma^2\gamma}{2}(\gamma+1) \right] dt - \gamma\sigma dB_t. \quad (\text{A3})$$

Thus a change in relative consumption affects future marginal utility except when $\gamma = 1$. For $\gamma > 1$, an increase in ω raises the intertemporal marginal rate of substitution (the ratio of future to current marginal utility). In other words, the stock becomes more expensive relative to the current dividend, as the state prices for future dividend claims increase. This explains the positive relation between the price-dividend ratio and relative consumption.

LEMMA 6. In the homogeneous economy with catching up with the Joneses preferences, (a) the Sharpe ratio is constant and given by $\gamma\sigma$, and (b) the instantaneous interest rate is given by

$$r_t = \rho - \lambda(\gamma-1)(\omega_t - \bar{\omega}) + \lambda\bar{\omega} - \frac{1}{2}\gamma^2\sigma^2.$$

Lemma 6 follows from the standard consumption capital asset pricing model. The lemma shows that the price of risk is constant. The instantaneous interest rate inherits the stochastic behavior of relative consumption. Moreover, its variation is increasing in both λ and risk aversion.

As (A3) indicates, the growth rate of the marginal utility is state-dependent for $\gamma \neq 1$. This implies that volatility also depends on the state of the economy. The next lemma formally shows that the conditional volatility of stock returns is also a monotone function of relative consumption.

LEMMA 7. In an economy with homogeneous preferences, the following prop-

erties hold: (a) Return volatility is increasing in the state variable ω for all risk preferences other than the logarithmic type. Formally,

$$\frac{d\sigma_R(\omega)}{d\omega} \begin{cases} > 0 & \text{for } \gamma \neq 1 \\ = 0 & \text{for } \gamma = 1. \end{cases}$$

(b) The instantaneous correlation between changes in volatility and returns is positive for $\gamma \neq 1$ and equal to zero for $\gamma = 1$.

Proof. Part a: From the expression for return volatility,

$$\begin{aligned} \frac{d\sigma_R(\omega)}{d\omega} &= \sigma \left[\frac{d^2 \bar{P}/d\omega^2}{\bar{P}} - \left(\frac{d\bar{P}/d\omega}{\bar{P}} \right)^2 \right] \\ &= \sigma(\gamma - 1)^2 \left[\frac{\bar{P}_2}{\bar{P}} - \left(\frac{\bar{P}_1}{\bar{P}} \right)^2 \right], \end{aligned}$$

where the second equality follows from part b of lemma 5. Showing that the expression in brackets is positive is equivalent to showing that

$$\left(\int_0^\infty \bar{\kappa}_i dt \right) \left[\int_0^\infty \bar{\kappa}_i (1 - e^{-\lambda t})^2 dt \right] > \left[\int_0^\infty \bar{\kappa}_i (1 - e^{-\lambda t}) dt \right]^2, \tag{A4}$$

where $\bar{\kappa}_i \equiv \kappa_i \exp [(1 - \gamma)e^{-\lambda t}\omega]$. Expression (A4) follows from Schwartz's inequality.

Part b: The instantaneous correlation between changes in volatility and returns is given by

$$\text{sgn} \left(\frac{d\sigma_R}{d\omega} \cdot \sigma_R \right) = \text{sgn} \left(\frac{d\sigma_R}{d\omega} \cdot \left[\sigma + \sigma \frac{d(P/Y)/d\omega}{P/Y} \right] \right).$$

As we have shown in lemma 5, $\text{sgn} (d\sigma_R/d\omega) \geq 0$. In addition, according to (A2),

$$\frac{d(P/Y)/d\omega}{P/Y} = (\gamma - 1) \left(1 - \frac{\bar{P}_1}{\bar{P}} \right) \geq -1;$$

therefore,

$$\text{sgn} \left\{ \sigma \left[1 + \frac{d(P/Y)/d\omega}{P/Y} \right] \right\} \geq 0.$$

This establishes the result of part b. Q.E.D.

References

- Abel, Andrew B. "Asset Prices under Habit Formation and Catching Up with the Joneses." *A.E.R. Papers and Proc.* 80 (May 1990): 38–42.
- . "Risk Premia and Term Premia in General Equilibrium." *J. Monetary Econ.* 43 (February 1999): 3–33.
- Bakshi, Gurdip S., and Chen, Zhiwu. "The Spirit of Capitalism and Stock-Market Prices." *A.E.R.* 86 (March 1996): 133–57.
- Basak, Suleyman, and Cuoco, Domenico. "An Equilibrium Model with Restricted Stock Market Participation." *Rev. Financial Studies* 11 (Summer 1998): 309–41.

- Benninga, Simon, and Mayshar, Joram. "Heterogeneity and Option Pricing." Manuscript. Tel Aviv: Tel Aviv Univ.; Jerusalem: Hebrew Univ., 1997.
- Black, Fischer. "Studies of Stock Price Volatility Changes." In *1976 Proceedings of the Business and Economics Statistics Section, American Statistical Association*. Washington: American Statis. Assoc., 1976.
- Brav, Alon; Constantinides, George M.; and Geczy, Christopher C. "Asset Pricing with Heterogeneous Consumers and Limited Participation: Empirical Evidence." *J.P.E.* 110 (August 2002): 793–824.
- Campbell, John Y., and Cochrane, John H. "By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior." *J.P.E.* 107 (April 1999): 205–51.
- Campbell, John Y., and Hentschel, Ludger. "No News Is Good News: An Asymmetric Model of Changing Volatility in Stock Returns." *J. Financial Econ.* 31 (June 1992): 281–318.
- Campbell, John Y.; Lo, Andrew W.; and MacKinlay, A. Craig. *The Econometrics of Financial Markets*. Princeton, N.J.: Princeton Univ. Press, 1997.
- Chan, Yeung L., and Kogan, Leonid. "Catching Up with the Joneses: Heterogeneous Preferences and the Dynamics of Asset Prices." Manuscript. Philadelphia: Univ. Pennsylvania, Wharton School, 2000.
- Constantinides, George M. "Habit Formation: A Resolution of the Equity Premium Puzzle." *J.P.E.* 98 (June 1990): 519–43.
- Constantinides, George M., and Duffie, Darrell. "Asset Pricing with Heterogeneous Consumers." *J.P.E.* 104 (April 1996): 219–40.
- Cox, John C.; Ingersoll, Jonathan E., Jr.; and Ross, Stephen A. "An Intertemporal General Equilibrium Model of Asset Prices." *Econometrica* 53 (March 1985): 363–84.
- Detemple, Jerome B., and Murthy, Shashidhar. "Intertemporal Asset Pricing with Heterogeneous Beliefs." *J. Econ. Theory* 62 (April 1994): 294–320.
- Detemple, Jerome B., and Zapatero, Fernando. "Asset Prices in an Exchange Economy with Habit Formation." *Econometrica* 59 (November 1991): 1633–57.
- Duffie, Darrell. *Dynamic Asset Pricing Theory*. 2d ed. Princeton, N.J.: Princeton Univ. Press, 1996.
- Duffie, Darrell, and Huang, Chi-fu. "Implementing Arrow-Debreu Equilibria by Continuous Trading of Few Long-Lived Securities." *Econometrica* 53 (November 1985): 1337–56.
- Dumas, Bernard. "Two-Person Dynamic Equilibrium in the Capital Market." *Rev. Financial Studies* 2, no. 2 (1989): 157–88.
- Ferson, Wayne E., and Constantinides, George M. "Habit Persistence and Durability in Aggregate Consumption: Empirical Tests." *J. Financial Econ.* 29 (October 1991): 199–240.
- Ferson, Wayne E., and Harvey, Campbell R. "The Variation of Economic Risk Premiums." *J.P.E.* 99 (April 1991): 385–415.
- Gali, Jordi. "Keeping Up with the Joneses: Consumption Externalities, Portfolio Choice, and Asset Prices." *J. Money, Credit and Banking* 26 (February 1994): 1–8.
- Grossman, Sanford J., and Zhou, Zhongquan. "Equilibrium Analysis of Portfolio Insurance." *J. Finance* 51 (September 1996): 1379–1403.
- Harvey, Campbell R. "The Specification of Conditional Expectations." Manuscript. Durham, N.C.: Duke Univ., Fuqua School Bus., 1991.
- Heaton, John. "An Empirical Investigation of Asset Pricing with Temporally Dependent Preferences Specifications." *Econometrica* 63 (May 1995): 681–717.

- Heaton, John, and Lucas, Deborah J. "Evaluating the Effects of Incomplete Markets on Risk Sharing and Asset Pricing." *J.P.E.* 104 (June 1996): 443–87.
- . "Stock Prices and Fundamentals." In *NBER Macroeconomics Annual 1999*, vol. 14, edited by Ben S. Bernanke and Julio J. Rotemberg. Cambridge, Mass.: MIT Press, 2000.
- Hindy, Ayman, and Huang, Chi-fu. "Intertemporal Preferences for Uncertain Consumption: A Continuous Time Approach." *Econometrica* 60 (July 1992): 781–801.
- . "Optimal Consumption and Portfolio Rules with Durability and Local Substitution." *Econometrica* 61 (January 1993): 85–121.
- Hindy, Ayman; Huang, Chi-fu; and Zhu, Steven H. "Optimal Consumption and Portfolio Rules with Durability and Habit Formation." *J. Econ. Dynamics and Control* 21 (February–March 1997): 525–50.
- Karatzas, Ioannis; Lehoczky, John P.; and Shreve, Steven E. "Existence and Uniqueness of Multi-agent Equilibrium in a Stochastic, Dynamic Consumption/Investment Model." *Math. Operations Res.* 15 (February 1990): 80–128.
- Lucas, Robert E., Jr. "Asset Prices in an Exchange Economy." *Econometrica* 46 (November 1978): 1429–45.
- Mankiw, N. Gregory. "The Equity Premium and the Concentration of Aggregate Shocks." *J. Financial Econ.* 17 (September 1986): 211–19.
- Mehra, Rajnish, and Prescott, Edward C. "The Equity Premium: A Puzzle." *J. Monetary Econ.* 15 (March 1985): 145–61.
- Ryder, Harl E., Jr., and Heal, Geoffrey M. "Optimum Growth with Intertemporally Dependent Preferences." *Rev. Econ. Studies* 40 (January 1973): 1–33.
- Schwert, G. William. "Why Does Stock Market Volatility Change over Time?" *J. Finance* 44 (December 1989): 1115–53.
- Siegel, Jeremy J. "The Real Rate of Interest from 1800–1990: A Study of the U.S. and the U.K." *J. Monetary Econ.* 29 (April 1992): 227–52.
- Storesletten, Kjetil; Telmer, Chris I.; and Yaron, Amir. "Asset Pricing with Idiosyncratic Risk and Overlapping Generations." Manuscript. Philadelphia: Univ. Pennsylvania, Wharton School, 2001.
- Sundaresan, Suresh M. "Intertemporally Dependent Preferences and the Volatility of Consumption and Wealth." *Rev. Financial Studies* 2, no. 1 (1989): 73–89.
- Wang, Jiang. "The Term Structure of Interest Rates in a Pure Exchange Economy with Heterogeneous Investors." *J. Financial Econ.* 41 (May 1996): 75–110.
- Weil, Philippe. "The Equity Premium Puzzle and the Risk-Free Rate Puzzle." *J. Monetary Econ.* 24 (November 1989): 401–21.