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THE EFFECT OF COSTLY CONSUMPTION ADJUSTMENT ON ASSET PRICE VOLATILITY

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Abstract

We investigate Grossman and Laroque's (1990) conjecture that costs of adjusting consumption can reconcile the low variance of aggregate consumption growth with the high variance of asset returns. We incorporate small fixed costs of consumption adjustment into a consumption-based capital asset pricing model (CCAPM) with uninsurable idiosyncratic shocks. We calibrate the model to match the first and second moments of asset returns observed in post-war U.S. data, and ask whether the model can replicate observed moments of aggregate consumption process. We find that the CCAPM's implications are non-robust to extremely small adjustment costs. In particular, undetectably small consumption adjustment costs can account for most of the discrepancy between the observed variance of nondurable consumption growth and the predictions of the CCAPM. However, the model is unable to match the moments of the growth rate of the service flow from the stock of durables or housing.

1. INTRODUCTION

The consumption-based capital asset pricing model (CCAPM)[1] of Lucas (1978), Breeden (1979), and Grossman and Shiller (1982) has not fared well empirically. Perhaps the most basic problem with the CCAPM is that it has difficulty replicating the high volatility we see in asset price data. (See, e.g., Grossman, Melino, and Shiller (1987), Hansen and Jagannathan (1991).) The source of this problem is clear. The asset pricing operator delivered by the CCAPM is a function of aggregate consumption, which is a very smooth series. This pricing operator can only generate volatile asset prices if it imposes a highly nonlinear transformation on aggregate consumption data. In practice, the CCAPM must incorporate extreme curvature into the utility function by assuming high risk aversion[2] or a high degree of habit persistence.[3]

In this paper, we seek to reconcile the high variance of asset returns with the low variance of aggregate consumption growth *without* extreme curvature assumptions on preferences. Following a conjecture of Grossman and Laroque (1990), we ask whether the empirical failure of the CCAPM may be due to frictions in consumption transactions. In particular, Grossman and Laroque (1990) assume that changing the rate of consumption requires payment of a fixed cost. To see why consumption adjustment costs could affect the implications of the CCAPM, notice that the CCAPM has the following three properties:

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[1] By "CCAPM" I refer to models where the stochastic discount factor determining asset prices is a function of aggregate consumption.

[2] For example, the estimation exercises in Grossman, Melino, and Shiller (1987) that yield the least evidence against their CCAPM deliver estimates of the coefficient of relative risk aversion of 154 and 185.

[3] For example, in Constantinides's (1990) habit-formation model, agents' subsistence point is, on average, 80% of current consumption. In other words, if consumption is constant a long time and then drops by 20%, the consumer experiences a utility of negative infinity.

1. An asset's price is determined by the covariance between the asset's payoff and investors' intertemporal marginal rate of substitution (IMRS) in wealth.
2. The IMRS in wealth equals the IMRS in consumption.
3. The IMRS in consumption is a function of the aggregate consumption process.

The first of these properties is shared by all modern asset-pricing theories. The second is the *envelope property*. It only holds if wealth can be converted into consumption one-for-one. Consumption adjustment costs drive a wedge between the IMRS in wealth and the IMRS in consumption, invalidating the envelope property. The third property is the *aggregation property*. Models with fixed adjustment costs do not aggregate: aggregate consumption does not resemble the optimal consumption path of any individual agent. Rather, an individual's optimal consumption follows a discontinuous (S,s) pattern, while aggregate consumption is smooth.[4] Caballero (1990) shows that the variance of this aggregate consumption process can be substantially lower than the variance of individual consumption.

These considerations suggest that the CCAPM may be sensitive to fixed costs of consumption adjustment. However, it not known whether *plausible* adjustment costs are sufficient to reconcile the high variance of asset returns with the low variance of aggregate consumption growth. In this paper, we address this question. We introduce fixed consumption adjustment costs into a simple consumption-based model with heterogeneous agents. We then compute the relative means and variances of asset returns and aggregate consumption growth implied by the model, and compare these statistics with estimates from post-war US data.

[4] Lynch (1994) explores an asset pricing model similar to ours in which the (S,s) consumption pattern is imposed directly on individual agents.

What constitutes a "plausible" adjustment cost? The answer depends critically on what we mean by "consumption". Grossman and Laroque (1990) and Reider (1993) interpret consumption as the service flow from a stock of durable goods or housing: the cost of consumption adjustment is the cost of changing this stock. Under this interpretation, high adjustment costs are plausible. Consider, for example, the closing costs in a real estate transaction or the wholesale/retail spread paid when trading in a used car.

Alternatively, one could follow most of the empirical literature on consumption-based asset pricing, and interpret consumption as expenditures on nondurable goods. The problem with this interpretation is that there are no major costs to changing the flow rate of nondurable consumption. However, we argue that costs of adjusting nondurables are plausible *provided* the costs are undetectably small. That is, we would only consider costs so small that they would swamped by simple measurement error in collecting aggregate consumption data. These costs might include the time spent implementing a new consumption/savings plan, search costs in finding vendors for the new, better (or worse) quality goods to be purchased, or even the psychological effort of thinking about reoptimizing consumption, rather than continuing with last period's consumption plan. (This last category of adjustment costs is similar to what Cochrane (1989) calls "near-rational behavior".) Marshall (1994) provides evidence that undetectably small adjustment costs are sufficient to dramatically change the relative variances of consumption growth and asset returns. Intuitively, there is a relatively small utility gain from period-by-period adjustment of consumption in response to movements in asset returns. Even a small fixed cost of consumption adjustment would be sufficient to induce agents to forego this small utility gain, and to choose a consumption path that is virtually flat. When we evaluate our adjustment cost model, we will consider both the "durables" and the "nondurables" interpretation for consumption.

In the standard formulation of the CCAPM (e.g., Lucas (1978)), aggregate consumption is taken as an exogenous endowment flow, calibrated to observed aggregate consumption data. The researcher then asks whether the returns implied by the model are sufficiently volatile to match the data. In our paper, we reverse this logic. Following Constantinides (1990), we take the returns process as given, calibrated to observed asset return data. We then compute the optimal consumption decisions given this returns process, and we ask whether the implied aggregate consumption process is sufficiently *non-volatile* to match observed consumption data. This strategy is essentially a partial equilibrium approach, although one could interpret this model as a general equilibrium economy in which the capital assets are in infinitely elastic supply. We adopt this approach because the fixed adjustment cost introduces a nonconvexity into the standard CCAPM. To solve for equilibrium prices in such a model would require us to compute the equilibrium of a nonconvex economy. The theoretical and computational difficulties of such an exercise are prohibitive in an economy with multiple agent-types.[5]

Our model does not possess the aggregation property, so it is essential to explicitly model cross-sectional heterogeneity. The way this is usually done is to assume that each agent receives an idiosyncratic, uninsurable endowment, which is a proxy for uninsurable labor income.[6] In our model, we take returns as exogenous rather than endowments, so we assume that each agent has access to an idiosyncratic investment technology, whose return is stochastic and uninsurable. One can think of this idiosyncratic asset as a proxy for investment in human capital, household production, or a family business.

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[5] For a fuller discussion of these issues, see Marshall (1994).

[6] See, e.g., Lucas (1990), Marcet and Singleton (1990), Heaton and Lucas (1991), Telmer (1993), and Constantinides and Duffie (1992).

Our results confirm that a very small fixed cost of consumption adjustment sharply reduces the variance of aggregate consumption growth predicted by the model. In our benchmark case, adding an adjustment cost equal to (2/1000)^{ths} of current consumption cuts the variance of aggregate monthly consumption growth by almost 70%, which is almost enough to match the variance of the growth rate of nondurable consumption in post-war US data. On the other hand, we find that even very large adjustment costs cannot reduce the variance of consumption growth sufficiently to match data measuring the service flow from the stock of durables or housing.

We interpret these result as evidence that (1) the empirical rejections of the CCAPM using data on nondurable consumption may be due in part to the omission of extremely small adjustment costs from the model; and (2) reinterpreting consumption as a service flow from a stock of illiquid durable goods is unlikely to help the empirical performance of the CCAPM. More generally, our results show that the quantitative implications of the CCAPM are non-robust to the introduction of extremely small frictions.

The remainder of the paper is organized as follows. Section 2 introduces the model, which incorporates the consumption/portfolio problem of Grossman and Laroque (1990) into a heterogeneous-agent economy. In section 3, we simulate the model, characterize the moments of aggregate consumption growth implied by the model, and compare these implications to post-war US data. Section 4 summarizes our conclusions.

2. THE MODEL

A. Basic Structure

There are N agents. Each agent can invest in two risky assets and one risk-free asset. The risk-free asset pays an instantaneous rate of return, denoted r, which is constant through time.

The first risky asset is available to all agents. We will refer to this asset as the market asset.[7] Let b_t denote the value of one unit of the market asset at date t. It is assumed that b_t is a diffusion process:

$$db_t = b_t\left[(\mu + r)dt + \sigma dw_t\right] \tag{1}$$

where μ and σ are mean excess return and the standard deviation respectively of the market return, and w_t is a standard Wiener process. Let X_t^j denote the value of the j^{th} agent's holdings of the market asset, and let B_t^j denote the value of the j^{th} agent's holdings of the risk-free asset.

The second risky asset is idiosyncratic to the individual agent. Let b_{It}^j denote the value of one unit of agent j's idiosyncratic asset. The increment in b_{It}^j represents the payoff flow from the idiosyncratic investment. Its law of motion is analogous to that of the market asset:

$$db_{It}^j = b_{It}^j\left[(\mu_I + r)dt + \sigma_I dz_{j,t}\right] \tag{2}$$

where μ_I and σ_I denote the mean excess return and the standard deviation for the idiosyncratic investment, and $z_{j,t}$ is a standard Wiener process. It is assumed that μ_I and σ_I are the same for all agents, but the shocks to the idiosyncratic returns are uncorrelated with each other and with the shock to the market return:

$$\begin{aligned} \text{cov}(z_{j,t}, z_{k,t}) &= 0, \ \forall j,k \\ \text{cov}(z_{j,t}, w_t) &= 0, \ \forall j. \end{aligned} \tag{3}$$

Let I_t^j denote the stock of the idiosyncratic investment held by agent j. There are no other assets available. In particular, there is no market in claims contingent on the realization of $z_{j,t}$, so the

[7] Grossman and Laroque (1990) show that two-fund separation holds in this model, so there is no loss of generality in assuming a single publicly-traded risky asset, rather than a number of such assets.

risk of the idiosyncratic investment cannot be hedged.

It is costless for an agent to maintain the same rate of consumption, but changing the rate of consumption involves a fixed cost, which is proportional to the previous rate of consumption. Specifically, if the consumption rate immediately before a consumption change at date t for agent j is denoted $c_{t^-}^j$, the cost at date t of changing consumption is $\lambda c_{t^-}^j$, where $0 \leq \lambda \leq 1$.

Agent j's total wealth, Q_t^j, is given by

$$Q_t^j \equiv B_t^j + X_t^j + I_t^j. \tag{4}$$

If consumption is not adjusted at date t, the law of motion for Q_t^j is:

$$dQ_t^j = Q_t^j r dt + X_t^j(\mu dt + \sigma dw_t) + I_t^j(\mu_I dt + \sigma_I dz_{j,t}) - c_t^j dt. \tag{5}$$

If consumption is adjusted at date τ,

$$Q_\tau = Q_{\tau^-} - \lambda c_{\tau^-}. \tag{6}$$

Finally, agents face a no-bankruptcy condition:

$$Q_t^j - \lambda c_t^j \geq 0. \tag{7}$$

Agents are not infinitely-lived. Rather, as in Blanchard (1985), death is a Poisson process, uncorrelated across agents. In particular, in the time interval (t, t+Δt), each agent faces a probability of dying equal to $p\Delta t + o(\Delta t)$, where $p > 0$ is the Poisson parameter. Under this assumption, the steady state cross-sectional distribution of age and the remaining lifetime of each agent are both exponentially distributed.

Let an agent's (random) date of death be denoted tx. Each agent solves the following optimal control problem:

$$\max_{X_t, I_t, c_t} E \int_0^{t x} e^{-\delta t} \frac{(c_t)^a}{a} dt, \quad \delta>0,\ a<1,\ a\neq 0 \tag{8}$$

subject to constraints (4), (5), (6), and (7), and initial conditions $\{Q_{0^-}^j, c_{0^-}^j\}$. Parameters δ and *a* are assumed to be the same for each agent. As shown in Merton (1971), the objective function in (8) is equivalent to that of an infinitely-lived agent with a higher discount rate:

$$\max_{X_t, I_t, c_t} E \int_0^{\infty} e^{-(\delta+p)t} \frac{(c_t)^a}{a} dt, \quad \delta>0,\ a<1,\ a\neq 0 \tag{9}$$

In the event of an agent's death, the agent is replaced by a single newly-born agent. All agents born at a given date t are endowed with the same initial wealth, $\tilde{Q}_t$, where the stochastic process $\tilde{Q}_t$ is defined such that $\log(\tilde{Q}_t)$ equals the cross-sectional mean of $\log(Q_t^j)$. The lagged consumption c_{t^-} of each newborn agent (which determines that agent's initial consumption adjustment cost) equates the newborn's consumption/wealth ratio to the consumption/wealth ratio of the recently deceased agent that this newborn replaces. These assumptions insure that both the cross-sectional distribution of $\log(Q_t^j)$ around its cross-sectional mean and the cross-sectional distribution of the consumption/wealth ratio are stationary.

B. Optimality Conditions

When $\lambda = 0$ (no adjustment costs) the optimization problem corresponds to Merton (1971). Optimal consumption and asset holdings are proportional to wealth:

$$c_t^j = \left[\frac{\beta}{1-a}\right] Q_t^j$$

$$X_t^j = \left[\frac{1}{1-a}\right] \frac{\mu}{\sigma^2} Q_t^j$$

$$I_t^j = \left[\frac{1}{1-a}\right] \frac{\mu_I}{\sigma_I^2} Q_t^j \tag{10}$$

where

$$\beta \equiv \delta + p - ar - \frac{1}{2}\left[\frac{a}{1-a}\right]\left[\frac{\mu^2}{\sigma^2} + \frac{\mu_I^2}{\sigma_I^2}\right]$$

When $\lambda > 0$, the problem corresponds to that studied by Grossman and Laroque (1990). The derivation of the optimality conditions is provided in the Appendix. In this section we summarize the optimality conditions. Let V(Q,c) denote the maximized value of the objective in (9), starting from initial conditions (Q,c). V is homogeneous of degree *a*, so the dimensionality of the state space can be reduced. Define:

$$\begin{aligned} y &\equiv \frac{Q}{c} - \lambda, \\ h(y) &\equiv c^{-a} V(Q,c) \equiv V(\lambda + y, 1), \\ M &\equiv \sup_y (y+\lambda)^{-a} h(y). \end{aligned} \tag{11}$$

The optimal consumption and asset holdings of an individual agent are functions of the transformed value function h(y). If $h(y) = y^a M$, then it is optimal to adjust consumption. If h(y)

> $y^a M$, it is not optimal to adjust consumption. The optimal asset holdings are given by

$$X = c \frac{-h'(y)}{h''(y)} \frac{\mu}{\sigma^2} \tag{12}$$

and

$$I = c \frac{-h'(y)}{h''(y)} \frac{\mu_I}{\sigma_I^2}, \tag{13}$$

(where the superscripts and subscripts in X_t^j and I_t^j have been suppressed). The function h(y) satisfies the differential equation

$$-\frac{1}{2} \frac{h'(y)^2}{h''(y)} \left[\frac{\mu^2}{\sigma^2} + \frac{\mu_I^2}{\sigma_I^2} \right] + h'(y)[r(y+\lambda)-1] - (\delta+p)h(y) + \frac{1}{a} = 0. \tag{14}$$

Following Grossman and Laroque (1990), it can be proved that the optimal consumption strategy is determined by three points $y_1 \leq y^* \leq y_2$, where y_1 and y_2 satisfy

$$\begin{aligned} h(y_i) &= y_i{}^a M \\ h'(y_i) &= a y_i{}^{a-1} M, \quad i = 1, 2, \end{aligned} \tag{15}$$

and $y^* \equiv \text{argmax}_y\, (y+\lambda)^{-a} h(y)$. The interval (y_1, y_2) is the region of inaction for consumers: when $y \in (y_1, y_2)$, it is optimal not to adjust consumption. Whenever $y = y_1$ (i.e., the wealth/consumption ratio is sufficiently low) or $y = y_2$ (i.e., the wealth/consumption ratio is sufficiently high) it is optimal to adjust consumption so that $y = y^*$, in which case

$$c_t = \frac{Q_t}{y^* + \lambda}. \tag{16}$$

Notice that δ and p enter the optimal decision rules only as the composite discount rate

$\delta + p$. Also, by substituting (12) and (13) into (5), one can see that μ_I and σ_I affect consumption, wealth, and asset holdings only through the Sharpe ratio μ_I/σ_I. For this reason, we treat μ_I/σ_I as the single parameter characterizing the idiosyncratic return process.

3. SIMULATION RESULTS

For a given set of parameter values, we compute the equilibrium by numerically solving equation (14) to obtain the function h. (Details are provided in the Appendix.) Once the function h has been computed, we use this function in (11) and (15) to compute y_1, y_2, and y^*. We then simulate the returns processes, and we use the optimal consumption and portfolio rules (12) and (13) to trace the evolution of consumption through time for a population of 1000 individuals. We approximate continuous time by evaluating the consumption and portfolio rules at time intervals $\Delta t = (1/120)^{th}$ of a year. For each parameter set, the model is simulated for 50,000 periods (416.67 years). The choice of initial value for the cross-sectional mean of wealth is arbitrary, since the model is homothetic in wealth. As described in the appendix, the initial cross-sectional distribution of the log of wealth around this arbitrary mean is set equal to the steady-state cross-sectional distribution when $\lambda = 0$. Aggregate consumption is computed by summing the 1000 individual consumptions cross-sectionally, then temporally aggregating up to a monthly or quarterly series.

We calibrate μ and σ^2 to match the mean and variance of the monthly real return to the value-weighted portfolio of NYSE stocks from 1959:2 through 1986:12. The risk-free rate r is calibrated to the mean of the monthly real return to one-month treasury bills over this same period. In particular, the mean monthly log return on the value-weighted stock portfolio is .0038, and the standard deviation of this return is .0425. The mean monthly log return on one month

T-bills over this period is .00072. The rate-of-return parameters μ, σ, and r, are annualized rates, so the mean of the monthly log return is $(\mu + r - \sigma^2/2)/12$, the variance is $\sigma^2/12$, and the monthly risk-free log return is r/12. Setting these expressions equal to the moments in the observed monthly data, we obtain $\mu = .0484$, $\sigma = .147$, and $r = .008$.

We must choose values for the other parameters $\{a, \lambda, \delta, p, \mu_I/\sigma_I\}$. The values of parameter a we consider are -1 and -4, which correspond to a coefficient of relative risk aversion of 2 and 5 respectively. The parameters δ (the subjective discount rate) and p (the Poisson parameter governing the probability of death) enter the individual's decision rule only as the sum $\delta + p$. (See equation (9).) In principle, δ and p could affect the behavior of the economy in distinct ways because p affects the cross-sectional distribution of wealth. In practice, however, varying p while keeping $\delta + p$ constant has no detectable effect on aggregate consumption for the range of parameters we use. Therefore, in reporting our results we treat δ + p as the parameter to be varied. We report simulations for $\delta + p = .02$ and .04.

We think of the idiosyncratic asset as analogous to human capital, home production, or investment in a small family business. Unfortunately, reliable data for the mean and variance of the return to these types of investments are unavailable, so we have little empirical guidance in choosing values for μ_I/σ_I. We proceed by assuming that μ_I/σ_I does not differ greatly from μ/σ, the Sharpe ratio for the market return. Noting that $\mu/\sigma = 0.33$, we consider values of μ_I/σ_I between 0.2 and 0.6.

We wish to simulate the model for reasonable values of the adjustment cost. When consumption is interpreted as the service flow from the stock of durables or housing, we set $\lambda = 0.4$ as the upper limit of the adjustment cost parameter. We regard this figure as conservative. If the fixed cost of changing one's house is 6% of the value of the house being sold and the annual service flow from a house is 15% of its value, then λ would equal 40%. Similarly, suppose the adjustment cost involved with buying a car is equal to the retail/wholesale spread that the consumer loses on the trade-in. If this spread equals 8% of the trade-in's value (a rather low figure), and if the service flow from a car equals 20% of the car's value, then λ would again equal 40%. On the other hand, when consumption is interpreted as the expenditure on nondurable goods, we consider only trivially small adjustment costs: for this case, we set λ = .002 as the upper limit of the adjustment cost parameter. To give an idea of the magnitude of the fixed costs involved, per capita consumption of nondurables and services in the United States in 1993 was approximately $14,000. A value of λ equal to .002 would correspond to a fixed cost of consumption adjustment of $28. Costs this small are virtually undetectable.

We take as our benchmark case the parameterization $\{a = -4, \delta + p = .04, \mu_I/\sigma_I = .2\}$. Results from simulating this benchmark case are displayed in Table 1. Increasing λ has little effect on the mean of monthly aggregate consumption growth, but it substantially reduces the variance of this series. The most rapid variance reduction is for small values of the adjustment cost. For example, when we increase λ from 0 to .002 in this benchmark case, we observe a 67% reduction in the variance of monthly aggregate consumption growth, from .00024 to .00008. This rapid fall-off in variance as λ increases is illustrated in Figure 1, which graphs the variance as a function of $\lambda \in [0, .002]$. The convex shape of this graph is typical for all parameterizations of this model: in all cases, very small adjustment costs have the biggest proportional impact on consumption-growth variance. Additional increases in the adjustment cost parameter beyond .002 imply relatively smaller additional variance reductions: for the benchmark case, increasing λ from .002 to .01, a five-fold additional increase in λ, only reduces the variance of monthly consumption growth from .00008 to .00005.

Tables 2 and 3 display how the behavior of the model changes as we move away from the benchmark case. In Table 2, we set $a = -1$. This lower value of risk aversion implies both a higher mean and a higher variance of consumption growth, since agents hold a larger fraction of wealth in the risky assets. As in Table 1, most of the variance reduction from increasing the adjustment cost comes at very low values of λ. In Table 3 we change $p + \delta$ and μ_I/σ_I from the benchmark levels. In all these cases, the variance reduction from increasing λ follows the pattern displayed in Figure 1, so we only report the moments for three values of λ. In Panels A and B of Table 3, we reduce the composite discount rate $p + \delta$ to .02. The effect on the moments of aggregate consumption growth is concentrated on the mean: lower discounting of the future implies more savings, and therefore a higher mean growth rate of consumption. There is virtually no effect on the variance of consumption growth. Finally, Panels C and D of Table 3 show the effect of increasing the productivity of the idiosyncratic asset. As μ_I/σ_I increases, the idiosyncratic asset becomes more attractive, agents invest more in this risky asset, so both the mean and variance of aggregate consumption growth are higher. The effect on the variance, however, is rather small, compared to the effect of decreasing risk aversion.

We now ask how well the benchmark case replicates the moments of consumption growth and asset returns observed in the data. The risk-free rate and the mean and variance of the market return are already calibrated to match observed asset returns; the key question is whether plausible adjustment costs can reduce the variance of aggregate consumption growth to the level observed in the post-war US economy. In Table 4 we display means and variances of the monthly growth rate of expenditures on nondurables and on nondurables plus services. We also display the means and variances of the quarterly growth rate of the service flow from the stock of durables and of the service flow from the stock of residential housing. These four cases correspond to four different interpretations for consumption in our model. We consider each interpretation in isolation. For example, when we interpret consumption as purchases of nondurable goods, we abstract from consumption of services from durables, and vice versa. This procedure is essential for tractability: to include multiple types of consumption, each with a different cost of adjustment, would vastly complicate the model.

Let us first compare the performance of the benchmark model, displayed in Table 1, with the moments of observed data on consumption of nondurable goods, reported in the first row of Table 4. For all values of λ, the mean of monthly aggregate consumption growth in the benchmark case is within one standard error of the value of 1.0007 estimated using data on nondurable consumption. In the absence of adjustment costs, the benchmark model implies a consumption-growth variance of 2.4×10^{-4}, more than four times the variance observed for nondurable consumption growth in the data. However, when we increase λ to .002, the variance of consumption growth in the model drops to 8×10^{-5}, which is quite close to the estimated variance of 5.4×10^{-5}. It appears from this evidence that the observed variances of equity returns and nondurable consumption growth are consistent with a simple CCAPM when extremely small consumption adjustment costs are introduced.

If it is assumed that consumer services are prefect substitutes for consumption of nondurable goods, it is appropriate to construct an alternative measure of consumption by adding these two series. The mean and variance of this measure of consumption are displayed in the second row of Table 4.[8] The mean growth rate of consumption of nondurables and services is

[8] Our measure of expenditures on services excludes the service flow from housing, which is usually included in data on consumption of services as reported by the Bureau of Economic Analysis. We do so because the adjustment cost on this service flow from housing is likely to be much larger than the other components of expenditures on services.

estimated to be about 1.0013, somewhat higher than the prediction of the benchmark model, while the estimated variance is $2.4x10^{-5}$, which is substantially lower than that predicted by the model. The model's prediction for the mean can be increased by assuming a lower composite discount rate. (See, for example, Panel A of Table 3.) However, in order to match the observed variance of consumption of nondurables plus services, one would have to assume a value of λ around .02. We regard costs of this magnitude as implausibly high. To summarize, plausible consumption adjustment costs can account for about 75% of the discrepancy between the variance of consumption growth predicted by the frictionless CCAPM (i.e., $\lambda = 0$) and the variance of the observed growth rate of nondurables plus services.

Let us now turn to an alternative interpretation of consumption as a service flow from durables. Adjustment costs have a natural interpretation in this context as the cost of changing the stock of durables. Reider (1993) suggests that the empirical performance of the CCAPM may improve if consumption is interpreted in this way. Somewhat surprisingly, we fine that the adjustment cost model fares rather poorly for this measure of consumption. Even with values of λ as high as 0.4, the model cannot match the low variance of the growth rate of the services from durables or housing. Table 4 reports that the mean of the quarterly growth rate of the service flow imputed from the stock of consumer durables is 1.008, and the variance of this growth rate is 0.000025. The corresponding moments for the growth rate of the service flow from the stock of housing are 1.005 and .000016. In both cases, the benchmark model underpredicts the mean quarterly growth rate, and, even with λ set at .40, the variance of quarterly consumption growth predicted by the model is over four times the observed variance. The growth rate of service flows from consumer durables or housing seems too smooth to be explained by this simple model, even when large adjustment costs are assumed.

4. CONCLUSIONS

The results of this paper support our conjecture that fixed costs of consumption adjustment have quantitatively important implications for the co-movements of aggregate consumption and asset returns. We find that costs too small to be detected empirically can reduce the variance of aggregate consumption growth by more than 60%. Costs of this magnitude can account for most of the discrepancy between the high variance of asset returns and the low variance of observed aggregate nondurable consumption. Our results do not support Reider's (1993) conjecture that illiquidity in *durable* goods can explain the poor empirical performance of the CCAPM. We find that even high adjustment costs cannot reconcile the high volatility of asset returns with the low volatility of consumption services from durables or housing.

Our results have important implications for the use of the CCAPM. In particular, they suggest that predictions of consumption-based models for the short-run movements of asset returns are non-robust to extremely small perturbations. It follows that the consumption-based approach is not well-suited to modelling high frequency asset-price behavior. On the other hand, this class of models still may be useful for understanding the co-movements of asset returns and macroeconomic quantity variables at cyclical or longer frequencies.[9]

[9] For a recent effort in this direction, see Campbell and Cochrane (1994).

Appendix: Derivation of Optimality Conditions; Discussion of Simulation Procedure

This sketch of the derivation of the optimality conditions follows Grossman and Laroque (1990), with appropriate changes to accommodate the features we add. For a more complete description, the interested reader can refer to Grossman and Laroque (1990).

Let V(Q,c) denote the maximized value of the objective in (9), starting from initial conditions (Q,c). If τ denotes the first date at which it is optimal to adjust consumption, and c^* denotes the consumption level immediately following that adjustment, then V(Q,c) satisfies

$$V(Q,c) = \sup_{c^*,\tau,(X_t,I_t,t\in[0,\tau])} E\left[\int_0^\tau e^{-(\delta+p)t}\frac{c_t^a}{a}dt + e^{-(\delta+p)\tau}V(Q_{\tau^-}-\lambda c_{\tau^-},c^*)\right] \quad \textbf{(17)}$$

subject to (4), (5), (6), and (7). Use (11) to transform (17) in terms of the single variable y:

$$h(y) = \sup_{\tau,x_t,\eta_t} E\left[\int_0^\tau \frac{e^{-(\delta+p)t}}{a}dt + e^{-(\delta+p)\tau}My_{\tau^-}^a\right]. \quad \textbf{(18)}$$

where $x_t \equiv X_t/c$ and $\eta_t \equiv I_t/c$, and the maximization is subject to the appropriately transformed constraints. In particular, the law of motion for the new state variable, y, can be obtained from (5):

$$dy = \left[r(y+\lambda)-1\right]dt + x\left[\mu dt + \sigma dw\right] + \eta\left[\mu_I + \sigma_I dz\right] \quad \textbf{(19)}$$

and the no bankruptcy condition is simply $y_t \geq 0$.

Grossman and Laroque's (1990) key insight is that, for fixed M, control problem (18) is an optimal stopping problem in which the payoff upon stopping in state y is simply My^a. Let h(y;M) denote the function h which solves problem (18) for a particular fixed M. This function can be characterized using results from the optimal control literature. Once h(y;M) has been determined, h can be computed as the function $h(\cdot;M^*)$, where M^* is implicitly defined by:

$$M^* \equiv \sup_y (y+\lambda) h(y;M^*) \tag{20}$$

The function $h(y;M)$ has the following properties: $h(y;M) \geq y^a M$ (since it is always feasible to stop immediately). If $h(y;M) > y^a M$ then it is not optimal to stop. In this case, consumption equals c for a time interval $[0, \Delta t]$, and the function $h(y;M)$ must satisfy the Bellman equation

$$h(y_0) = \sup_{x_t, \eta_t} E\left[\int_0^{\Delta t} \frac{e^{-(\delta+p)s}}{a} ds + e^{-(\delta+p)\Delta t} h(y_{\Delta t})\right] \tag{21}$$

subject to (19) (where the dependence of $h(y;M)$ on M is suppressed for simplicity). Taking limits as $\Delta t \to 0$ and applying Ito's Lemma, one obtains the Hamilton-Jacobi-Bellman equation

$$\sup_{x,\eta}\left[\frac{h''(y)}{2}[x^2\sigma^2 + \eta^2\sigma_I^2] + h'(y)[x\mu + r(y+\lambda) - 1 + \eta\mu_I] - (\delta+p)h(y) + \frac{1}{a}\right] = 0 \tag{22}$$

The optimal portfolio choices, can be found by maximizing equation (22) with respect to x and η. Doing so, one obtains equations (12) and (13). By substituting (12) and (13) into (22), one obtains (14). If $h(y) = y^a M$, then it is optimal to stop. At these stopping times, the smooth pasting condition $h'(y) = ay^{a-1}$ must hold.

Finally, it can be shown, using a proof strategy analogous to that used in Grossman and Laroque (1990, Theorem 3.3), that the set $\{y \,|\, h(y) \geq y^a M\}$ is a closed interval $[y_1, y_2]$, so the optimal strategy is to keep consumption constant until $y = y_1$ or $y = y_2$, at which point consumption is adjusted to set $y = y^* \equiv \operatorname{argmax}_y (y+\lambda)^{-a} h(y)$. Equations (15) immediately follow.

To solve the model we choose an initial guess for M and an initial guess for y_1, set $h(y_1) = y_1^a M$ and $h'(y_1) = ay^{a-1}M$, continue h by solving differential equation (14) using a fifth-order Runge-

Kutta algorithm, until a value for $y > y_1$ is found where $h'(y) = ay^{a-1}M$. If, at this value of y, it is also the case that $h(y) = y^a M$, then this value of y corresponds to y_2, and the computed path for $h(\cdot)$ corresponds to $h(\cdot;M)$ for the given M. If not, we adjust y_1 and repeat the process until we have an $h(\cdot,M)$ process for which all boundary conditions hold. We then evaluate our initial guess for M by computing, as a criterion function, $S(M) \equiv \left[M - \max_y (y+\lambda)^{-a} h(y;M)\right]^2$. The algorithm searches for a value M^* for which $S(M^*) = 0$.

When $\lambda = 0$, the cross-sectional distribution of the log of wealth at date t is a time-invariant mixture-of-normals with identical means and exponentially-distributed variances.[10] (The mean of this distribution is a random variable.) In our simulations, use this time-invariant distribution as the initial cross-sectional distribution of the log of wealth for all values of λ. (The initial value of the cross-sectional mean is arbitrary.)

Time is discretized in units of $\Delta t = (1/120)^{th}$ of a year. (Experiments setting Δt equal to one day yielded virtually identical results.) The gross return to the market asset between t and $t+\Delta t$ equals $\exp[\mu+r+\sigma^2/2)\Delta t + \sigma(\Delta t)^{.5}\varepsilon]$, where ε is a standard normal variate. (The returns to the idiosyncratic asset are computed analogously.) The only approximation in discretizing time is that agents are allowed to adjust their consumption and portfolios only at discrete intervals.

[10] The normality assumption on the return to the idiosyncratic asset, along with equation (13), imply that the cross-sectional distribution of the log of wealth for agents of age τ is Gaussian with variance $\tau(\mu_I/[(1-a)\sigma_I])^2$. Death is a Poisson process, so the cross-sectional distribution of age τ is exponential.

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Table 1

Moments of Aggregate Consumption Growth

As Consumption Adjustment Costs Increase:

Benchmark Case

Coefficient of Relative Risk Aversion = 5
$p + \delta = .04$
$\mu_I/\sigma_I = .2$

λ's	Mean of Monthly (c_t/c_{t-1})	Variance of Monthly (c_t/c_{t-1})	Reduction in Variance of Monthly (c_t/c_{t-1})	Mean of Quarterly (c_t/c_{t-1})	Variance of Quarterly (c_t/c_{t-1})	Reduction in Variance of Quarterly (c_t/c_{t-1})
0.0000	1.00076	0.000235		1.0023	0.00070	
0.0002	1.00071	0.000137	41.7%			
0.0003	1.00070	0.000127	46.0%			
0.0005	1.00069	0.000109	53.5%			
0.0007	1.00069	0.000101	56.9%			
0.0010	1.00068	0.000092	61.0%			
0.0020	1.00068	0.000078	66.8%			
0.0050	1.00066	0.000056	76.2%			
0.0100	1.00066	0.000046	80.6%			
0.0200	1.00067	0.000036	84.5%	1.00205	0.00022	69.0%
0.0500	1.00067	0.000027	88.3%	1.00204	0.00017	76.1%
0.1000	1.00065	0.000023	90.2%	1.00198	0.00014	79.8%
0.2000	1.00065	0.000019	91.8%	1.00198	0.00012	83.1%
0.4000	1.00065	0.000016	93.1%	1.00197	0.00010	85.8%

Notes: The model was simulated for a cross-section of 1000 individuals; 50,000 time periods were simulated, each period corresponding to $(1/120)^{th}$ of a year. The parameters of the market return process are: $r = .008$; $\mu = .0484$; $\sigma = .147$. Aggregate consumption c_t is computed by summing individual consumptions cross-sectionally, then temporally aggregating up to a monthly series (for columns 2 and 3) or a quarterly series (for columns 5 and 6). The columns labelled "Reduction in Variance of (c_t/c_{t-1})" give the percentage reduction in variance, compared to the case with $\lambda = 0$.

Table 2

Moments of Aggregate Consumption Growth

As Consumption Adjustment Costs Increase:

Lower Risk Aversion

Coefficient of Relative Risk Aversion = 2
$p + \delta = .04$
$\mu_I/\sigma_I = .2$

λ's	Mean of Monthly (c_t/c_{t-1})	Variance of Monthly (c_t/c_{t-1})	Reduction in Variance of Monthly (c_t/c_{t-1})	Mean of Quarterly (c_t/c_{t-1})	Variance of Quarterly (c_t/c_{t-1})	Reduction in Variance of Quarterly (c_t/c_{t-1})
0.0000	1.00276	0.00148		1.0070	0.00444	
0.0002	1.00255	0.00105	28.7%			
0.0003	1.00251	0.00098	33.7%			
0.0005	1.00247	0.00089	40.0%			
0.0007	1.00243	0.00082	44.8%			
0.0010	1.00239	0.00075	49.1%			
0.0020	1.00233	0.00062	57.8%			
0.0050	1.00226	0.00047	67.9%			
0.0100	1.00221	0.00038	74.1%			
0.0200	1.00178	0.00031	79.1%	1.0057	0.00181	59.3%
0.0500	1.00174	0.00024	84.0%	1.0055	0.00141	68.1%
0.1000	1.00170	0.00019	87.1%	1.0054	0.00117	73.7%
0.2000	1.00169	0.00016	89.2%	1.0053	0.00097	78.0%
0.4000	1.00167	0.00013	91.1%	1.0052	0.00082	81.6%

Notes: See notes for Table 1.

Table 3

Moments of Aggregate Consumption Growth

For Alternative Parameterizations of the Model

Panel A

Coefficient of Relative Risk Aversion = 5
$p + \delta = .02$
$\mu_I/\sigma_I = .2$

λ's	Mean of Monthly (c_t/c_{t-1})	Variance of Monthly (c_t/c_{t-1})	Reduction in Variance of Monthly (c_t/c_{t-1})
0.0000	1.00110	0.000235	
0.0010	1.00103	0.000086	63.2%
0.0100	1.00100	0.000046	80.6%

Panel B

Coefficient of Relative Risk Aversion = 2
$p + \delta = .02$
$\mu_I/\sigma_I = .2$

λ's	Mean of Monthly (c_t/c_{t-1})	Variance of Monthly (c_t/c_{t-1})	Reduction in Variance of Monthly (c_t/c_{t-1})
0.0000	1.00319	0.00148	
0.0010	1.00283	0.00074	49.7%
0.0100	1.00266	0.00038	74.1%

Table 3 (Continued)

Panel C

Coefficient of Relative Risk Aversion = 5
$p + \delta = .04$
$\mu_I/\sigma_I = .4$

λ's	Mean of Monthly (c_t/c_{t-1})	Variance of Monthly (c_t/c_{t-1})	Reduction in Variance of Monthly (c_t/c_{t-1})
0.0000	1.00178	0.000236	
0.0010	1.00171	0.000103	56.2%
0.0100	1.00169	0.000051	78.3%

Panel D

Coefficient of Relative Risk Aversion = 5
$p + \delta = .04$
$\mu_I/\sigma_I = .6$

λ's	Mean of Monthly (c_t/c_{t-1})	Variance of Monthly (c_t/c_{t-1})	Reduction in Variance of Monthly (c_t/c_{t-1})
0.0000	1.00347	0.000239	
0.0010	1.00342	0.000123	48.7%
0.0100	1.00340	0.000062	74.1%

Notes: See notes for Table 1.

Table 4

Moments of Growth Rate of Aggregate Consumption

Estimated from Post-War US Data

Consumption Definition	Mean Consumption Growth	Variance of Consumption Growth
Monthly Consumption Measures		
Consumer Expenditures on Nondurable Goods	1.000677 (0.000303)	0.0000588 (0.0000058)
Consumer Expenditures on Nondurables plus Services	1.001309 (0.000235)	0.0000238 (0.0000020)
Quarterly Consumption Measures		
Imputed Service Flow from Stock of Consumer Durables	1.00798 (0.00111)	0.0000251 (0.0000048)
Imputed Service Flow from Stock of Housing	1.00541 (0.00073)	0.0000163 (0.0000025)

Notes: Monthly data for consumer expenditures on nondurables and on services are from the consumer expenditure survey of the BEA. Data for monthly expenditures on services excludes the imputed service flow from housing. Quarterly data for the imputed service flow from the stock of consumer durables is from the Federal Reserve Board. Quarterly data for the imputed service flow from the stock of residential housing is from the CITIBASE database. The sample period for the monthly series is 1959:01 - 1986:12, and the sample period for the quarterly series is 1959:01 - 1986:04. All data is seasonally adjusted, and is rendered per capita by dividing by a measure of the noninstitutional civilian population over age 16 from the Bureau of Labor Statistics. Robust Hansen-White standard errors are in parentheses, and are computed using the Newey-West estimate of the residual covariance matrix with six lags.

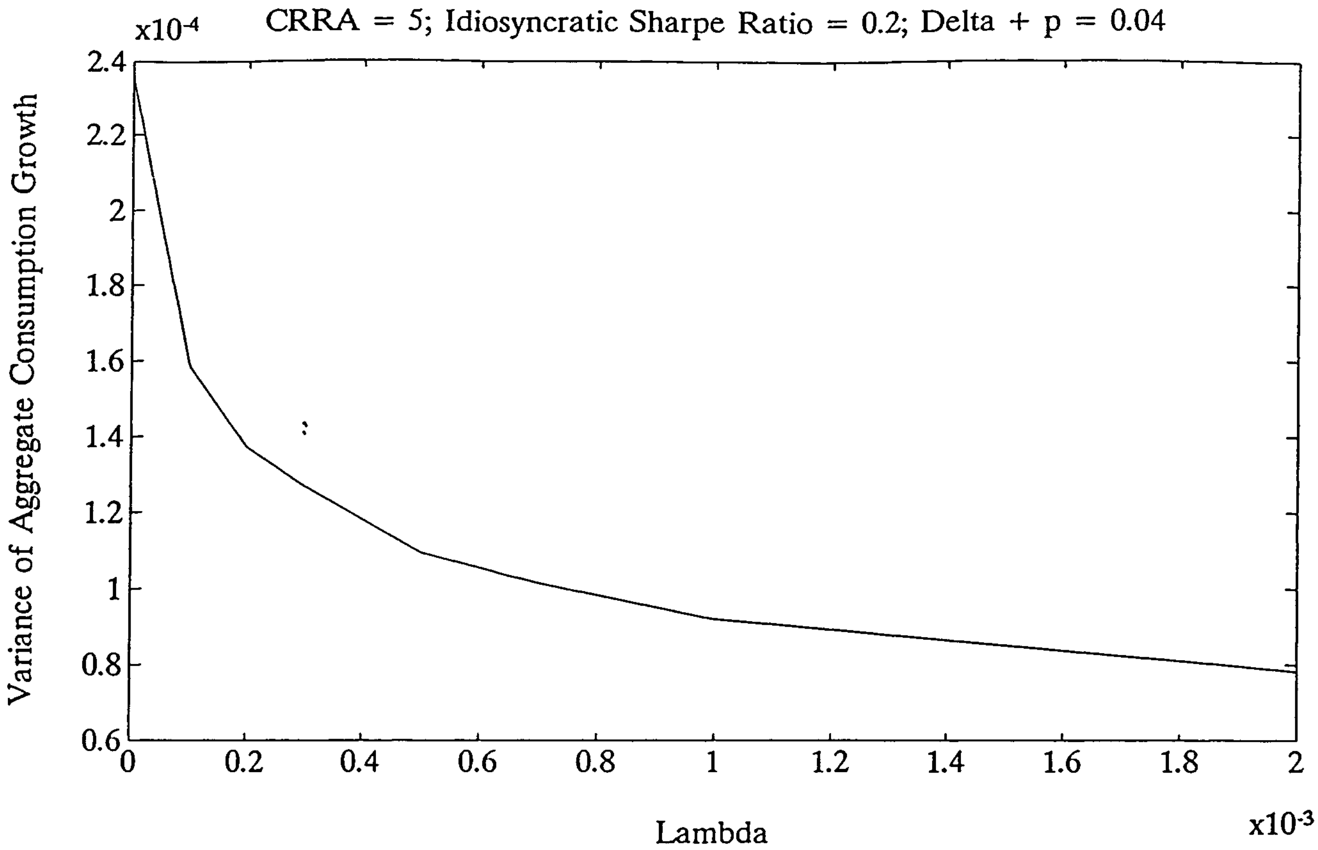

Figure 1: The variance of aggregate consumption growth implied by the benchmark model is plotted as a function of λ, for λ ranging from 0 to .002.

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