Habit Formation and Aggregate Consumption Dynamics

Martin Sommer*

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Abstract

This paper finds that a benchmark model of habit formation in consumer preferences can explain two well-known failures of the permanent income hypothesis: the sensitivity of aggregate consumption to predictable changes in income and to lagged consumer sentiment. One novel feature of the paper's methodology is to allow for measurement errors and other transitory elements (for example, weather-related disturbances) in consumption data. In contrast with traditional wisdom, aggregate consumption growth appears to be highly persistent after controlling for measurement errors and transitory consumption fluctuations: the estimates of persistence in quarterly consumption growth jump up from the commonly assumed 0.3 to about 0.7.

Keywords: consumer sentiment, excess sensitivity, habit formation, measurement error, sticky expectations.

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1. Introduction

A standard version of the permanent income hypothesis (PIH) predicts that the level of aggregate consumption follows a random walk and consumption growth is unforecastable (Hall, 1978). Many researchers have found that this prediction does not hold even to the first approximation because a number of macroeconomic indicators such as unemployment rate or stock market index can forecast a large fraction of future consumption growth. Campbell and Mankiw (1989) provided a simple reinterpretation of the literature documenting the predictability of consumption growth by building a model in which some consumers make their consumption decisions optimally according to the PIH, while the others follow a "rule of thumb" and simply spend all their income in any given period. This type of model implies that consumption growth should be correlated with income growth—including its predictable component. Campbell and Mankiw found that various macroeconomic series had no statistically significant ability to forecast future consumption growth beyond the information they contained about future income growth.[1] Therefore, the Campbell-Mankiw model seemed to provide a cohesive framework for explaining the predictability of consumption growth.

However, Carroll, Fuhrer and Wilcox (1994) noted that the models with rule-of-thumb behavior (or similarly, liquidity constraints) cannot explain why consumption growth can be forecast using various indices of consumer sentiment, even after controlling for predicted income growth.[2] The literature therefore exposed two seemingly unrelated failures of the PIH for which it did not have a unifying explanation: the sensitivity of aggregate consumption to predictable changes in income and to lagged consumer sentiment. Deaton (1992) suggested that habit formation might be an alternative explanation for the sensitivity of consumption

[1] Earlier studies documenting the relationship between consumption and past or predicted income include Flavin (1981), Hall and Mishkin (1982), Deaton (1987), and Campbell and Deaton (1989), among others.

[2] In addition to Carroll, Fuhrer and Wilcox (1994), the ability of consumer sentiment to forecast future consumption growth is also documented by Acemoglu and Scott (1994), Braum and Ludvigson (1998), Ludvigson (2004), and Slacalek (2004). Alternative explanations for the sensitivity of consumption to predicted income changes include substitution between home and market consumption (Baxter and Jermann, 1999), precautionary saving motive (Ludvigson and Michaelides, 2001) and nonseparability between durables and nondurables (Deaton, 1987). It remains an open question, however, whether these channels can generate income sensitivity of the degree observed in the data, and whether they can explain the sensitivity of consumption to sentiment.

to predicted income growth. Indeed, this paper argues—more broadly—that habit formation models (or other models generating serial correlation in aggregate consumption growth) can provide a simple framework for explaining *both* the sensitivity of aggregate consumption to predicted income growth and sentiment. In the habit formation model, some fraction of current aggregate consumption growth is determined by events that took place in the past.[3] Habit formation therefore creates a channel through which a variety of macroeconomic variables—including consumer sentiment—can become good predictors of future consumption growth. Habit formation can also help to reinterpret the evidence on the sensitivity of aggregate consumption to predictable changes in income. Predicted income growth is calculated from instruments that reflect past information. The observed sensitivity of consumption to predicted income growth can therefore be thought of as a delayed response of consumption to news about income and wealth due to habit formation.

It may seem surprising that habit formation can explain the two puzzling consumption sensitivities through its implication of serial correlation in consumption growth. It is well known that ordinary least squares estimates of autoregressive models for consumption growth yield significant but relatively small coefficients on lagged consumption growth of about 0.3. But the case for habit formation becomes stronger once the estimation techniques allow for measurement errors and other transitory fluctuations in consumption.

As documented below, reported quarterly consumption data are subject to substantial measurement error. This measurement error biases downward the OLS (and even some GMM) estimates of serial correlation in consumption growth. After controlling for measurement error, the estimate of persistence in consumption growth jumps up from the commonly assumed 0.3 to about 0.7. Such a strong stickiness then helps to reinterpret the existing evidence on the sensitivity of aggregate consumption to predicted income growth and sentiment. Of course, the finding also has important implications for the assessment of the impact of monetary and fiscal policies. For example, the immediate marginal propensity to consume out of permanent shocks such as tax cuts hinges critically on the degree of habit formation in consumer preferences (Carroll, 2000). This paper suggests

[3] With habit formation in preferences, consumers become used to the level of consumption they experienced in the past and therefore derive utility from both the level and the growth rate of consumption. As a result, consumers adjust their consumption levels to news about income and wealth only gradually and aggregate consumption growth is serially correlated (Muellbauer, 1988).

that after controlling for the serial correlation in consumption, the sentiment index has no predictive power for consumption growth. Moreover, the coefficient on predictable income growth is much smaller than previously estimated in the literature, about 0.1-0.2 instead of the commonly assumed 0.5, and is generally not statistically significant.

The rest of the paper is organized as follows. Section 2 summarizes the implications of habit formation for the dynamics of aggregate consumption growth. Section 3 explains the sources of measurement error and other transitory fluctuations in quarterly consumption data. Section 4 then examines the methodology of computing sentiment indexes and demonstrates that the indexes are tightly linked to current aggregate consumption growth. In addition, since sentiment is largely independent of the measurement error in consumption data, the sentiment index is a helpful instrument for consumption growth. Section 5 presents estimates of persistence in consumption growth implied by the habit formation model. The section concludes by examining the sensitivity of consumption growth to predicted income growth and sentiment using techniques that minimize the biases arising from measurement errors.

2. The habit formation model

The assumption of habit formation in consumer preferences has become common in many areas of economics. It has proven helpful in explaining several important failures of standard optimizing models.[4] This paper adopts one of the simplest possible formalization of habits originally proposed by Muellbauer (1988). A representative consumer maximizes a stream of discounted utility subject to a budget constraint:

$$\max_{\{C_t\}} E_t \sum_{t=s}^{\infty} \beta^{t-s} u\left(C_t - \gamma C_{t-1}\right) \qquad s.t. \quad A_t = R(A_{t-1} + Y_{t-1} - C_{t-1}). \qquad (1)$$

Here, C_t denotes the level of consumption per capita, A_t is the stock of wealth, β is the time preference factor, and R is the gross real interest rate. C_{t-1} represents the "habit stock," i.e., the reference level to which the consumer compares

[4] For example, habit formation offers an explanation for the relationship between saving and growth, the hump-shaped response of consumption to monetary policy shocks, the level of equity premium, and the cyclical properties of asset prices. See Carroll, Overland, Weil (2000) for a review.

her current consumption level. The parameter γ captures the strength of habits. When $\gamma = 0$, habits play no role and the consumer cares only about the consumption level. At the opposite extreme, when $\gamma = 1$, habits are most powerful and the consumer derives utility only from the consumption growth rate. In the intermediate case with $\gamma \in (0, 1)$, the consumer considers both the level and the growth rate of consumption. This can be seen when the utility function is rewritten as $u(C_t - \gamma C_{t-1}) = u((1-\gamma) C_t + \gamma \Delta C_t)$.

The Bellman equation for the problem is:

$$V(A_t, C_{t-1}) = \max_{\{C_t\}} \{u(C_t - \gamma C_{t-1}) + \beta E_t V(R(A_t + Y_t - C_t), C_t)\}.$$

As shown by Muellbauer (1988) and further explored in a well-known paper by Dynan (2000), the solution of this dynamic problem for consumption growth can be approximated under the assumption of a CRRA outer utility as follows:

$$\Delta \ln C_t \approx c_0 + \gamma \Delta \ln C_{t-1} + \widetilde{v}_t, \tag{2}$$

where $\widetilde{v}_t$ is a noise reflecting innovations to lifetime resources. Ignoring the constant, the equation (2) states that current consumption growth equals a fraction γ of the last period's consumption growth plus a random element. Hence, in contrast to the standard utility specification, some of the period t consumption growth is predetermined at time $t-1$. As suggested in the introduction, this serial correlation property of the model can potentially explain why current consumption growth is correlated with past information contained in either sentiment or other variables through predicted income growth.[5]

Equation (2) can also be derived from a model with standard preferences but with incomplete information. For example, Carroll and Slacalek (2006) present a sticky-expectations model in which γ roughly corresponds to the fraction of population that has not yet gathered all the necessary information to form an accurate opinion about its future income.[6] However, this paper focuses specifically

[5] In more general models of habit formation such as in Abel (1990) and Carroll, Overland, and Weil (2000), the habit stock equals the weighted average of past consumption levels. In these models, consumption growth in equation (2) would follow an AR process of order higher than one. Note also that without habit formation in preferences ($\gamma = 0$), equation (2) would collapse to $\Delta \ln C_t = v_t$, which is the standard white noise implication of the PIH.

[6] Serially correlated aggregate consumption growth can also be obtained in the learning model of Pischke (1995) and in the consumer-inattention model of Reis (2006).

on the habit formation model because it is currently the most frequently used framework within the group of models that generate serial correlation in aggregate consumption growth.

3. Measurement error in quarterly consumption data

Wilcox (1992) has shown that some categories of disaggregated consumption expenditures suffer from large and possibly serially correlated measurement errors. However, as discussed below, measurement error is also an important concern in *quarterly* aggregate consumption data. Since consumption growth is a right-hand-side regressor in equation (2), and since consumption growth is often used as an instrument in its estimation, the failure to account for measurement errors is likely to produce misleading conclusions.

There are multiple sources of measurement error in the quarterly aggregate personal expenditure (PCE) data. First, retail and food services sales estimates, which account for approximately one-half of aggregate consumption, are subject to two types of errors: sampling and nonsampling errors. The sampling error arises because the retail sales survey is conducted only on a limited number of firms. This error is fairly small in levels but can be economically significant in growth rates. Specifically, Census Bureau (2007) reports that the standard deviation of the retail and food services sales estimates (excluding motor vehicles and parts) is 0.71% for year-on-year growth rates. This is equivalent to almost 20% of the variability in year-on-year sales growth since 1992 (this is the first year for which the same-methodology sales data are available). The nonsampling error in retail data is mostly due to the imputation of missing data for survey non-respondents. This type of error can be quantitatively important as the imputed sales routinely account for up to 25% of total retail sales (Census Bureau, 2006, pg. A-7). While the retail sales data are eventually revised based on a mandatory annual survey that has a much higher response rate, the within-year fluctuations in retail sales largely continue to reflect the monthly estimates with sampling and nonsampling errors (Census Bureau, 2006, pp. vii-ix). Furthermore, a substantial fraction of quarterly services data (about 40 percent of services PCE) is not directly measured but is estimated using a "judgmental trend" from the underlying annual or biennial data sources (Bureau of Economic Analysis, BEA, 1990 (Table 13) and 2006 (Table 1)). Finally, within-year fluctuations in the main components of housing services are estimated using data on newly completed housing units, which is an imperfect indicator of the actual housing consumption. Given all these sources of imprecision in the BEA estimates of quarterly consumption expenditures, the measurement error must account for a non-trivial fraction of quarterly consumption variability.[7]

In addition to measurement errors, there may be other sources of transitory fluctuations in consumption, for example, those reflecting the economic impact of weather-related events. Hurricane Katrina had a severe impact on economic activity in a region accounting for roughly 3/4 of one percent of total U.S. consumption expenditures.[8] Assuming that the hurricane cut consumption expenditures in this most affected area by 1/3 for one quarter (which may be a conservative assumption given the extent of infrastructure destruction), the negative impact on quarter-on-quarter PCE growth would be about 1/4 of a percentage point—and a full percentage point on the annualized basis. But the weather-related shocks do not need to be severe to have a significant impact on the aggregate consumption dynamics. Warm winter weather contributed to about 1/4 of a percentage point reduction in the annualized quarter-on-quarter growth in nondurables and services PCE in the first quarter of 2006, through lower outlays on energy.[9] The bottom line is that any of these transitory weather-related consumption disturbances bias downward estimates of consumption persistence in equation (2) in the same way as measurement errors.

The statistical properties of the various transitory consumption components clearly matter for the estimation of equation (2). However, taking the classical approach (where measurement error is assumed to be white noise in the level of consumption) may not be *a priori* justifiable. Bell and Hillmer (1990) have shown that the sampling error in the retail trade survey is highly serially correlated and follows a complicated pattern. The pattern is caused by the fact that the retail sales data are estimated from overlapping observations and firms are surveyed in

[7] The introduction of Census Bureau's Quarterly Services Survey in 2004 has improved the quality of thereafter-published BEA quarterly services data accounting for about 20 percent of services PCE.

[8] This figure corresponds to the share of Gulfport-Biloxi-Pascagoula (Mississippi), Mobile-Daphne-Fairhope (Alabama), and New Orleans-Metairie-Bogalusa (Louisiana) regions in total U.S. retail sales from the 2002 Economic Census. Economic activity was significantly affected also in other regions; for comparison, the Gulf coast of Alabama, Louisiana, Mississippi, and Texas contributes about 3.2 percent to total U.S. retail sales. See http://www.census.gov/econ/census02/guide/Hurricanes.HTM for details.

[9] The number of heating degree days as reported by the Department of Commerce was lower by about 7.6 percent in the first quarter of 2006 compared with the same period of 2005, and by about 9.5 percent compared with the same period of 2004.

rotating panels. Imputing of retail sales and interpolation of services data are also likely to generate serially correlated errors. If a consumer receives innovation to her lifetime resources, she will immediately (although not necessarily fully) respond, while the official statistics are likely to smooth out the data. For simplicity, it is assumed here that adding up all three error components (and potentially also the other transitory components of consumption) leads to an MA(1) error structure in the log-level of consumption: $u_t + \theta u_{t-1}$. In economic terms, measurement error is allowed to be serially correlated but the impact of error on the serial correlation properties of the consumption data is limited. Taking first differences leads to a model of measurement error for consumption growth: $u_t + (\theta - 1)u_{t-1} - \theta u_{t-2}$. As a robustness check, we will also examine implications of the simpler classical error model ($\theta = 0$): $u_t - u_{t-1}$. In any case, as will become apparent below, most conclusions about the sensitivity properties of habit formation models can be established without relying on a particular specification of the measurement error process.

4. Consumer sentiment as a useful instrument for actual consumption

This section shows that indices of consumer sentiment are closely related to contemporaneous consumption growth. This finding is important for two reasons. First, it helps to explain why the lag of consumption growth in equation (2) could account for the correlation between consumption and past sentiment. Secondly, the finding suggests that sentiment could become a good instrument for "true" consumption growth. Indeed, as argued below, sentiment is correlated with consumption growth, yet it is likely to be uncorrelated with measurement error in the published consumption data.

Indices of consumer sentiment (or confidence) are typically computed from responses of consumers to questions about their personal income and wealth, as well as about aggregate economic activity. The best known survey, the Index of Consumer Sentiment (prepared by the University of Michigan), is based on responses to five questions. The answers of individual respondents are qualitative, i.e., consumers are asked whether they expect a given variable to rise, fall, or stay the same. Nevertheless, the construction of the index guarantees that sentiment carries quantitative information about the current growth rate of aggregate consumption.

Consider the following example. Question #2 of the survey is: "Now looking ahead, do you think that a year from now you (and your family living there) will be better off financially, or worse off, or just about the same as now?" The sentiment index is computed as the difference between the fraction of people who answered that they would be better off and those who answered that they would be worse off. It is straightforward to show that such an index contains information about expected aggregate income growth. Suppose that all consumers have the same initial income $\ln Y_t$ in period t and that the distribution of expected income $\ln Y^e_{t+1,i}$ is uniform with mean $\ln Y^e_{t+1}$ and half-range a. The sentiment index S_t can then be expressed as:

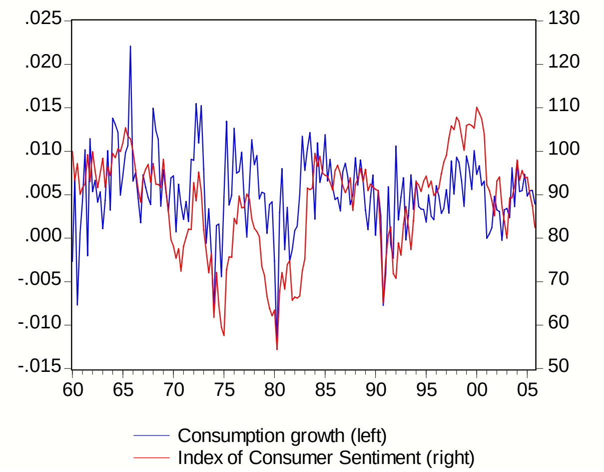
$$\begin{aligned} S_t^{Question\ \#2} &= P\left(\ln Y^e_{t+1,i} > \ln Y_t\right) - P\left(\ln Y^e_{t+1,i} < \ln Y_t\right) \\ S_t^{Question\ \#2} &= 1 - 2 \int\limits_{\ln Y^e_{t+1}-a}^{\ln Y_t} \frac{1}{2a} d \ln Y^e_{t+1,i} = \frac{1}{a}\left(\ln Y^e_{t+1} - \ln Y_t\right), \end{aligned}$$

and so the sentiment index is proportional to expected aggregate income growth. A similar argument can be repeated for the other questions underlying the Index of Consumer Sentiment.[10] Questions #1-#4 are essentially questions about the wealth and income parts of the intertemporal budget constraint. Question #5 asks directly about one category of consumption (durables). Since the budget constraint makes (nondurables and services) consumption a function of all these variables, the Sentiment Index must carry information regarding contemporaneous movements in aggregate consumption. Figure 1 illustrates that this theoretical result holds strongly in the data. The correlation between quarterly consumption growth and sentiment is 0.43.[11] This strong link makes sentiment a useful instrument for consumption in equation (2), especially given the fact that

[10] The index based on question #1 extracts information about the change in the aggregate wealth, and question #3 (similarly to question #2) reflects beliefs about next year's aggregate income growth. Question #4 surveys expectations of long-term aggregate income growth, and–finally–question #5 examines the level and growth of durables consumption.

[11] The permanent income hypothesis predicts that consumption growth is unforecastable. Therefore it should only be the *innovation* to current sentiment that is correlated with current consumption growth. Past innovations to sentiment should have no predictive power. Under habit formation, however, current consumption growth is influenced by both current and past innovations. Since the actual sentiment series is serially correlated, the level of sentiment contains information about both current and past innovations to lifetime resources. We would therefore expect a high correlation between the *level* of sentiment and current consumption growth es-

Figure 1: Measured consumption growth and the Index of Consumer Sentiment



the methodology of computing sentiment is completely different from the BEA methodology of constructing personal consumption expenditures. The difference in methodologies makes it less likely that sentiment data will be influenced by the measurement error in the published consumption data. One piece of evidence in support of this hypothesis is the relatively low correlation between sentiment and the *initial* announcements of consumption that could presumably contaminate sentiment with some measurement error: it is 0.32, compared with 0.47 for the final consumption data (based on comparable samples). Moreover, the correlation between the ex-post revision to nondurables and services consumption and sentiment is -0.02, which also suggests that sentiment and measurement error in the published data are likely to be largely uncorrelated. The sentiment index could still be correlated with other transitory elements of consumption—for example, those due to the impact of hurricanes or earthquakes—but since this transitory consumption is very short-lived, this complication can be avoided by lagging sentiment for a sufficient number of quarters when it is used as an instrument. More details on this point are provided below.

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pecially if consumers form habits. Interestingly, the correlation between consumption growth and level of sentiment is much higher than that between consumption growth and change in sentiment (0.43 versus 0.21). Similarly, consumption growth is significantly correlated with past levels of sentiment. Both features of the data may be interpreted as a violation of the PIH.

5. Regressions with measurement error and transitory consumption

The two failures of the PIH can be mathematically expressed as follows:

$$\Delta \ln C_t = c_0 + \lambda E_{t-i} \Delta \ln Y_t + \delta(L) E_{t-i} S_{t-1} + \epsilon_t,$$

where $\Delta \ln Y_t$ is the real disposable income per capita, S_t is the measure of consumer sentiment, and i determines the timing of instruments (i is usually set to 2 to avoid a time-aggregation bias). In many empirical implementations of this equation, $\lambda \neq 0$ and $\delta(L) \neq 0$ in violation of the PIH (Campbell and Mankiw, 1989, Carroll, Fuhrer and Wilcox, 1994). If habit formation provided a framework for explaining the sensitivity of consumption to sentiment and predicted income growth, estimates of λ and δ's should fall toward zero and become statistically insignificant after a lag (or lags) of consumption growth is added to the equation:

$$\Delta \ln C_t = c_0 + \gamma E_{t-i} \Delta \ln C_{t-1} + \lambda E_{t-i} \Delta \ln Y_t + \delta(L) E_{t-i} S_{t-1} + \widetilde{\epsilon}_t. \tag{3}$$

Before proceeding with an estimation of equations of this form, it is helpful to spell out the implications of measurement error and time aggregation for the error term $\widetilde{\epsilon}_t$. Starting with equation (2), one can write out measured consumption growth, $\Delta \ln C_t$, as the sum of "true" consumption growth, $\Delta \ln C_t^*$, and measurement error (see equation (4)). The measurement error process expressed using the u_t terms is serially correlated, and is either of the MA(2) type (general measurement error), or the MA(1) type if θ=0 (classical measurement error).

$$\Delta \ln C_t = \Delta \ln C_t^* + u_t + (\theta - 1) u_{t-1} - \theta u_{t-2}. \tag{4}$$

Under the assumption of habit formation, "true" consumption growth has an autoregressive component (equation (2)), while time aggregation generates an MA(2) component, making true consumption follow an ARMA(1,2) process:

$$\Delta \ln C_t^* = c_0 + \gamma \Delta \ln C_{t-1}^* + v_t + \lambda_1(\gamma) v_{t-1} + \lambda_2(\gamma) v_{t-2}, \tag{5}$$

where v_t denotes the innovation to life-time resources. The coefficients on the MA terms, λ_1 and λ_2, are complicated functions of the persistence parameter γ (see

Technical Appendix for details).[12]

Substituting equation (5) into equation (4) yields:

$$\begin{aligned}\Delta \ln C_t &= c_0 + \gamma \Delta \ln C_{t-1} + v_t + \lambda_1(\gamma) v_{t-1} + \lambda_2(\gamma) v_{t-2} + u_t \\ &\quad +(\theta - 1 - \gamma) u_{t-1} - [\theta + \gamma(\theta - 1)] u_{t-2} + \gamma \theta u_{t-3}.\end{aligned} \tag{6}$$

This equation describes the dynamics of consumption growth with habit formation. To test the sensitivity properties of model (6), one can simply add a predicted income term and lags of sentiment—this would yield equation (3).

To estimate equation (6) and its encompassing variant, equation (3), two alternative econometric techniques are used to allow for a different treatment of measurement error. First, the coefficients are estimated using the two stage least squares estimator. The main advantage of this approach is that with appropriate instruments, the estimated consumption persistence parameter γ does not hinge on validity of the particular structure of measurement error in equation (6). As a more efficient alternative, the Kalman filter is used to jointly estimate the habit formation coefficient γ and the measurement error parameter θ, but this method relies on the specific assumptions about the measurement error process discussed above. That said, the Kalman filter helps to separate true consumption growth from measurement error.

5.1. Two stage least squares estimates using published data

To obtain a consistent estimate of γ using two stage least squares (2SLS), it is necessary to find variables that are correlated with consumption growth but uncorrelated with measurement error u_t. As discussed in Section 4, one good candidate is the sentiment index: it is highly correlated with consumption growth, yet it is likely to be orthogonal to the measurement error in consumption data. The instrument sets also include standard variables used in the literature such as

[12] In a standard PIH model, the innovation to "true" consumption growth in equation (5) would follow an MA(1) process due to time aggregation (Christiano, Eichenbaum, and Marshall, 1991). However, the process becomes MA(2) when consumers form the simple form of habits as in section 2 (Muellbauer, 1988). As shown in the Technical Appendix of this paper, the coefficient on the first MA term is about 0.4 when the persistence coefficient γ>0.3, and the coefficient on the second MA term is close to zero.

the T-bill rate, unemployment rate, and S&P 500 return.[13] Lags of consumption growth are not included in the instrument sets: consumption growth would need to be lagged for at least four quarters due to its correlation with $u_{t,\ldots,t-3}$, which in practice makes it an uninformative instrument. Moreover, the serial correlation in measurement error may well go beyond the assumed MA(2) structure, so it is safer to avoid using consumption growth as an instrument altogether. All instrument sets are timed t-3, t-4, and t-5. Instruments dated t-2 are not used to avoid a time-aggregation bias due to the correlation of instruments with $\lambda_2 v_{t-2}$.[14]

Table 1 reports the regression results. The data are quarterly and cover the period of 1960:q1-2005:q4. The estimation is mostly based on real nondurables and services consumption growth per capita (Panels 1-3), but the main results are qualitatively similar when only nondurables consumption per capita is used instead (Panel 4). The first set of results (Panel 1) focuses on the estimates of persistence in consumption growth, γ. The 2SLS estimates of γ are large, between 0.72-0.89, and are highly statistically significant. By contrast, the OLS estimate of γ is only 0.35, less than one-half of the instrumental variables estimate. The discrepancy between the 2SLS and OLS estimates demonstrates the danger of estimating autoregressive specifications for consumption growth without accounting for the transitory noise in consumption data.

The second set of estimates (Panel 2) examines the correlation between consumption and predicted income growth. After the lag of consumption is added to the equation, the coefficient λ falls from 0.4-0.5 to 0.1-0.2 and becomes statistically

[13]The Index of Consumer Sentiment is used to measure consumer sentiment. The estimation results are similar when the Index of Consumer Expectations is used instead. T-bill rate and S&P 500 index could in principle be affected by consumption measurement error as markets and policymakers respond to current data releases. However, the instruments are lagged for three quarters, which should minimize the impact of measurement error on the coefficient estimates. More broadly, the 2SLS estimates of consumption persistence γ are very close to the Kalman filter estimates in the next subsection. This suggests that even if the lags of instruments used in this subsection happened to be contaminated with some measurement error from the BEA consumption data, the practical impact on the paper's 2SLS estimates is not large.

[14]In practice, the bias from using instruments dated t-2 may be small because λ_2 is close to zero for any $\gamma \in(0,1)$. During estimation, instruments are used both on their own and in interaction with a dummy that takes on a value of 0 prior to 1978 and a value of 1 afterward. There are two reasons for using this dummy. First, the methodology of retail sales survey changed in 1977, with implications for the structure of measurement error (Wilcox, 1992); second, sentiment began to be measured consistently at the monthly frequency in 1978. Such methodological changes have changed the correlation structure between published consumption data and instruments. The main estimation results are similar when the partial sample 1978-2005 is used instead of the full sample 1960-2005.

Table 1

Two stage least squares estimates

$$\Delta \ln C_t = c_0 + \gamma E_{t-3} \Delta \ln C_{t-1} + \lambda E_{t-3} \Delta \ln Y_t + \delta(L) E_{t-3} S_{t-1} + \widetilde{\epsilon}_t$$

	Nondurables and services consumption growth											Nondurables consumption growth			
	Panel 1			Panel 2				Panel 3				Panel 4			
Instrument set	OLS	A	B	A	B	A	B	A	B	A	B	A	B	A	B
γ	0.35^{**}	0.89^{**}	0.72^{**}			0.72^{**}	0.55^{**}			0.86	0.48^{*}	1.10^{**}	0.66^{**}	1.75	0.42^{*}
	(0.06)	(0.16)	(0.13)			(0.22)	(0.17)			(0.57)	(0.24)	(0.30)	(0.14)	(1.16)	(0.18)
λ				0.45^{**}	0.36^{**}	0.14	0.18	0.21^{+}	0.23^{*}	0.00	0.14			-0.06	0.23
				(0.11)	(0.08)	(0.16)	(0.11)	(0.12)	(0.09)	(0.23)	(0.13)			(0.31)	(0.17)
p-value sentim.								0.07	0.02	0.63	0.42			0.87	0.53
Overid. test	N.A.	0.59	0.53	0.06	0.07	0.38	0.36	0.04	0.11	0.40	0.24	0.98	0.76	0.97	0.42

Notes: Quarterly consumption growth per capita; the sample is 1960:1-2005:4. The constant is not reported. Newey-West standard errors; the lag truncation parameter is set equal to 4. Row 3 reports p-values of the exclusion test on the lags of sentiment S_t. Row 4 reports p-values of the overidentification test. Instrument set A: constant, sentiment, change in the three-month T-bill rate; the timing of instruments is from t-3 up to t-5. Instrument set B: set A plus change in unemployment and S&P 500 index; the timing is also from t-3 to t-5. All instruments are used on their own and in interaction with a dummy that has a value of 0 during 1960:1-1977:4 and a value of 1 during 1978:1-2005:4. + denotes significance at the 10 percent level, * denotes significance at the 5 percent level, and ** denotes significance at the 1 percent level.

insignificant.[15] Moreover, the estimated coefficient on consumption persistence γ falls only marginally. This suggests that habit formation is indeed able to account for most of the observed sensitivity of consumption to predicted income growth, although the crowding of estimated λ's in a narrow range around 0.1-0.2 suggests that habits may not be the only channel that generates the sensitivity. Interestingly, the test of overidentifying restrictions rejects the Campbell-Mankiw model in which the sensitivity of consumption to past information is only allowed through the predicted income term.

The final set of estimates (Panel 3) tests the sensitivity of consumption to sentiment. In the specifications without the consumption lag, both predicted income growth and sentiment are statistically significant, as discussed by Carroll, Fuhrer, and Wilcox (although the overidentification test rejects one of the specifications). However, both sentiment and predicted income growth become insignificant after a lag of consumption growth is added. The estimated consumption persistence γ remains large. The standard error of γ is sizeable but this is natural–both sentiment and reported consumption data can be thought of as noisy measures of true consumption growth and are collinear. In sum, the estimation results in Panel 3 are broadly consistent with the hypothesis of habit formation and measurement error.

5.2. Kalman filter estimation

To obtain a more efficient estimate of consumption persistence, the model specified by equations (4) and (5) was rewritten in a state-space form (see Technical Appendix) and estimated using the Kalman filter. For the purposes of this subsection, the correlation structure of measurement error is assumed to remain unchanged over the sample period.

Table 2 presents the estimation results. As in the case of the 2SLS estimates, the consumption persistence coefficient γ is large and highly statistically significant. Its estimated value is 0.67 (with the standard error of 0.09) for nondurables and services consumption growth per capita (the PIH would have implied $\gamma = 0$).[16] The estimation results are similar for the data on nondurables consump-

[15] Kiley (2005) suggests that disposable income excluding property income is a more appropriate measure of income in equations like (3). However, in the specifications presented in this paper, using this alternative income measure leads to only small changes in the estimated coefficients.

[16] This coefficient estimate is comparable with the estimates by the other authors (Ferson

Table 2

Kalman filter estimates under two alternative assumptions about measurement error

$$\Delta \ln C_t = \Delta \ln C_t^* + u_t + (\theta - 1)u_{t-1} - \theta u_{t-2}$$
$$\Delta \ln C_t^* = c_0 + \gamma \Delta \ln C_{t-1}^* + v_t + \lambda_1(\gamma)v_{t-1} + \lambda_2(\gamma)v_{t-2}$$

	Nondurables and services consumption growth		Nondurables consumption growth
Specification	General measurement error	Classical measurement error	General measurement error
γ	0.67**	0.61**	0.57**
	(0.09)	(0.10)	(0.13)
θ	0.30**	-	0.21
	(0.14)		(0.17)
$\ln\,\sigma_u^2$	-12.18**	-12.53**	-11.21**
	(0.22)	(0.19)	(0.26)
$\ln\,\sigma_v^2$	-12.40**	-12.15**	-11.49**
	(0.32)	(0.29)	(0.38)
$\frac{var\Delta \ln C^*}{var\Delta \ln C}$	0.46	0.53	0.36
R^2	0.47	0.40	0.34

Notes: General measurement error = MA(1) error in the log-level of consumption. Classical measurement error = white noise error in the log-level of consumption. Quarterly consumption growth per capita; the sample is 1960:1-2005:4. Consumption growth was demeaned before estimation. The R^2 refers to the explanatory power of equation for "true" consumption $\Delta \ln C^*$. See Technical Appendix for details.

tion growth. It is encouraging that the Kalman filter estimates of consumption persistence are very close to the 2SLS estimates. Even if the lags of sentiment and other instruments happened to be contaminated with some measurement error from the BEA consumption data, the practical impact on the 2SLS estimates reported in the previous subsection does not seem large.

The Kalman filter has attributed approximately 50% of the variation in quarterly consumption growth to the sum of measurement error in consumption growth and transitory consumption.[17] The implied signal to noise ratio of 1:1 is consistent with the gap between the OLS and 2SLS estimates found in the previous subsection. The estimation also confirms that the measurement error in the level of consumption is serially correlated. The estimate of the moving-average coefficient θ is 0.30 and the standard error of this estimate is 0.14.

5.2.1. Second-stage regressions using consumption growth without transitory components

The Kalman filter extracted from the published data true consumption growth, $\Delta \ln C_t^*$ (see Figure 2). The interesting question is whether sentiment and predictable income carry any information about true consumption growth beyond the information already contained in consumption persistence. To examine this issue, regressions of the following form were estimated:

$$\Delta \ln C_t^* = c_0 + \gamma E_{t-3} \Delta \ln C_{t-1}^* + \lambda E_{t-3} \Delta \ln Y_t + \delta(L) E_{t-3} S_{t-1} + \mu_t. \tag{7}$$

Table 3 presents the regression results for two categories of consumption based on the model with the general measurement error. The lags of sentiment are jointly statistically insignificant in all reported specifications. This result strengthens the conjecture based on the 2SLS regressions in the previous subsection, which established that habit formation might account for the sensitivity of consumption to sentiment. Moreover, a large fraction of the predictable income effect disappears as well. All point estimates of λ are much smaller than the 0.5 estimated by

and Constantinides, 1991, Fuhrer, 2000, Gruber, 2004). It is also close to the theoretical value of γ required to explain various puzzles in the macroeconomics and finance literatures (e.g., Constantinides, 1990, Jermann, 1998, Carroll, 2000).

[17] The correlation between measurement error extracted by the Kalman filter and lagged instruments used in the previous subsection is low and statistically insignificant.

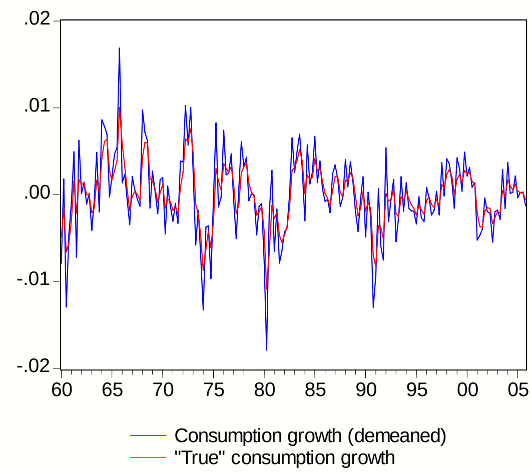
Table 3
Second stage regressions using consumption growth without measurement error

$$\Delta \ln C_t^* = c_0 + \gamma E_{t-3} \Delta \ln C_{t-1}^* + \lambda E_{t-3} \Delta \ln Y_t + \delta(L) E_{t-3} S_{t-1} + \mu_t$$

	Nondurables and services consumption growth				Nondurables consumption growth			
Instrument set	A	B	A	B	A	B	A	B
γ	0.71**	0.70**	0.67**	0.62**	0.80**	0.67**	0.70**	0.60**
	(0.10)	(0.08)	(0.15)	(0.12)	(0.12)	(0.09)	(0.20)	(0.13)
λ	0.10	0.09*	0.07	0.09	0.08	0.14*	0.05	0.14*
	(0.06)	(0.04)	(0.07)	(0.04)	(0.07)	(0.06)	(0.08)	(0.06)
p-value sentim.			0.39	0.44			0.44	0.66
Overid. test	0.15	0.26	0.13	0.20	0.16	0.33	0.15	0.21

Notes: Quarterly consumption growth per capita; the sample is 1960:1-2005:4. The constant is not reported. Instrument sets contain the same variables as in Table 1 plus true consumption growth. The timing of instruments is from t-3 to t-5. Row 3 reports p-values of the exclusion test on the lags of sentiment S_t. Row 4 reports p-values of the overidentification test.

Figure 2: Measured consumption growth (demeaned) and consumption growth from the Kalman filter



Campbell and Mankiw (1989) and other authors. The estimates of λ are mostly statistically insignificant, but, interestingly, they are all clustered around 0.1. The results are again consistent with the hypothesis that habit formation controls for most of the predicted income effect in the data, but it may not be the only channel that generates the sensitivity. Finally, the coefficient on the consumption lag changes very little after adding sentiment and predicted income growth to equation (7), which suggests that the Kalman filter did a good job in extracting true consumption from the noisy data.

6. Conclusions

After allowing for measurement error and other transitory noise in consumption data, the estimates of persistence in quarterly consumption growth jump up from the commonly assumed 0.3 to about 0.7. A benchmark model of habit formation in consumer preferences (or other models that generate serial correlation in aggregate consumption growth) is capable of explaining the sensitivity of aggregate consumption fluctuations to sentiment and most of the sensitivity to predictable changes in income. On balance, the evidence hints that a small part of the income sensitivity may be present even after controlling for consumption persistence. It is an open question whether this is because some fraction of consumers is myopic, is subject to liquidity constraints, or has a strong precautionary saving motive. As follows from the work of Carroll (1997) and as shown in detail by Ludvigson and Michaelides (2001), the precautionary motive slows consumers' reaction to anticipated events. Combined with habit formation, the precautionary saving channel could explain the remainder of the income sensitivity puzzle. Analyzing the sensitivity properties of this category of models is an important area of future research.

7. Technical Appendix

7.1. Details of the Kalman filter estimation

Equations (4) and (5) can be rewritten in the state-space form as follows:

$$\Delta \ln C_t = c_0 + [1\ 0\ 0\ 1\ 0\ 0] \begin{bmatrix} \Delta \ln C_t^* \\ \mathrm{u}_t \\ (\theta\text{-}1)\mathrm{u}_t\text{-}\theta \mathrm{u}_{t-1} \\ u_t + (\theta\text{-}1)\mathrm{u}_{t-1}\text{-}\theta \mathrm{u}_{t-2} \\ v_t \\ v_{t-1} \end{bmatrix} + 0,$$

$$\begin{bmatrix} \Delta \ln C_t^* \\ \mathrm{u}_t \\ (\theta\text{-}1)\mathrm{u}_t\text{-}\theta \mathrm{u}_{t-1} \\ \mathrm{u}_t + (\theta\text{-}1)\mathrm{u}_{t-1} \\ \text{-}\theta \mathrm{u}_{t-2} \\ v_t \\ v_{t-1} \end{bmatrix} = \begin{bmatrix} \gamma & 0 & 0 & 0 & \lambda_1 & \lambda_2 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\theta & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \Delta \ln C_{t-1}^* \\ \mathrm{u}_{t-1} \\ (\theta\text{-}1)\mathrm{u}_{t-1}\text{-}\theta \mathrm{u}_{t-2} \\ \mathrm{u}_{t-1} + (\theta\text{-}1)\mathrm{u}_{t-2} \\ \text{-}\theta \mathrm{u}_{t-3} \\ v_{t-1} \\ v_{t-2} \end{bmatrix} +$$

$$+ \begin{bmatrix} v_t \\ \mathrm{u}_t \\ (\theta\text{-}1)\mathrm{u}_t \\ \mathrm{u}_t \\ v_t \\ 0 \end{bmatrix},$$

with the associated covariance matrixes: H=0 and

$$Q=\begin{bmatrix} \sigma_v^2 & 0 & 0 & 0 & \sigma_v^2 & 0 \\ 0 & \sigma_u^2 & (\theta\text{-}1)\sigma_u^2 & \sigma_u^2 & 0 & 0 \\ 0 & (\theta\text{-}1)\sigma_u^2 & (\theta\text{-}1)^2\sigma_u^2 & (\theta\text{-}1)\sigma_u^2 & 0 & 0 \\ 0 & \sigma_u^2 & (\theta\text{-}1)\sigma_u^2 & \sigma_u^2 & 0 & 0 \\ \sigma_v^2 & 0 & 0 & 0 & \sigma_v^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}.$$

The state-space form was estimated with the Kalman filter using nondurables and services consumption per capita over 1960:1-2005:4. The coefficients λ_1 and λ_2 are not free parameters but instead depend on the consumption persistence coefficient γ: $\lambda_1 = f(\gamma), \lambda_2 = g(\gamma)$.The Kalman filter estimation takes into consideration this relationship between γ, λ_1, and λ_2. The second part of this Appendix characterizes the functional forms f and g.

7.2. Time aggregation in a habit formation model

This subsection describes the impact of time aggregation on consumption growth in a habit formation model. It is assumed that consumption decisions are made monthly while the measured consumption data are quarterly. Let c_m denote the level of aggregate consumption in month m, and C_Q denote the level of aggregate consumption in quarter Q. If consumers form habits, (demeaned) monthly consumption growth approximately follows:

$$\Delta^m \ln c_m = \alpha \Delta^m \ln c_{m-1} + \varepsilon_m,$$

where the Δ^m operator denotes monthly changes. To simplify algebra, the time aggregation of monthly consumption into quarterly observations is defined in log-levels:

$$\ln C_Q = \ln c_m + \ln c_{m-1} + \ln c_{m-2}.$$

The expression for the quarterly consumption growth $\Delta^Q \ln C_Q = \ln C_Q - \ln C_{Q-1}$ can be expanded as:

$$
\begin{aligned}
\Delta^Q \ln C_Q &= (\ln c_m + \ln c_{m-1} + \ln c_{m-2}) - (\ln c_{m-3} + \ln c_{m-4} + \ln c_{m-5}) \\
&= \Delta^m \ln c_m + 2\Delta^m \ln c_{m-1} + 3\Delta^m \ln c_{m-2} + 2\Delta^m \ln c_{m-3} + \Delta^m \ln c_{m-4}.
\end{aligned}
$$

Similarly, $\Delta^Q \ln C_{Q-1} = \Delta^m \ln c_{m-3} + 2\Delta^m \ln c_{m-4} + 3\Delta^m \ln c_{m-5} + 2\Delta^m \ln c_{m-6} + \Delta^m \ln c_{m-7}$. Using the fact that consumers form habits at the monthly frequency, one can write:

$$
\Delta^m \ln c_m = \alpha^3 \Delta^m \ln c_{m-3} + \varepsilon_m + \alpha\varepsilon_{m-1} + \alpha^2 \varepsilon_{m-2}
$$

and

$$
\begin{aligned}
\Delta^Q \ln C_Q &= \alpha^3 \Delta^Q \ln C_{Q-1} + (\varepsilon_m + \alpha\varepsilon_{m-1} + \alpha^2\varepsilon_{m-2)} + 2(\varepsilon_{m-1} + \alpha\varepsilon_{m-2} + \alpha^2\varepsilon_{m-3}) \\
&\quad +3(\varepsilon_{m-2} + \alpha\varepsilon_{m-3} + \alpha^2\varepsilon_{m-4}) + 2(\varepsilon_{m-3} + \alpha\varepsilon_{m-4} + \alpha^2\varepsilon_{m-5}) \\
&\quad +(\varepsilon_{m-4} + \alpha\varepsilon_{m-5} + \alpha^2\varepsilon_{m-6}) \\
\Delta^Q \ln C_Q &= \alpha^3 \Delta^Q \ln C_{Q-1} + \varepsilon_m + (2+\alpha)\varepsilon_{m-1} + [2 + (1+\alpha)^2]\varepsilon_{m-2} \qquad (8) \\
&\quad +[2 + \alpha(3+2\alpha)]\varepsilon_{m-3} + [1 + \alpha(2+3\alpha)]\varepsilon_{m-4} \\
&\quad +\alpha(1+2\alpha)\varepsilon_{m-5} + \alpha^2\varepsilon_{m-6} \\
\Delta^Q \ln C_Q &= \alpha^3 \Delta^Q \ln C_{Q-1} + \upsilon_Q + \lambda_1 \upsilon_{Q-1} + \lambda_2 \upsilon_{Q-2}. \qquad (9)
\end{aligned}
$$

The quarterly aggregate consumption growth therefore follows an ARMA(1,2) process. The equation (9) corresponds to equation (5) in the main text. To obtain expressions for λ_1 and λ_2 in terms of the coefficient α (and γ), one can match the variance and the first two covariances of the innovation processes in equations (8) and (9) (note that the higher-order covariances are zero):

$$
\begin{aligned}
(1 + \lambda_1^2 + \lambda_2^2)\sigma_\upsilon^2 &= \{1 + (\alpha+2)^2 + [2 + (1+\alpha)^2]^2 + [2 + \alpha(3+2\alpha)]^2 \\
&\quad +[1 + \alpha(2+3\alpha)]^2 + [\alpha(1+2\alpha)]^2 + \alpha^4\}\sigma_\varepsilon^2 \\
\lambda_1(1+\lambda_2)\sigma_\upsilon^2 &= [2 + \alpha(3+2\alpha)] + [1 + \alpha(2+3\alpha)](\alpha+2) \\
&\quad +\alpha(1+2\alpha)[\alpha(2+\alpha)+3] + \alpha^2[\alpha(3+2\alpha)+2]\}\sigma_\varepsilon^2 \\
\lambda_2\sigma_\upsilon^2 &= \alpha^2\sigma_\varepsilon^2
\end{aligned}
$$

Substituting the first expression into the other two expressions leads to:

$$\frac{\lambda_1(1+\lambda_2)}{1+(\lambda_1)^2+(\lambda_2)^2} = \frac{4+\alpha(11+\alpha(20+\alpha(11+4\alpha)))}{19+\alpha(32+\alpha(39+\alpha(32+19\alpha)))}, \text{ and}$$

$$\frac{\lambda_2}{1+(\lambda_1)^2+(\lambda_2)^2} = \frac{\alpha^2}{19+\alpha(32+\alpha(39+\alpha(32+19\alpha)))}.$$

Recognizing that $\alpha^3=\gamma$, the relationship between λ_1, λ_2, and γ can be expressed as:

$$\begin{aligned}
\frac{\lambda_1(1+\lambda_2)}{1+(\lambda_1)^2+(\lambda_2)^2} &= \frac{4+\gamma^{\frac{1}{3}}(11+\gamma^{\frac{1}{3}}(20+\gamma^{\frac{1}{3}}(11+4\gamma^{\frac{1}{3}})))}{19+\gamma^{\frac{1}{3}}(32+\gamma^{\frac{1}{3}}(39+\gamma^{\frac{1}{3}}(32+19\gamma^{\frac{1}{3}})))}, \\
\frac{\lambda_2}{1+(\lambda_1)^2+(\lambda_2)^2} &= \frac{\gamma^{\frac{2}{3}}}{19+\gamma^{\frac{1}{3}}(32+\gamma^{\frac{1}{3}}(39+\gamma^{\frac{1}{3}}(32+19\gamma^{\frac{1}{3}})))}.
\end{aligned}$$

While the expressions for λ_1 and λ_2 may seem complicated, in practice, $\lambda_1 \approx 0.4$ (when $\gamma > 0.3$) and $\lambda_2 \approx 0$. Indeed, the estimated consumption persistence coefficient γ of 0.67 reported in Table 2 (for the model with general measurement error) implies $\lambda_1 = 0.41$ and $\lambda_2 = 0.01$.

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