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Disciplines
Economic Theory | International and Comparative Labor Relations | Labor Economics

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Staff Paper 220

The Dynamic Effects of Permanent and Transitory Labor Income on Consumption

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February 1991
Abstract

This paper develops a version of the Permanent Income Hypothesis in which permanent and transitory components of consumption and labor income are explicitly accounted for. The model is used to derive a restricted vector autoregressive representation of adjusted measures of consumption and saving, which is used to test the theory and to study the dynamic effects of the two components of labor income on consumption. We find that the restrictions on the VAR are not easily rejected for quarterly post-war U.S. data. An analysis of the restricted VAR leads us to conclude that consumption can be almost entirely explained in terms of the permanent component of labor income.
1. Introduction

Since Hall's (1978) formulation of a rational expectations version of the Permanent Income Hypothesis (PIH), a large literature has developed to extract and test the restrictions implied by the theory for aggregate measures of consumption and income. For the most part, this literature has argued that the restrictions cannot be reconciled with the data. Hall, for example, characterized the rational expectations version of the PIH by the restriction that current consumption changes should be nearly unpredictable given past information if real interest rates are constant over time. The more highly restricted and commonly used version of the PIH developed by Flavin (1981) implies the same restriction, omitting the qualifier "nearly." The apparent serial correlation in observed consumption changes and the ability of lagged income changes to help explain current consumption changes contradict this restriction and define the "excess sensitivity" of consumption. If labor income is a difference stationary process whose first differences are positively autocorrelated, which appears to be a feature of U.S. quarterly real per capita labor income, then Deaton (1987) and others have argued that observed consumption is far less volatile than the theory predicts. This is referred to as the "excess smoothness" of consumption. Campbell (1987) developed, tested, and rejected the restrictions implied by the PIH for the vector autoregressive representation of the change in labor income and the level of saving (or an adjusted measure of saving) under the assumption that labor income is difference stationary.

Naturally, these results have led some to explore departures from the basic model in order to explain the observed time series data. These departures consider, for example, the roles of durable goods which provide consumption services, liquidity constraints, and time variation in the expected real interest rate. Hall's (1989) survey of the consumption theory literature discusses these
efforts.

However, recent work by Falk and Lee (1990) and Quah (1990) suggest that the incompatibility of the data with the implications of the PIH may have been overstated. More specifically, these papers argue that the apparent excess smoothness of consumption is based on the assumption that households do not distinguish between permanent labor income and transitory labor income. Similarly, Falk and Lee (1990) argue that the apparent excess sensitivity of consumption is based on the assumption that there is not a transitory component in consumption. Empirical evidence presented in these two papers suggest that these assumptions may be inappropriate.

The main purpose of this paper is to identify the permanent and transitory component of labor income and to study the dynamic effects of innovations in these components on consumption and saving subject to the restrictions implied by the PIH. We do this by pulling together techniques developed by Campbell (1987), Blanchard and Quah (1989), and Quah (1990). Speaking more formally, we derive a restricted bivariate vector autoregressive representation of adjusted measures of consumption and saving implied by the rational expectations version of the Permanent Income Hypothesis where i) consumption is the sum of permanent consumption, which is proportional to permanent income, and transitory consumption and ii) labor income, which is assumed to be a difference stationary process, is the sum of permanent labor income and transitory labor income. We test and fail to reject the restrictions the theory imposes on the VAR. Furthermore, the restrictions enable us to empirically identify the permanent and transitory components of labor income and study the dynamic responses of our (adjusted) consumption and saving measures to innovations in these two components of labor income. We find that the dynamic behavior of consumption can be well-
explained by the innovations in the permanent component of labor income while the
dynamic behavior of (adjusted) saving can be well-explained by the innovations
in the transitory component of labor income. We believe that this evidence
strengthens the conjectures of Falk and Lee (1990) and Quah (1990) that the
excess sensitivity and excess smoothness puzzles largely reflect the failure to
adequately account for distinctions between the permanent and transitory
components of consumption and labor income.

In Section 2 a standard rational expectations version of the PIH is
developed accounting for transitory consumption and a decomposition of labor
income into permanent and transitory components. The restricted bivariate VAR
representation of (adjusted) consumption and saving is derived in Section 3. Our
empirical analysis is presented in Section 4 and concluding remarks are offered
in Section 5.

2. A Bivariate Model of Consumption and Income

2.1 The Permanent Income Hypothesis (PIH)

We adopt the version of the PIH formulated by Flavin (1981), which built
upon the earlier work of Hall (1978) and Sargent (1978) and which was
subsequently extended by Campbell (1987) and Quah (1990). Consider the
consumption decision of an infinitely-lived representative household in period
t. The household enters period t with a stock of nonhuman wealth whose real value
is \( W_t \), which generates capital income at the start of period t equal to \( y_{k,t} \)
according to

\[
y_{k,t} = rW_t, \quad 0 < r < 1
\]

(1)

where \( r \) is the known constant real interest rate. In addition, the household will
receive real labor income in period t, y_t, which evolves as an exogenous stochastic process. Given r, W_t, y_t, and the household's real consumption in period t, c_t, the household enters period t+1 with a stock of real wealth whose value is W_{t+1}, which is determined by the intertemporal budget constraint

\[ W_{t+1} = (1+r)W_t + y_t - c_t. \]  

The household's permanent income in period t, \( y^p_t \), is defined as the rate of consumption in period t that would leave perceived real (human and nonhuman) wealth unchanged. That is, permanent income is the annuity value of the sum of \( W_t \) and the expected present value of current and future labor income:

\[
y^p_t = r[ W_t + \sum_{j=0}^{\infty} (1+r)^{-j-1}E_t y_{t+j}] \\
= y_{k,t} + r\Sigma(1+r)^{-j-1}E_t y_{t+j}
\]

where \( E_t \) denotes the conditional expectations operator based on the information set available in period t. For econometric purposes we will interpret \( E_t \) as the linear least squares projection operator.

Then, according to the PIH, consumption is the sum of permanent consumption and transitory consumption where permanent consumption is proportional to permanent income, i.e.,

\[
c_t = c^p_t + c^s_t \\
= (1/\theta)y^p_t + c^s_t, \quad \theta \geq 1 \\
= (1/\theta)[y_{k,t} + r\Sigma(1+r)^{-j-1}E_t y_{t+j}] + c^s_t
\]

where \( c^p_t \) is permanent consumption and \( c^s_t \) is transitory consumption. An important implication of allowing for transitory consumption in the PIH is that it permits it permits lagged consumption and income changes to help predict future consumption changes. The presence of a transitory component in consumption will eventually play a crucial role in helping us identify the permanent and
transitory components of observed labor income.

Next, define total disposable income, $y_t$, and the spread, $s_t$, by

$$y_t = y^*_t + y_k,t$$

and

$$s_t = y_t - \theta c_t.$$  

Note that when $\theta$ is equal to one, the spread reduces to saving, $SV_t$, where

$$SV_t = y_t - c_t.$$  

Thus the spread can be interpreted as an adjusted saving measure. Campbell (1987) shows that by rearranging equation (4) the spread can be rewritten as

$$s_t = -\Sigma(l+r)^{-j}E_t\Delta y_{t+j} - \theta c^*_t$$  

where $\Delta$ denotes the first difference operator. Equation (7) states that the spread is equal to the expected present value of future declines in labor income minus a multiple of transitory consumption. When $\theta$ is equal to one and there is no transitory component in consumption, the interpretation of equation (7) is that saving is the optimal forecast of the present value of future declines in labor income.

For future reference, we note several additional implications of the consumption model described above. First, rearranging equation (2) and then using equations (1), (5), and (6) we obtain

$$\Delta y_{k,t} = r(y_{t-1} - c_{t-1}) = rSV_{t-1}.$$  

Next, rearranging equation (4) and using equation (8), we obtain

$$\Delta c_t = (1/\theta)(\Delta y_{k,t} + r\Sigma(l+r)^{-j}E_t\Delta y_{1,t+j} - E_{t-1}\Delta y_{1,t+j-1}) + \Delta c^*_t$$  

Finally, we define the adjusted first difference in consumption, $\Delta d_t$, according to
\[
\Delta d_t = \Delta c_t - (1/\theta) rSV_{t-1} \\
= (1/\theta)(\Delta y_{1,t} + \Sigma(1+r)^{-j}[E_t \Delta y_{1,t+j} - E_{t-1} \Delta y_{1,t+j-1}]) + \Delta c^e_t, \\
\]

where the second equality follows directly from equation (9). An alternative expression for \(\Delta d_t\), which can be derived from (10.a) using equation (7) is

\[
\Delta d_t = \Delta c_t - (1/\theta) \Delta y_{k,t}, \\
\]

so that \(\Delta d_t\) can be interpreted as the change in consumption in excess of a constant fraction of the change in capital income.

2.2 A model of labor income

To complete the model, we must specify the properties of the exogenous labor income process. We will assume that labor income is an integrated of order one, I(1), process, i.e., labor income is nonstationary in levels, but is stationary in first differences. The existence of a unit root in quarterly U.S. post-war labor income has been observed and documented by Deaton (1987), Campbell and Deaton (1989), and West (1988). Deaton was the first to note that if U.S. labor income is fitted to an ARIMA (p,1,q) model, then the PIH implies a degree of volatility in consumption far greater than what is actually observed in quarterly U.S. consumption. Possible resolutions of the "excess smoothness" of observed consumption when labor income has a unit root, which is also referred to as Deaton's Paradox, have been offered by Falk and Lee (1990) and by Quah (1990). Quah (1990), for example, shows how the paradox can be resolved if households perceive labor income as changing in response to two types of disturbances, one of which has permanent effects and the other has only transitory effects.

Following Quah (1990), we assume that households perceive their labor
income as being subject to two types of structural disturbances, one type having a permanent effect on the level of labor income and the other type having only a transitory effect. Formally, we begin by assuming that households perceive the difference stationary labor income process, \( y_{1,t} \), to be the sum of two components: a difference stationary permanent component, \( y^p_{1,t} \), which is not to be confused with permanent income defined by equation (3), and a stationary transitory component, \( y^s_{1,t} \), so that for all \( t \)

\[
y_{1,t} = y^p_{1,t} + y^s_{1,t}. \tag{11}
\]

Since \( \Delta y^p_{1,t} \) and \( y^s_{1,t} \) are covariance stationary processes, they have unique Wold representations

\[
(1-L)y^p_{1,t} = \sum_{i=0}^{\infty} r_i \varepsilon^p_{1,t-i} = r(L)\varepsilon^p_{1t}
\]

and

\[
y^s_{1,t} = \sum_{i=0}^{\infty} q_i \varepsilon^s_{1,t-i} = q(L)\varepsilon^s_{1t} \tag{12}
\]

where \( r(L) \) and \( q(L) \) are the polynomials in the lag operator \( L \) implied by the first equalities in (12) such that \( r_0 = q_0 = 1 \) and the zeroes of \( r(z) = 0 \) and \( q(z) = 0 \) all lie outside of the unit circle. \( \varepsilon^p_{1t} \) and \( \varepsilon^s_{1t} \) are the innovations in the permanent and transitory components of labor income, respectively, defined according to \( \varepsilon^p_{1t} = y^p_{1,t} - E[y^p_{1,t} | y^p_{1,t-s}, s > 0] \) and \( \varepsilon^s_{1t} = y^s_{1,t} - E[y^s_{1,t} | y^s_{1,t-s}, s > 0] \). We will refer to them as the permanent and transitory shocks to labor income. By construction, \( \varepsilon^p_{1t} \) and \( \varepsilon^s_{1t} \) must be serially uncorrelated processes. We will assume that they are uncorrelated contemporaneously with one another. It follows from (11) and (12) that

\[
\Delta y_{1,t} = (1-L)y_{1,t} = r(L)\varepsilon^p_{1t} + (1-L)q(L)\varepsilon^s_{1t} \tag{13}
\]

We assume further that \( r(L) \) and \( q(L) \) can be factored such that \( y^p_{1,t} \) has the
ARIMA \((P_1,1,Q_1)\) representation

\[(1-L)r_2(L)y_{1,t} = r_1(L)e_{1t}\]  \(14.a\)

and \(y_{1,t}\) has the ARIMA \((P_2,0,Q_2)\) representation

\[q_2(L)y_{1,t} = q_1(L)e_{2t}\]  \(14.b\)

where \(r_1(L), r_2(L), q_1(L),\) and \(q_2(L)\) are finite-order polynomials in \(L\) such that the zeroes of \(r_1(z) = 0, r_2(z) = 0, q_1(z) = 0,\) and \(q_2(z) = 0\) all lie outside of the unit circle.

We now introduce a proposition that shows the relationship between the representation of \(\Delta y_{1,t}\) given by (13) and the univariate ARIMA representation of labor income, which will be useful later when we will need to transform forecasts of future changes in labor income into distributed lags of the innovations in its permanent and transitory components.

**Proposition** - If \(X_{1t}\) is an ARIMA \((P_1,1,Q_1)\) process and \(X_{2t}\) is an ARIMA \((P_2,0,Q_2)\) process then \(X_t = X_{1t} + X_{2t}\) is an ARIMA \((P,1,Q)\) process where \(P \leq P_1 + P_2\) and \(Q \leq \max\{P_2+Q_1, P_1+Q_2+1\}\), with equality holding if all of the roots of the AR and MA polynomials of \(X_{1t}\) and \(X_{2t}\) are distinct. This conclusion holds regardless of the extent of the contemporaneous correlation between the white noise components of \(X_{1t}\) and \(X_{2t}\).

**Proof:** See Granger and Morris (1976, p.250).

From this proposition and equations (11) - (14) we can infer that \(y_{1,t}\) has an ARIMA \((P,1,Q)\) representation

\[h_1(L)(1-L)y_{1,t} = h_2(L)e_t\]  \(15\)

and \(\Delta y_{1,t}\) has Wold moving average representation

\[\Delta y_{1,t} = h(L)e_t\]  \(16\)

where \(e_t\) is the innovation in \(\Delta y_{1t}\) and the zeroes of \(h(z) = 0\) all lie outside of the unit circle. A comparison of (13) and (16) yields the following relationship
between $\epsilon_t$ and the permanent and transitory shocks $\epsilon_{1t}$ and $\epsilon_{2t}$:

$$
\epsilon_t = h(L)^{-1}A\epsilon_{1t} = h(L)^{-1}[r(L)\epsilon_{1t} + (1-L)q(L)\epsilon_{2t}].
$$

(17)

2.3 Restrictions on transitory consumption

The main purpose of this paper is to identify the permanent and transitory components of labor income and to study the dynamic effects of innovations in these components on consumption and saving implied by the PIH. The identification procedure we will use is based on Blanchard and Quah (1989). That procedure assumes that there are only two sources of disturbances in the system. As our model of the PIH currently stands, there are three possible sources of disturbances in the system: the innovation in the permanent component of labor income, $\epsilon_{1t}$, the innovation in the transitory component of labor income, $\epsilon_{2t}$, and the innovation in the transitory component of consumption.

In order to use the Blanchard-Quah strategy to identify the permanent and transitory components of labor income, one possibility would be to assume away transitory consumption, as has occasionally been done in previous studies of the PIH such as Flavin (1981) and Quah (1990). However, as we noted earlier, the presence of transitory consumption may be important in explaining the excess sensitivity puzzle and Campbell's (1987) tests of the PIH suggest that transitory consumption may be important in fitting the PIH to the data. Furthermore, as we will show below, simply ignoring the transitory component in consumption does not facilitate identification.

Another possibility would be to assume that transitory consumption (or the innovation in transitory consumption) has a component that is exogenous with respect to the permanent and transitory shocks in labor income and extend Blanchard and Quah's approach to a trivariate and three disturbance case. We have
explored this option but have not been able to solve the identification problem for this more general case.

Instead we assume that transitory consumption is a stationary process that is a linear function of the current and possibly past innovations in transitory labor income. That is, we assume that

\[ c^*_t = \alpha(L)\varepsilon_{2t}, \quad (18) \]

where the \( \alpha(L) \) is a finite-order polynomial in the lag operator such that the zeroes of \( \alpha(z) = 0 \) all lie outside of the unit circle. This representation of transitory consumption, which reduces \( c^*_t \) to a white noise process as a special case, implies that the innovation in transitory consumption is proportional to the innovation in transitory labor income. Of course, if transitory income or transitory consumption is serially correlated then the correlation between transitory consumption and transitory labor income can be arbitrarily small. The economic interpretation of this assumption is that transitory consumption arises only when households "splurge" in response to perceived temporary increases in labor income (due, for example, to a Christmas bonus or unexpected overtime) or when they temporarily "tighten their belts" in response to temporary decreases in labor income (due, for example, to health problems that create a temporary work loss and generate temporary medical expenses). The assumption that transitory consumption responds to transitory labor income shocks seems less bothersome than the restriction that transitory labor income shocks are the only sources of transitory consumption.

3. The Vector Autoregressive Representation of (Adjusted) Consumption and Saving

In this section we develop a bivariate vector autoregression implied by the PIH subject to our model of labor income in order to allow us to identify the
permanent and transitory components of labor income and the dynamic responses of consumption and saving to permanent and transitory disturbances in labor income. Campbell (1987) first pointed out that the presence of a unit root in labor income has important implications with regard to the existence of finite vector autoregressions for variables restricted by the PIH. For example, Campbell shows that when \( \theta \) is equal to one, \( y_{k,t} \) and \( c_t \) are also integrated of order one. However, in this case, \( y_{k,t}, y_{l,t}, \) and \( c_t \) are cointegrated of order \((1,1)\) and so a finite vector autoregressive representation of the vector of their first differences does not exist. If \( \theta \) is greater than one, then Campbell shows that \( c_t \) and \( y_{k,t} \) are explosive processes. Thus, their first differences are not stationary and so in this case too a finite vector autoregressive representation of the first differences of \( y_{k,t}, y_{l,t}, \) and \( c_t \) does not exist. Furthermore, in neither case will a finite vector autoregression of \( \Delta y_t \) \((= \Delta y_{l,t} + \Delta y_{k,t})\) and \( \Delta c_t \) exist. However, Campbell shows that in either case, a finite vector autoregressive representation of \( \Delta y_{l,t} \) and the spread, \( s_t \), exists. This is the vector autoregression Campbell studies. It is not the most convenient representation for our purposes since it does not identify the permanent and transitory shocks to labor income. Instead, we consider the vector autoregressive representation of \( s_t \) and the adjusted change in consumption, \( \Delta d_t \), defined by equations (10).

3.1 The bivariate MAR of (adjusted) consumption and savings

We begin by establishing the existence of an invertible bivariate moving average representation of \( \Delta d_t \) and \( s_t \). For expositional convenience we rewrite the expressions for \( \Delta d_t \) and \( s_t \) from equations (10.a) and (7), respectively, below:
\[ \Delta d_t = \Delta c_t - (1/\theta)rS v_{t-1} \]
\[ = (1/\theta)(\Delta y_{1,t} + \sum (1+r)^{-j}[E_t \Delta y_{1,t+j} - E_{t-1} \Delta y_{1,t+j-1}]) + \Delta c^s_t \]  
(19.a)

and
\[ s_t = y_{k,t} + y_{1,t} - \theta c_t \]
\[ = -\sum (1+r)^{-j}E_t \Delta y_{1,t+j} - \theta c^s_t. \]  
(19.b)

Recall from equation (10.b) that \( d_t = c_t - (1/\theta)y_{k,t} \). Therefore, if \( y_{1,t} \) is integrated of order one, then from the second equality in (19.a) we infer that \( d_t \) is also integrated of order one (since we are assuming that transitory consumption is stationary). According to the second equality in (19.b), \( s_t \) is integrated of order zero. Since \( s_t \) is equal to \( y_{1,t} - \theta d_t \), it follows that \( y_{1,t} \) and \( d_t \) are cointegrated of order (1,1) with cointegrating vector \([1 - \theta]^t\) and so a finite vector autoregressive representation of \( \Delta y_{1,t} \) and \( \Delta d_t \) does not exist. However, following an argument analogous to Campbell (1987) based on the Granger Representation Theorem (Engle and Granger, 1987), we can infer the existence of a finite vector autoregressive representation of \( \Delta d_t \) and \( s_t \) from the error-correction representation of \( \Delta y_{1,t} \) and \( \Delta d_t \).

According to equation (16), \( \Delta y_{1,t} \) has Wold moving average representation \( \Delta y_{1,t} = h(L)\epsilon_t \). By applying the Wiener-Kolmogorov prediction formula (Sargent, 1987, pp.290-294), we observe that \( E_t \Delta y_{1,t+j} = [h(L)L^{-j}]_+ \), where \([ ]_+ \) denotes the annihilation operator and means "ignore the negative powers of \( L \)." For example, \( [... + a_{-2}L^{-2} + a_{-1}L^{-1} + a_0 + a_1L + a_2L^2 + ...]_+ = a_0 + a_1L + a_2L^2 + ... \). It follows that (19.a) and (19.b) can be rewritten as:

\[ \Delta d_t = (1/\theta)[h(L) + (1-L)g(L)]\epsilon_t + \Delta c^s_t \]
\[ = G(L)\epsilon_t + \Delta c^s_t \]  
(20.a)
and
\[ s_t = -g(L)e_t - \theta c^*_t \]  
(20.b)

where \( g(L) = \sum_{j=1}^{\infty} (1+r)^{-j\{h(L)L^{-j}\}} \) and \( G(L) = (1/\theta)[h(L)+(1-L)g(L)] \).

Using equation (17) to rewrite \( \epsilon_t \) in terms of \( \epsilon_{1t} \) and \( \epsilon_{2t} \), and using equation (18) to rewrite \( c^*_t \) in terms of \( \epsilon_{2t} \), we can rewrite (20) as

\[ \Delta d_t = G(L)h(L)^{-1}[r(L)\epsilon_{1t} + (1-L)q(L)\epsilon_{2t}] + \alpha(L)(1-L)\epsilon_{2t} \\
= G(L)h(L)^{-1}r(L)\epsilon_{1t} + (1-L)[G(L)h(L)^{-1}q(L) + \alpha(L)]\epsilon_{2t} \]  
(21.a)

and

\[ s_t = -g(L)[r(L)\epsilon_{1t} + (1-L)q(L)\epsilon_{2t}] - \theta \alpha(L)\epsilon_{2t} \\
- g(L)r(L)\epsilon_{1t} - [g(L)(1-L)q(L) + \theta \alpha(L)]\epsilon_{2t}. \]  
(21.b)

Letting \( Z_t \) be defined as \([\Delta d_t \ s_t]'\), we note from (21) that \( Z_t \) has the bivariate moving average representation (BMAR)

\[ Z_t = \begin{bmatrix} B_{11}(L) & B_{12}(L) \\ B_{21}(L) & B_{22}(L) \end{bmatrix} \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{bmatrix} \]  
(22)

where \( B_{ij}(L) = \sum_{s=0}^{\infty} b_{ij,s}L^s \), for \( i,j = 1,2 \). This BMAR identifies the two disturbances as the permanent and transitory disturbances in labor income. Furthermore, as can be seen from (21.a), it is characterized by the restriction that \( B_{12}(1) \) is equal to zero.

We conclude this section by noting the important role that transitory consumption plays in deriving this identifying restriction. Suppose that there is no transitory consumption so that \( c^*_t = 0 \) for all \( t \). Then equation (21) reduces to

\[ \Delta d_t = G(L)h(L)^{-1}r(L)\epsilon_{1t} + (1-L)G(L)h(L)^{-1}q(L)\epsilon_{2t} \]  
(23.a)

and
In this case, the restriction that $B_{12}(1) = 0$ still holds. However, notice that in this case $B_{22}(L) = -(1-L)g(L)q(L)$ and so $B_{22}(1) = 0$, too. Therefore, without transitory consumption the theory implies that the EMAR is characterized by the restrictions that $B_{12}(1) = B_{22}(1) = 0$, and so it is not invertible. We also note that our assumption that the innovation in transitory consumption is proportional to the innovation in transitory labor income is what allowed us to obtain a Wold representation of $\Delta d_t$ and $s_t$ in terms of the innovations in the permanent and transitory components of labor income.

### 3.2 An example

Suppose that the permanent component of labor income is a random walk and the transitory component is an AR(1) process, i.e.,

$$y^p_{1t} = (1-L)^{-1} \epsilon_{1t}$$

and

$$y^s_{1,t} = (1-\rho L)^{-1} \epsilon_{2t}, \quad |\rho| < 1$$

so that $r(L) = 1$ and $q(L) = (1-\rho L)^{-1}$ in (12). Thus, since labor income is the sum of $y^p_{1,t}$ and $y^s_{1,t}$,

$$\Delta y_{1,t} = \epsilon_{1t} + (1-L)(1-\rho L)^{-1} \epsilon_{2t}.$$

Using the proposition we cited in Section 2, we can show that $y_{1,t}$ also has an ARIMA $(1,1,1)$ representation of the form

$$(1-\rho L)\Delta y_{1,t} = (1-aL)\epsilon_t, \quad |a| < 1,$$

where $\epsilon_t$ is the innovation in $y_{1,t}$. Applying the Wiener-Kolmogorov prediction formula to this ARIMA $(1,1,1)$ model of labor income, we obtain

$$E_t(\Delta y_{1,t+j}) = [(1-aL)(1-\rho L)^{-1}L^{-j}]_t \epsilon_t = \rho^{j-1}(\rho-a)(1-\rho L)^{-1} \epsilon_t.$$
Thus,
\[
\sum_{j=1}^{\infty} (1+r)^{-j} E_t (\Delta y_{1,t+j}) = \sum_{j=1}^{\infty} (1+r)^{-j} \rho^{j-1} (\rho-a)(1-\rho L)^{-1} \epsilon_t
\]

\[
= (\rho-a)(1+r-\rho)(1-\rho L)^{-1} \epsilon_t.
\]

We then infer from (19) that
\[
\Delta d_t = \frac{1}{\theta}(1-\rho L)^{-1}[(1-aL) + (p-a)(1+r-\rho)^{-1}(1-L)] \epsilon_t + \Delta c^a_t
\]

and
\[
\Delta s_t = (a-p)(1+r-\rho)^{-1}(1-\rho L)^{-1} \epsilon_t - \theta c^a_t
\]

where \( G(L) = \frac{1}{\theta}(1-\rho L)^{-1}[(1-aL) + (p-a)(1+r-\rho)^{-1}(1-L)] \) and \( g(L) = \frac{(p-a)(1+r-\rho)(1-\rho L)^{-1}}{\theta} \). Note that \( y^2_{1,t} \) is \( I(1) \) while \( y_1^2, \Delta y_{1,t}, \Delta d_t, \) and \( s_t \) are each \( I(0) \).

From the representations of \( \Delta y_{1,t} \) in terms of i) \( \epsilon_t \) and ii) \( \epsilon_1t \) and \( \epsilon_2t \), we can infer that
\[
\epsilon_t = (1-aL)^{-1}[(1-\rho L) \epsilon_1t + (1-L) \epsilon_2t].
\]

Substituting this into the expressions given above for \( \Delta d_t \) and \( s_t \), and recalling from (18) that \( c^a_t = \alpha(L) \epsilon_2t \), yields
\[
\Delta d_t = G(L)(1-aL)^{-1}(1-\rho L) \epsilon_1t + (1-L)[G(L)(1-aL)^{-1} + \alpha(L)] \epsilon_2t
\]

and
\[
s_t = -g(L)(1-\rho L)(1-aL)^{-1} \epsilon_1t - [g(L)(1-L)(1-aL)^{-1} + \theta \alpha(L)] \epsilon_2t,
\]
which is the bivariate moving average representation corresponding to equation (22). It is easy to see that this BMAR is characterized by the restriction that \( B_{12}(1) = 0 \). Also note that in the absence of transitory consumption the BMAR is characterized by the restriction that \( B_{12}(1) = B_{22}(1) = 0 \).
3.3 The restricted VAR

As a practical matter, the bivariate MAR in equation (22) is derived by inverting a bivariate VAR. Therefore, we discuss how we can impose restrictions on the VAR representation of $\Delta d_t$ and $s_t$ in a way that will ensure the conditions on the bivariate MAR that i) $B_{12}(l)$ is equal to zero and ii) the moving average disturbances are contemporaneously uncorrelated. Suppose that $\Delta d_t$ and $s_t$ have the VAR representation:

$$Z_t = \begin{bmatrix} \Delta d_t \\ s_t \end{bmatrix} = A(L)Z_{t-1} + u_t \quad \text{where } u_t = \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix},$$

where $u_t = [u_{1t} \ u_{2t}]'$ is the innovation vector in $Z_t$ whose contemporaneous variance-covariance matrix we denote by the 2x2 matrix $\Sigma$. A moving average representation of $Z_t$ is derived by inversion of the VAR, i.e.,

$$Z_t = \begin{bmatrix} I - A(L)L \end{bmatrix}^{-1} u_t = k(L)u_t, \quad (25)$$

where $I$ is the 2x2 identity matrix.

The moving average representations of $Z_t$ given by (22) and (25) are related to each other as follows. Since $\Sigma$ is a symmetric positive definite matrix, its inverse, $\Sigma^{-1}$, is also symmetric and positive definite. Thus, there exists a nonsingular matrix, $G$, such that $\Sigma^{-1} = G^tG$. Define a transformed innovation $\epsilon_t = [\epsilon_{1t} \ \epsilon_{2t}]'$ from $u_t$ according to $\epsilon_t = Gu_t$ and note that $\text{var}(\epsilon_t) = \text{var}(Gu_t) = GG^t = I$. Thus, using (25), $Z_t$ can be written as

$$Z_t = \sum_{s=0}^{\infty} k(s)u_{t-s} = \sum_{s=0}^{\infty} k(s)G^{-1}Gu_{t-s} = \sum_{s=0}^{\infty} B(s)\epsilon_{t-s} = B(L)\epsilon_t, \quad (26)$$

which is a moving average representation of $Z_t$ in terms of contemporaneously uncorrelated disturbances and so coincides with the moving average representation of $Z_t$ given by (22). It follows (see, for example, Blanchard and Quah, 1989, p. 657) that the restriction that $B_{12}(l) = 0$ will hold if and only
if $A_{12}(1) = 0$ in the VAR (24). In the absence of transitory consumption, recall that the identifying restrictions on (22) are $B_{12}(1) = B_{22}(1) = 0$ so that $Z_t$ will not have a finite vector autoregressive representation. However, if $B_{22}(1)$ is close to but not equal to zero then $Z_t$ will have a finite VAR representation characterized by the restrictions on (24) that $A_{12}(1) = 0$ and $A_{11}(1)$ is close to one. This suggests that one way to test the importance of transitory consumption is to test the restrictions on (24) that $A_{12}(1) = 0$ and $A_{11}(1) = 1$.

Thus, the identifying restriction leads to a restricted bivariate vector autoregressive representation of (adjusted) consumption and (adjusted) saving, providing a convenient way to test this version of the PIH. Furthermore, we can use the estimated restricted VAR as the basis for innovation accounting analysis to study the dynamic responses of consumption and saving to innovations in the transitory and permanent components of labor income. It can also be used to obtain an historical decomposition of realized consumption and saving into the components attributable to the transitory and permanent components of labor income, respectively.

4. Empirical Analysis

4.1 Data

For our empirical analysis of the model we use quarterly U.S. data over the 1947:1 - 1989:III sample period. We use real disposable personal income divided by population to measure income ($y_t$). We measure consumption ($c_t$) by real per capita consumption expenditures on nondurable goods and services. These data are U.S. National Income and Product Account data obtained from the Citibase data file and are expressed as annualized seasonally adjusted rates. The constant real interest rate ($r$) is measured as the average return over the sample period on
three-month U.S. Treasury bills, adjusted for inflation using the CPI inflation rate, expressed as an annual real rate. The estimated value for $r$ is $0.00854$, i.e., about $.85$ percent per year.

To compute $\Delta d_t$ and/or $s_t$ we use the data on $y_t$ and $c_t$, equations (5), (6), and (10.a) and an estimate of the parameter $\theta$. Recall that $s_t = y_t - \theta c_t$ and that $s_t$ is a stationary process if labor income, $y_{1,t}$, is difference stationary. If $\theta$ is equal to one, then $y_t$ and $c_t$ will also be difference stationary, i.e., $y_t$ and $c_t$ are cointegrated of order (1,1) with cointegrating vector $[1 -1]'$. It follows (Stock, 1984) that if $\theta$ is equal to one, the regression coefficient in a regression of $y_t$ on $c_t$ should converge in probability to one. If $\theta$ is greater than one, then our theory implies that $y_t$ and $c_t$ are explosive processes and this regression coefficient need not converge to $\theta$. Nevertheless, following Campbell (1987, pp.1258-9), we use this regression coefficient as our estimate of $\theta$, recognizing the absence of a formal justification, and estimate $\theta$ to be $1.3681$. This implies a marginal propensity to consume out of permanent income equal to $.73$.

Given the estimate of $\theta$, we compute $\Delta d_t$ and $s_t$ and then compute $d_t$ recursively from $\Delta d_t$. Table 1 provides summary information regarding the $d_t$, $\Delta d_t$, and $s_t$ time series. Sample autocorrelations and unit root test results are consistent with the theory's implication that $d_t$ is nonstationary but $\Delta d_t$ and $s_t$ are stationary. Notice that the correlation between $\Delta d_t$ and $\Delta c_t$ is $.995$, so that it seems reasonable to interpret our adjusted consumption change measure $\Delta d_t$ as an approximate measure of consumption changes. However, the correlation between $s_t$ and $SV_t$ is $.188$ so that we cannot reasonably interpret the spread or adjusted saving measure as an approximation to saving itself.
4.2 Testing the identifying restriction

Given our measures of $\Delta d_t$ and $s_t$ we proceed to estimate their vector autoregressive representation and test the restrictions implied by our theory on this VAR. Recall from Section 3, that the theory implies the restriction $B_{12}(1) = 0$ on the moving average representation of $[\Delta d_t s_t]'$, which translates into the restriction $A_{12}(1) = 0$ in its VAR representation. That is, the sum of the coefficients on lagged $s_t$ should be equal to zero in the equation for $\Delta d_t$. According to Table 2, which presents the result of this test based on a fourth-order vector autoregression estimated by OLS, the restriction cannot be rejected at conventional significance levels. The Granger causality tests presented in this table suggest that this is because the even stronger restriction that $A_{12}(L) = 0$ (and, hence, $B_{12}(L) = 0$) cannot be rejected, where $A_{12}(L) = 0$ is interpreted as the coefficient in the $p$-th order polynomial are jointly equal to zero. Notice by comparing equations (21.a) and (22) that while a conclusion that $B_{12}(L) = 0$ would imply that the transitory component of labor income does not influence (adjusted) consumption, it does not imply that transitory consumption is an unimportant component of consumption (which would require that $\alpha(L) = 0$). This is true even though we assume that transitory consumption is completely determined by current and past innovations in transitory labor income. We noted in Section 3 that as transitory consumption becomes negligible, $A_{11}(1)$ ought to go to one. This suggests that if transitory consumption is nonnegligible we should be able to reject the VAR restrictions $A_{12}(1) = 0$ and $A_{11}(1) = 1$. Table 2 indicates that this restriction can be rejected at the one percent significance level based on a fourth-order VAR.

We conclude that the data are consistent with the identifying restrictions implied by our version of the PIH. In the remainder of the paper, we use the
fourth-order VAR estimated subject to the restriction that $A_{12}(1) = 0$ to analyze the dynamic responses of (adjusted) consumption and the spread to innovations in the permanent and transitory components of labor income.

4.3 **Forecast error variance decomposition and impulse response simulations**

Following Sims (1980), we use the restricted fourth-order VAR representation of $\Delta d_t$ and $s_t$ to decompose each of their $j$-step ahead forecast error variances into components attributable to the innovations in the permanent and transitory components of labor income, respectively. The same exercise is performed for the implied VAR representation of $d_t$ and $s_t$. As Table 3 clearly shows, at all time horizons variations in (adjusted) consumption changes and levels are almost entirely explained by innovations in the permanent component of labor income. Variations in the spread are largely explained by innovations in the transitory component of labor income, though innovations in the permanent component of labor income appear to have some explanatory power. These findings are consistent with the usual interpretation of the PIH, i.e., that consumption responds primarily to income innovations which are perceived to have permanent effects.

Next, we use the estimated restricted VAR to simulate the dynamic effects of innovations in the permanent and transitory components of labor income on (adjusted) consumption and the spread. The results are presented in Figures 1 ($\Delta d_t$ and $s_t$) and 2 ($d_t$). The first graph in Figure 1 shows that a positive innovation in the permanent component of labor income has a strong positive initial impact on the change in (adjusted) consumption. The effect falls rapidly and then slowly diminishes further as the time-horizon increases, though it remains positive throughout the adjustment process. The effects of a positive
innovation in the transitory component of labor on the change in (adjusted) consumption can barely be seen. According to Figure 2, we see that in response to a positive innovation in the permanent component of labor income, the level of (adjusted) consumption immediately increases and then gradually but monotonically increases toward its long-run level, which is essentially attained within three years. The effects of an innovation in the transitory component of labor income on the level of (adjusted) consumption is negligible at all time horizons.

The second graph in Figure 1 (or, equivalently, the second graph in Figure 2) illustrates the dynamic responses of the spread to innovations in the permanent and transitory components of labor income. The response of the spread to a positive innovation in the temporary component of labor income is positive but diminishing at all time horizons, looking very much like the dynamic response of consumption changes to a positive innovation in the permanent component of labor income. In contrast, there is a strong negative initial response of the spread to a positive innovation in the permanent component of labor income. The response of the spread to this innovation remains negative over the next several quarters, diminishing in absolute value. Subsequently, the spread becomes positive and increases over the next several quarters after which it declines monotonically toward zero.

Finally, we decompose the historical values of (adjusted) consumption and the spread into two components: a component attributable to the accumulated effects of current and past permanent shocks in labor income (obtained by setting all transitory shocks equal to zero) and a component attributable to the accumulated effects of current and past transitory shocks in labor income (obtained by setting all permanent shocks equal to zero). Figure 3 shows the
results of this exercise for the sample period 1947:1 - 1989:III. As expected from the previous analysis, almost all variations in (adjusted) consumption, $c_t$, are due to innovations in the permanent component of labor income with transitory income playing little, if any, role in explaining the dynamic behavior of consumption. In particular, the component of consumption attributable to the effects of permanent labor income is visually indistinguishable from actual consumption.

A first glance at the decomposition of the spread in Figure 3 suggests that the spread can be well-explained by either the component generated by permanent labor income or the component generated by transitory labor income. However, closer examination reveals that the component generated by transitory labor income plays a more important role in explaining the spread's dynamic behavior. Again, this is consistent with the results of our previous analysis.

In summary, the results of forecast error variance decompositions, impulse response analysis, and historical decompositions provide a consistent story. The behavior of (adjusted) consumption can be almost entirely explained as responses to innovations in the permanent component of labor income. The spread can be explained largely, though not entirely, as responses to innovations in the transitory component of labor income.

5. Concluding Remarks

This paper has studied a rational expectations version of the Permanent Income Hypothesis that accounts for a transitory component in consumption and allows households to distinguish between innovations in labor income whose effects are permanent and innovations whose effects on labor income are transitory. Assuming that innovations in transitory consumption are proportional
to the innovation in transitory labor income allowed us to derive a restricted moving average representation of adjusted measures of consumption and saving whose innovations are precisely the innovations in the permanent and transitory components of labor income. Following Blanchard and Quah (1989), we were able to use this restricted MAR to impose testable restrictions on a bivariate VAR representation of (adjusted) consumption and saving and to use this restricted VAR to identify the permanent and tranitory components of labor income. Having identified these components of labor income, we were able to examine the dynamic responses of (adjusted) consumption and saving to innovations in each of these two components.

The main results are as follows. The restrictions the theory imposes on the VAR cannot be rejected. The dynamic behavior of (adjusted) consumption is almost entirely due to innovations in the permanent component of labor income while the dynamic behavior of (adjusted) saving is largely due to innovations in the transitory component of labor income. We conclude that the empirical results are formally consistent with the implications of the PIH and they are consistent with conventional heuristic interpretations of that model.

As noted above, the restrictions we derive from the theory and the identifiability of the permanent and transitory components of labor income rely on the assumption that transitory consumption is tied to transitory labor income in a very restrictive way. Furthermore, the restrictions the theory imposes on the VAR will be satisfied whenever, as is the case in our data set, (adjusted) saving fails to linearly Granger-cause (adjusted) consumption, though the reverse implication is not true. Thus, the power of the test we developed may be a concern. It would be interesting to develop a restricted trivariate MAR and VAR representation of observable variables which would allow innovations in
transitory consumption to be distinguished from innovations in the transitory component of labor income and perhaps imply a tighter set of restrictions on the parameters of the VAR. We have been exploring this possibility though we have not yet been able to derive a set of three variables which have a suitably restricted finite VAR representation that can be expressed in terms of these innovations and can be analyzed by methods like the ones we used in this paper.
^ In contrast to Campbell (1987), we are ignoring unanticipated capital gains, which would add a noise term to the right-hand-side of (2).

^ The failure of consumption to follow a random walk and the explanatory power of lagged income changes with respect to consumption changes are often referred to as the "excess sensitivity" of consumption. Falk and Lee (1990) discuss how the excess sensitivity issue is related to the absence or presence of a transitory component in consumption. Campbell’s (1987) tests of the PIH suggest that transitory component may be an important part of aggregate U.S. consumption. Sargent (1987, Chapter 12) provides an example of an economy in which transitory consumption emerges as a consequence of preference shocks while in Sargent (1989) transitory consumption is interpreted as measurement error. Shortly, we will provide our own economic interpretation of transitory consumption.

^ Assuming that there are exactly two types of structural disturbances in labor income and that these disturbances are contemporaneously uncorrelated is restrictive. If there are exactly two types of structural disturbances in labor income but they are partially correlated, then our analysis remains valid although the innovations we define in the permanent and transitory components of labor income should not be interpreted as structural disturbances. Instead, they ought to be interpreted as the innovations in an orthogonal decomposition of labor income that households construct for forecasting purposes. See Quah (1990, pp.457-8).

^ If \( x_t, y_t, \) and \( z_t \) are CI(1,1), then the vector Wold moving average representation of \( \Delta x_t, \Delta y_t, \) and \( \Delta z_t \) is not invertible. See Campbell (1987, pp. 1254-9) for a more detailed discussion of these issues.
Campbell (1987, p.1253) shows that the model we formulated in section 2.1 implies that $c_t = (1 + r[1-(1/θ)])c_{t-1} + (r/θ)v_t$, where $v_t$ is a white noise process that is the unpredictable revision between periods $t-1$ and $t$ in the expected value of human wealth. It follows that $c_t$ is $I(1)$ if $θ$ is equal to one and is explosive if $θ$ is greater than one. Since $s_t$ is stationary and $Δs_t = Δy_{k,t} + Δy_{l,t} - θΔc_t$, it follows that if $θ$ is equal to one, $y_{k,t}$ is $I(1)$ and if $θ$ is greater than one, $y_{k,t}$ is explosive.

The discussion in this subsection draws heavily from Blanchard and Quah (1989).

We also considered the broader measure of personal consumption expenditures which includes expenditures on durable goods. The results we report here are invariant across these two consumption measures.

More precisely, quarterly real rates of return were calculated by averaging monthly averages of auction rates on newly issued three-month Treasury bills and then adjusting these nominal rates by the quarterly average CPI. The CPI data are seasonally adjusted with base year 1982. This base year coincides with the base year used for our measures of consumption and income.

Formal cointegration tests, such as those proposed by Engle and Granger (1987) are not very helpful in our setting since these tests consider the null that two processes are each $I(1)$ but are are not CI$(1,1)$ against the alternative that they are CI$(1,1)$. In our model, the interesting alternative to CI$(1,1)$ is that the two processes are not $I(1)$ processes.

When we include expenditures on durable goods in our measure of consumption, we estimate $θ$ to be 1.098 and $β$ to be .91.

The time series $d_t$ can be inferred from the time series $Δd_t$ given an initial value $d_0$. Recall that $d_t = c_t - (1/θ)y_{k,t}$, where $y_{k,t}$ is capital income. Since
capital labor income tends to make up about 70 percent of total national income according to the National Income and Product Accounts, we calculated $d_0$ according to $d_0 = c_0 - .3y_0/\theta$. We also considered $d_0 = c_0$ in which case the results were virtually identical to those we report here.
REFERENCES


Table 1. Sample Characteristics of $d_t$, $\Delta d_t$, and $s_t$

Sample period: 1947, I - 1989, III

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std.Dev</th>
<th>Autocorrelations</th>
<th>D-F</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>$p(1)$</td>
<td>$p(2)$</td>
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<tr>
<td>$d_t$</td>
<td>5.58</td>
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<td>.968</td>
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<tr>
<td>$\Delta d_t$</td>
<td>.0187</td>
<td>.0339</td>
<td>.214</td>
<td>.127</td>
</tr>
<tr>
<td>$s_t$</td>
<td>.0008</td>
<td>.110</td>
<td>.735</td>
<td>.587</td>
</tr>
</tbody>
</table>

$\text{Corr}(\Delta d_t, s_t) = -.139$

$\text{Corr}(\Delta d_t, \Delta c_t) = .995$

$\text{Corr}(s_t, SV_t) = .188$

Notes:
1. $\Delta d_t = \Delta c_t - (r/\theta)SV_{t-1}$, $s_t = y_t - \theta c_t$, where $c_t =$ real per capita personal consumption expenditures on nondurables and services, $y_t =$ real per capita disposable income, $SV_t =$ real per capita saving ($= y_t - c_t$), $r = .00854$, and $\theta = 1.3681$.

2. $p(k) =$ sample $k$-th order autocorrelation of $x_t$.

3. D-F is Dickey-Fuller $\tau(\alpha)$ statistic from a fourth-order augmented Dickey-Fuller regression. Under the null hypothesis that $x_t$ has a unit root and with 100 observations, the critical values of $\tau(\alpha)$ are -2.58 (10 %), -2.89 (5 %), -3.17 (2.5 %), and -3.51 (1 %). See Fuller (1976, Table 8.5.2, p. 373).
Table 2. Test of Identifying Restrictions

Bivariate VAR:
\[
\begin{bmatrix}
\Delta d_t \\
 s_t
\end{bmatrix} =
\begin{bmatrix}
A_{11}(L) & A_{12}(L) \\
A_{21}(L) & A_{22}(L)
\end{bmatrix}
\begin{bmatrix}
\Delta d_{t-1} \\
 s_{t-1}
\end{bmatrix} +
\begin{bmatrix}
u_{1t} \\
u_{2t}
\end{bmatrix},
\]

where
\[
A_{ij}(L) = a_{ij,1} + a_{ij,2} L + a_{ij,3} L^2 + a_{ij,4} L^3.
\]

A. Test of identifying restrictions
1. H₀: A₁₂(1) = 0, F(1,158) = .077, p-value = .782
2. H₀: A₁₂(1) = 0 and A₁₁(1) = 1, F(2,158) = 5.95, p-value = .003

B. Test of causality
1. sₜ does not Granger-cause Δdₜ
   H₀: A₁₂(L) = 0, F(4,158) = .213, p-value = .93
2. Δdₜ does not Granger-cause sₜ
   H₀: A₂₁(L) = 0, F(4,158) = 2.263, p-value = .065

Notes:
1. A fourth-order VAR representation of Δdₜ and sₜ (see notes to Table 1) was estimated for the 1948,II - 1989, III sample period.
2. Assuming nonnegligible transitory consumption, the theory implies that A₁₂(1) = 0. As transitory consumption becomes negligible, the theory also implies that A₁₁(1) converges to one.
Table 3. Relative importance of permanent ($\varepsilon_{1t}$) and transitory ($\varepsilon_{2t}$) components (Variance decomposition)

<table>
<thead>
<tr>
<th>Model</th>
<th>$[\Delta d_t, s_t]'$</th>
<th>$[d_t, s_t]'$</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta d_t$</td>
<td>$s_t$</td>
</tr>
<tr>
<td>Variables Explained</td>
<td>$\varepsilon_{1t}$</td>
<td>$\varepsilon_{2t}$</td>
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<tr>
<td>Innovations in Horizons (Quarters)</td>
<td>(%)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>100.0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>99.8</td>
<td>0.2</td>
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<tr>
<td>3</td>
<td>99.7</td>
<td>0.3</td>
</tr>
<tr>
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<td>99.7</td>
<td>0.3</td>
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<td>99.7</td>
<td>0.3</td>
</tr>
<tr>
<td>24</td>
<td>99.7</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Notes:
1. see notes to Table 1.
2. $\varepsilon_{1t}$ and $\varepsilon_{2t}$ are innovations in permanent and transitory components of labor income, respectively.
Figure 1. Response of $\Delta d$ and $s$ to permanent and transitory shocks

Response of $\Delta d$ to permanent and transitory shocks

Response of $s$ to permanent and transitory shocks

notes:

1. see notes to Table 1.

2. $\ldots$ = response to permanent shocks
   $\ldots$ = response to transitory shocks.
Figure 2. Response of $d$ and $s$ to permanent and transitory shocks

Response of $d$ to permanent and transitory shocks

Response of $s$ to permanent and transitory shocks

notes:
1. see notes to Table 1.
2. $\ldots$ = response to permanent shocks
   $\ldots$ = response to transitory shocks.
3. $d_t = c_t - y_k, t/\theta$, and $d_0 = c_0 - (0.3)y_0/\theta$. 
Figure 3. Decomposition of $d$ and $s$ due to each shock

Deomposition of $d$ due to each shock

Deomposition of $s$ due to each shock

notes:
1. See notes to Table 1. $d_t = c_t - \gamma y_k, t/\theta$, and $d_0 = c_0 - (0.3) y_0/\theta$.
2. ------- = actual series,

-------- = component attributable to the accumulated effects of current and past permanent shocks in labor income (obtained by setting all transitory shocks equal to zero)

--- --- = component attributable to the accumulated effects of current and past transitory shocks in labor income (obtained by setting all permanent shocks equal to zero)