Another Look at Great Moderation: 
The Changes in the Dynamics of Consumption and Output∗

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Revised: March 13, 2015

Abstract Since 1984, the volatility of the U.S. real GDP has reduced significantly and has become known as the Great Moderation. However, even though a great deal of literature have addressed the sources of the Great Moderation, no previous study has focused on the relationship between the Great Moderation and the dynamics of macro variables. This paper finds that the reduction in precautionary savings due to lower income uncertainty has both weakened the negative correlation between permanent income and transitory consumption and lowered the persistence of transitory consumption; these have resulted in faster consumption adjustment to long-run level of income. Furthermore, we find that the lower persistence of transitory output due to the improvement in the information technology industry has contributed to the faster adjustment of output to its new long-run level and this result may be related to faster technology diffusion processes. Our results suggest that the Great Moderation has resulted in a change in the dynamics of consumption and output and future research should investigate the role of the change in the dynamics of consumption and output in explaining the source of the Great Moderation.

Key Words Great Moderation, Dynamics of Consumption and Output, Persistence, Unobserved Component Model, Precautionary Saving, Technology Diffusion

JEL Classification E21, E32, C32

∗Part of this paper comes from Chunji Xuan’s Ph.D. dissertation at Korea University. The authors would like to thank Kyuho Kang, Dukpa Kim, Jinill Kim, Jinho Bae, and the seminar participants at Korea University for their helpful comments and suggestions.
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1 Introduction

Since the mid-1980s, U.S. economy has stabilized remarkably. McConnell and Perez-Quiros (2000) and Kim and Nelson (1999) showed that a structural break in U.S. output volatility occurred in the first quarter of 1984. This phenomenon was labeled the Great Moderation and many previous studies have tried to explain the source of this moderation, including Clarida et al. (2000), Kahn, McConnell, and Perez-Quiros (2002), Stock and Watson (2002), Bernake (2004), Summers (2005), Dynan, Elmendorf, and Sichel (2006), Giannone, Lenza and Reichlin (2008), and Gali and Gambetti (2009). From these studies, several explanations for the source of the Great Moderation have been suggested: structural changes, better monetary policy, milder economic shocks (i.e., good luck), improved inventory management, and financial innovation.

Despite this body of previous research, to our knowledge no previous study has focused on the changes in the dynamics of macro variables such as consumption and output. However, Kim et al. (2004) found that structural breaks in volatility and the persistence of inflation occurred at about the same time as changes in output volatility, there may have been structural changes in the persistence (dynamics) of macro variables such as output and consumption. Campbell and Deaton (1989) argued that although the permanent income hypothesis (PIH) predicts the adjustment of consumption to permanent income, this adjustment is slower than predicted due to precautionary motives (i.e. excess smoothness of consumption). That is, consumers facing future income uncertainty will set aside part of their income as a buffer against income fluctuations and thus it would be natural to expect a reduction in income volatility to encourage consumers to adjust their consumption so that it is in line with their permanent income more quickly.

Why are dynamics changes and volatility in consumption and output worth investigating? Morley (2007) argued that a slow adjustment of consumption to permanent income is suggestive of habit formation in consumer preferences or the presence of a precautionary
savings motive. Habit formation in consumer preferences can help explain puzzling economic phenomena, including the asset-pricing anomalies and the gradual response of consumption and inflation to monetary policy. From this point of view, a change in the persistence of consumption may indicate a change in habit formation and this may affect the response of consumption to monetary policy. Hence, to track the changes in the dynamics of consumption and output during Great Moderation would be valuable in allowing a more effective evaluation of monetary policy performance.

The purpose of this paper is to examine whether the dynamics of U.S. consumption and output has changed over the last three decades due to Great Moderation. To this end, we focus on the relationship between the Great Moderation and the change in the dynamics of consumption and output. Following Morely (2007), we employ an unobserved component (UC) model in order to investigate the long-run dynamics change in U.S. consumption and output from 1954 to 2013 over the two subsamples based on the 1984, the beginning of the Great Moderation.

We find that, since 1984, the volatility of permanent and transitory shocks to income and consumption have reduced substantially, which is consistent with the findings of previous studies. Our results also show that the speed of adjustment of consumption to permanent income has increased greatly due to the reduction in uncertainty about future income and the speed of the adjustment of output to its long-run level also has been faster, which may be due to improvement in the information technology industry.

The structure of this paper is as follows. Section 2 outlines the implications of changes in the dynamics of consumption and output. In Section 3 we model the dynamics of consumption and output based on a UC model and propose a bivariate model where consumption and output are considered in a unified framework. In Section 4, the estimation results are presented and several implications are discussed. A summary and concluding remarks are provided in Section 5.
2 The implications of change in consumption and output dynamics

2.1 Precautionary savings and consumption dynamics

The permanent income hypothesis (PIH) implies that a representative consumer alters his consumption according not to his current income but to his permanent income. Hall (1978) shows that a rational representative agent’s consumption follows a random walk under the PIH. Cochrane (1994) reported that aggregate income is largely predictable and the PIH describes aggregate consumption behavior well. Campbell and Deaton (1989), however, point out that permanent income is much more volatile than consumption and that the PIH does not explain the smoothness of consumption. They argue that the slow adjustment of consumption to changes in income results in the smoothness of consumption. Morely (2007) employed a new approach to the estimation of cointegrated systems and found that permanent income appears to be relatively volatile with the slow adjustment of consumption over time and thus the standard PIH appears to be rejected. His results suggest alternative theories of consumption behavior such as habit formation or precautionary savings.

Why do consumers adjust their consumption to their income so slowly? Although there have been a number of studies investigating the reasons behind the non-instantaneous adjustment of consumption to permanent income, one of the most likely explanations is a precautionary saving motive. The buffer-stock saving model of Deaton (1991), Carroll, Hall, and Zeldes (1992), and Carroll (2001) considered the idea of the PIH that households attempt to maximize utility by using savings as a buffer against income fluctuations (which is the core idea of Friedman, 1957) but modifies the PIH to allow for the precautionary saving motive, impatience, and restrictions on borrowing. The buffer-stock theory postulates that an impatient consumer facing income uncertainty and liquidity constraints tends to engage in buffer-stock saving behavior where he sets up a target wealth-to-permanent-income ratio and if his actual wealth-to-permanent-income ratio is lower than the target due to a positive
shock to permanent income, he would build wealth by saving; the reverse is true for negative shocks.

Carroll (2009) stated that, in theory, if consumers are impatient and subject to transitory and permanent shocks, the optimal marginal propensity to consume out of permanent shocks (MPCP) is strictly less than one, because buffer-stock savers compare the actual wealth-to-permanent income ratio to the target wealth-to-permanent-income ratio. Carroll explained that optimizing agents facing an unexpected increase in their permanent income adjust their consumption to a level lower than the change in permanent income and set aside part of the unexpected permanent income as precautionary savings in the short run. Eventually, however, consumption must fully adjust to permanent income in the long run due to budget constraints.

One of crucial aspects of precautionary savings is how they are affected by income uncertainty. Carroll (1994) found that consumers with greater income uncertainty tend to have lower current consumption. Using panel data from the National Longitudinal Survey (NLS), Kazarosian (1997) showed that income uncertainty is positively correlated with the target wealth-to-permanent-income ratio. Based on this, greater income uncertainty tends to result in a stronger precautionary motive and thus we conjecture that a change in the precautionary motive due to the significant reduction in the volatility of U.S. income since 1984 has occurred and this change has resulted in changes in consumption dynamics.

Then how can the structural changes in consumption dynamics be measured? Following Carroll (2009), suppose log consumption can be represented as follows:

$$c_t = y_t^p + z_{ct},$$  \hspace{1cm} (1)$$

where $c_t$ denotes the logarithm of consumption; $y_t^p \equiv \log Y_t^P$ is the logarithm of permanent income and $z_{ct}$ is the transitory component of consumption that contains precautionary savings which we assume to be stationary. Suppose permanent income follows a random
walk process:

\[ y_t^P = \mu_{y_t} + y_{t-1}^P + v_t^P, \]  

where \( \mu_{y_t} \) is the growth rate of permanent income. We assume that the shock to permanent income, \( v_t^P \), follows a normal distribution: \( v_t^P \sim N \left( 0, \sigma_{v_t}^2 \right) \). To make the model tractable as in Morley (2007), we assume that the transitory component of consumption follows an AR(2) process:

\[ z_{ct} = \phi_{c1} z_{ct-1} + \phi_{c2} z_{ct-2} + c_{ct}, \]  

where the shock to transitory consumption follows a normal distribution \( c_{ct} \sim N(0, \sigma_{c_t}^2) \).

Carroll (2009) reported that optimizing consumers slowly adjust their consumption in response to changes in permanent income due to precautionary saving and this results in a negative correlation between the shocks to permanent income and transitory consumption. In other words, in above equations, \( v_t^P \) is negatively correlated with \( c_{ct} \). As a result, we can look further into the future consumption in response to a permanent income shock. Consider the \( j \)-period ahead consumption response to permanent income shock:

\[ \frac{\partial c_{t+j}}{\partial y_t^P} = 1 + \psi_{c j} \rho_{v_t c_t} \frac{\sigma_{c_t}}{\sigma_{v_t}}, \quad j = 0, 1, 2, \ldots \]  

where \( \psi_{c j} = \frac{\partial z_{ct+j}}{\partial c_{ct}} \), \( \psi_{c 0} = 1 \) and \( \rho_{v_t c_t} \) is the correlation between \( v_t^P \) and \( c_{ct} \): \( \text{Corr} (v_t^P, c_{ct}) = \rho_{v_t c_t} \). According to the buffer-stock theory, when there is positive shock to permanent income, a precautionary saving consumer sets aside part of the unexpected permanent income as buffer against income fluctuation in the short run, which indicates that the marginal propensity to consume out of permanent income (MPCP) is strictly less than one:

\[ \frac{\partial c_{t+j}}{\partial y_t^P} = \frac{\partial y_{t+j}^P}{\partial c_{ct}} + \frac{\partial y_{t+j}^P}{\partial v_t} = \frac{\partial y_{t+j}^P}{\partial c_{ct}} + \frac{\partial z_{t+j} \partial e_{ct}}{\partial v_t} = 1 + \psi_{c j} \rho_{v_t c_t} \frac{\sigma_{c_t}}{\sigma_{v_t}}. \]

For the specific derivation of \( \frac{\partial c_{t+j}}{\partial y_t^P} \), refer to Appendix C for a simulation of the consumption adjustment path.
\[ \frac{\partial c_t}{\partial v_t} = 1 + \rho_{v_t e_t} \frac{\sigma_{v_t}}{\sigma_{v_t}} < 1, \]

which implies that:

\[ \text{Corr}(v_t^p, e_t) = \rho_{v_t e_t} < 0. \]  

The magnitude of the negative correlation \( \rho_{v_t e_t} \) approximates the percentage of increased permanent income which is set aside as precautionary saving. Moreover, since \( \lim_{j \to \infty} \frac{\partial c_{t+j}}{\partial v_t} = 1 \), consumption fully adjusts to permanent income in the long run.\(^2\)

Equation (4) indicates that the consumption adjustment path for the shock to permanent income depends on two parameters: the negative correlation between the shock to permanent income and the shock to transitory consumption, \( \rho_{v_t e_t} \), and the Wold representation parameters of transitory consumption, \( \{\psi_{ij}\}_{j=1}^\infty \). The later decides the duration of adjustment of consumption in response to the change in permanent income. As transitory consumption become more persistent, it takes longer for consumption to fully adjust to the change in permanent income.

In order to understand the implications of these parameters in the consumption adjustment path for the shock to permanent income, we construct a simulation study based on equations (1) - (4). For simplicity, we assume that the relative ratio of standard error \( \frac{\sigma_{v_t}}{\sigma_{v_t}} \) to be 1 and that transitory consumption follows an AR(1) process. Thus equation (3) is simplified by setting \( \phi_{c1} = 0 \):

\[ z_{ct} = \phi_{c1} z_{ct-1} + e_{ct}. \]  

Note that \( \psi_{c2} = \phi_{c1}^j. \(^3\) In the simulation study, we consider various values for \( \rho_{v_t e_t} \) and \( \phi_{c1} \).

\(^2\)The stationarity of \( z_{ct} \) implies that \( \lim_{j \to \infty} \psi_{c,j} = 0 \).

\(^3\)When \( z_{ct} = \phi_{c1} z_{ct-1} + e_{ct} \), \( z_{ct} \) has the following Wold representation:

\[ z_{ct} = e_{ct} + \phi_{c1}^1 e_{ct-1} + \phi_{c1}^2 e_{ct-2} + \cdots = \psi_{c0} e_{ct} + \psi_{c1} e_{ct-1} + \psi_{c2} e_{ct-2} + \cdots = \psi_e (L) e_t \]
Figure 1 plots the adjustment path of consumption given a one-time shock to permanent income in two situations. The top panel summarizes the persistence parameters given the values of $\rho_{\psi e_c}$. We find evidence that the more persistent transitory consumption is, the longer it takes for consumption to fully adjust to the new permanent income level. The bottom panel displays different correlations for different values of $\phi_{c1}$. The larger the magnitude of $\rho_{\psi e_c}$, the larger the fraction of instantaneous precautionary savings in the presence of a one-unit shock to permanent income.

The simulation study above suggests that, as volatility in output has decreased significantly since 1984, income uncertainty has reduced and consumers have had less incentive to engage in precautionary saving; This fall in precautionary savings has resulted in a reduction in the magnitude of the negative correlation between the shock to permanent income and the shock to transitory consumption. Moreover, less precautionary savings also may reduce the persistence of transitory consumption because a more predictable income allows consumers to adjust their consumption to match their permanent income more closely and thus the persistence of transitory consumption decreases. In sum, we conjecture that reduced income uncertainty has changed the dynamics of consumption since 1984. We test this conjecture in Section 4.

2.2 Technology diffusion and output dynamics

A number of studies decompose real output into a trend component and a cyclical component (stationary process) where the former is driven by technology and the later by demand shocks. Beveridge and Nelson (1981), Harvey (1985), Clark (1987), Campbell and Mankiw (1987), and Morley (2007) assume that the trend component follows a random walk process. Lippi and Reichlin (1994), however, point out that imposing a random walk restriction on the trend component implies that technical innovations are adopted by different firms si-

\[ \psi_c(L) = \psi_{c0} + \psi_{c1}L + \psi_{c2}L^2 + \cdots \]

where
\[ \psi_{c0} = \phi_c. \]
multaneously, but this does not take into account typical property of technology diffusion.\textsuperscript{4} Incorporating the fact that different firms absorb technical innovation differently, they propose a more dynamic trend that follows an ARIMA process where the trend has a serial correlation in its difference:

\begin{align}
y_t &= \tau_t + z_{yt}, \quad (8) \\
\tau_t &= \mu + \tau_{t-1} + \psi_r(L) \eta_t, \quad (9) \\
z_{yt} &= \psi_y(L) \varepsilon_{yt}, \quad (10)
\end{align}

where $y_t$ is a real output, $\tau_t$ is the trend component of output, $z_{yt}$ is the cyclical component of output, $\eta_t$ denotes the shock to technology, $\varepsilon_{yt}$ denotes the demand shock, and $\varepsilon_{yt}$ is assumed to be independent of technology shock $\eta_t$. If technology diffusion is instantaneous, $\psi_r(L) \eta_t$ is white noise and there is no serial correlation in $\Delta \tau_t$; otherwise, the longer technology diffusion takes, the larger the serial correlation in $\Delta \tau_t$.\textsuperscript{5} Ma and Wohar (2013) found that the dynamics in the permanent component are statistically significant and distinct from those of transitory component, supporting the gradual technology diffusion proposed by Lippi and Reichlin (1994).

From this point of view, it is worth examining how the speed of technology diffusion affects output dynamics. Morely, Nelson and Zivot (2003) and Morley (2007) found that, with the decomposition of output into a random walk trend component and a transitory component,

\textsuperscript{4}A well-known feature of technology diffusion is its S-shaped diffusion path. Schumpeter (1943) is the first to refer to S-shaped technology diffusion. Schumpeter emphasizes the importance of two features of technology: learning inside firms and diffusion across firms. Griliches (1957) studied the use of hybrid seed coin in the United States, and found that the process of adopting and distributing a particular invention in different markets has a typical S-shaped pattern because any innovation is absorbed by different firms throughout the economy.

\textsuperscript{5}Except for technology diffusion, there is another strand of papers supportive of a more dynamic permanent trend component. In their influential work, Kydland and Prescott (1982) propose the "time-to-build" effect, which features the non-instantaneous construction of new productive capital. Since the construction of new productive capital takes several periods (i.e., the short-run elasticity of capital is low), income does not immediately adjust to a change in permanent income.
there is a negative correlation between shocks to the random walk component and the shocks to transitory component. Where does this negative correlation come from?

Using Beveridge Nelson decomposition, we can decompose $\tau_t$ in equation (8) into a random walk component $(x_{yt})$ and a stationary component $(\psi^*_\tau (L) \eta_t)$ as follows:\footnote{According to Beveridge-Nelson decomposition, if $\sum_{j=1}^{\infty} |\psi_j| < \infty$, then $\psi (L)$ can be decomposed into a permanent and a transitory components as follows: $\psi (L) = \psi (1) - \psi^* (L) (1 - L)$ where $\psi (1) = \sum_{j=0}^{\infty} \psi_j$, $\psi^* (L) = \sum_{j=0}^{\infty} \psi^*_j L^j$, and $\psi^*_j = \sum_{k=j+1}^{\infty} \psi_k$.}

\begin{align*}
\tau_t &= x_{yt} - \psi^*_\tau (L) \eta_t, \quad (11) \\
x_{yt} &= \mu + x_{yt-1} + \psi^*_\tau (1) \eta_t, \quad (12)
\end{align*}

where $\psi^*_\tau (L) = \psi^*_\tau 0 + \psi^*_\tau 1 L + \psi^*_\tau 2 L^2 + \cdots$, $\psi^*_\tau j = \sum_{i=j+1}^{\infty} \psi^*_{\tau i}$. Here, we specify that $x_{yt}$ is the long-run level of output and $-\psi^*_\tau (L) \eta_t$ is the transitory component of productivity driven by the technology shock. The basis of equations (11) and (12) is that the shock to technology is decomposed into a shock to the random walk component and a shock to the transitory component and, in the case of the non-instantaneous diffusion of technology, the transitory effect of the technology shock in the permanent component $\tau_t$ would be absorbed by the cyclical component and thus both the random walk and the cyclical components contain the technology shock. In other words, if technology is adopted by all firms instantaneously, $-\psi^*_\tau (L)$ becomes 0. On the other hand, if technology diffusion is not instantaneous, $\tau_t$ is not a random walk but follows a process which has serial correlations in difference.

Combining equations (8) and (10) with equations (11) and (12), we can rewrite $y_t$ as the sum of a random walk plus a transitory component:
The equations (13) - (15) can be rewritten in the form of ARIMA as follows:

\[ y_t = x_{yt} + \tilde{z}_{yt}, \]  
\[ x_{yt} = \mu + x_{yt-1} + \psi_{r}(1) \eta_t, \]  
\[ \tilde{z}_{yt} = z_{yt} - \psi_{r}^*(L) \eta_t, \]

where \( \psi_{r}(1) \eta_t \) is the shock to technology, \( \psi_{y}(L) e_{yt} \equiv \psi_{y}(L) \varepsilon_{yt} - \psi_{r}^*(L) \eta_t \), and the joint distribution of the shock to technology and the shock to the transitory component follows normal distribution:

\[
\begin{bmatrix}
\psi_{r}^* e_{yt} \\
\varepsilon_{yt}
\end{bmatrix}
\sim
N\left(
\begin{bmatrix}
0 \\
0
\end{bmatrix},
\begin{bmatrix}
\sigma_{\psi_{r} e_{yt}}^2 & \rho_{\psi_{r} e_{yt}} \sigma_{\psi_{r}} \sigma_{\varepsilon_{yt}} \\
\rho_{\psi_{r} e_{yt}} \sigma_{\psi_{r}} \sigma_{\varepsilon_{yt}} & \sigma_{\varepsilon_{yt}}^2
\end{bmatrix}
\right)
\]

where \( \rho_{\psi_{r} e_{yt}} \) denotes the correlation between the shock to the trend component and the shock to transitory component of output. Suppose that technology diffusion is instantaneous, i.e. \( \psi_{r}(1) = 1 \), then \( \psi_{r}^* (L) = 0 \). Otherwise, when technology diffusion is not instantaneous, the shock to the random walk component decreases while that to the transitory component increases, resulting in a negative correlation between these two shocks. In other words, \( \rho_{\psi_{r} e_{yt}} < 0 \) due to \( \psi_{r}^* (L) \eta_t \) in equation (15). Stock and Watson (1988) explained that real shocks such as technology shocks immediately shift the long-run path of output upward, leaving actual productivity below the long-run path of productivity. Thus, when we decompose the real output into a random walk component and a transitory component, the transitory component consists of the original business cycle and the temporal productivity adjustment toward the long-run level and this transitory adjustment would be the source of the negative correlation between
the random walk and the transitory component of real GDP\textsuperscript{7}. Morley et al (2003) show that
the estimated correlation in a univariate UC model framework is around -0.9.

In order to determine the adjustment path of output to its long-run level, we derive the
future output path in response to a one-unit shock to technology as follows\textsuperscript{8}:

\[ \frac{\partial y_{t+j}}{\partial \nu_t} = 1 + \tilde{\psi}_{ij} \rho_{\nu^*, e_y} \sigma_{e_y}. \]  
\text{(19)}

The adjustment path of output to its long-run level in equation (19) depends on two para-
parameters: the correlation between the shock to the random walk component and the shock to
the transitory component \( \rho_{\nu^*, e_y} \) and the persistence parameters of the transitory output \( \tilde{\psi}_{yj}. \)
We conjecture that as the result of new developments in the information technology industry
such as internet and computer, inventory management has improved (which is one of the
main sources of the Great Moderation), contributing to the faster diffusion of technology.
This diffusion of technology has resulted in a weaker negative correlation \( \rho_{\nu^*, e_y} \) and thus,
since 1984, the adjustment of output to its long-run level has been more rapid. Moreover,
the greater stability of output also has induced lower persistence of transitory component
of output. Recently Comin and Hobijn (2010) show by using data on the diffusion of 15
technologies in 166 countries over the last two centuries that newer technologies have been
adopted faster than old ones. In sum, since 1984, the speed of the technology diffusion has
been faster due to the improvement in information and technology industry such as internet
and computer and it has resulted in lower magnitude of negative correlation between the
shock to random component and the shock to transitory component of output and lower
persistence of transitory component. Consequently, the adjustment of output to its long-run
level has been faster as described in equation (19).

\textsuperscript{7}Morley (2007) states that since it takes a few quarters for the effects of the productivity to fully prop-
agate due to time-to-build effect (Kydland and Prescott 1982), movements in the permanent and transitory
components of real GDP should be negatively correlated.

\textsuperscript{8}The derivation of equation (19) is exactly the same as the case of consumption in the previous subsection
2.1.
3 Model

In line with Stock and Watson (1988) and Morely (2007), we construct a bivariate unobserved component model using the long-run relationship between aggregate consumption and aggregate output. Considering the structural break in the Great Moderation, we use the equations (1), (2), (3), (16), (17), and (18) and rewrite a bivariate model with a dummy \( S_t \) as follows:

\[
\begin{align*}
  c_t &= x_t + z_{ct}, \\
  y_t &= a_s + b x_t + z_{yt}, \\
  x_t &= \mu_s + x_{t-1} + v_t, \\
  z_{ct} &= \phi_{c1,s} z_{ct-1} + \phi_{c2,s} z_{ct-2} + e_{ct}, \\
  z_{yt} &= \phi_{y1,s} z_{yt-1} + \phi_{y2,s} z_{yt-2} + e_{yt}, \\
  \begin{bmatrix} v_t \\ e_{ct} \\ e_{yt} \end{bmatrix} &\sim iid \mathcal{N} \left( \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, Q_S \right), \\
  Q_S &= \begin{bmatrix}
    \sigma_{v,i}^2 & \rho_{vc,i} \sigma_{v,i} \sigma_{c,i} & \rho_{vy,i} \sigma_{v,i} \sigma_{y,i} \\
    \rho_{vc,i} \sigma_{c,i} \sigma_{v,i} & \sigma_{c,i}^2 & \rho_{cy,i} \sigma_{c,i} \sigma_{y,i} \\
    \rho_{vy,i} \sigma_{c,i} \sigma_{y,i} & \rho_{cy,i} \sigma_{c,i} \sigma_{y,i} & \sigma_{y,i}^2
  \end{bmatrix} \\
  S_t &= \begin{cases} 
    0 & \text{for } t \leq 1983Q4 \\
    1 & \text{otherwise}
  \end{cases}
\end{align*}
\]

where \( c_t \) and \( y_t \) are the logarithms of aggregate consumption and income, respectively, and they share a common stochastic trend (i.e. the permanent income) \( x_t \); The drift term \( \mu_{S_t} \) represents the long-run growth rate of economy; \( z_{c,t} \) and \( z_{y,t} \) are the transitory components.

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\(^9\)Following Morley et al. (2003) and Morely (2007), we approximate equation (18) with an AR(2) stationary process.
of consumption and income. The transitory components of income and consumption each follows an AR(2) process, which allows for a hump-shaped impulse-response function as in Morely et al. (2003). As outlined in Section 2, the negative correlation between the shock to the permanent component of output and the shock to transitory consumption, $\rho_{yc} < 0$, implies the existence of precautionary saving and $\rho_{yg} < 0$ implies technology diffusion. In accordance with the structural break time or the starting point of the Great Moderation in Kim and Nelson (1999), we divide the sample period into two subsamples. The former sample spans from the 1954:Q1 to the 1983:Q4 and the latter from 1984:Q1 to 2007:Q4, which coincides with the Great Moderation period.

4 Estimation Results

4.1 Data

Following Morley (2007), we construct real consumption and real output quarterly data from 1954:Q1 to 2007:Q4. For real output data we use 100 times the natural logarithm of U.S. per capita real GDP. The per capita real GDP and per capita real consumption are downloaded from the FRED website. The sample is divided into two subsamples based on the starting point of the Great Moderation: 1954:Q1 - 1983:Q4 and 1984Q1 - 2007Q4.

For the consumption data, we use 100 times the natural logarithm of U.S. per capita real consumption of non-durables and services. By dividing the nominal per capita consumption of non-durables with the chain-type price index, we get the per capita real consumption of non-durables. We construct the per capita real consumption of services exactly the same way. One aspect of the consumption data that should be noted is that, as pointed out in Whelan (2002), chain-type real data lack additivity. Following Whelan (2002)’s methodology,

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10 The state-space model for the equations (20) - (25) is outlined in Appendix C.
11 Morley (2007) points out that $\rho_{yc} < 0$ may also imply habit formation and attributes $\rho_{yg} < 0$ to the "time-to-build" effect.
12 The underlying data are seasonally adjusted and are available from the St. Louis Fed website (http://www.stls.frb.org/fred/).
we construct the consumption of non-durables and services. Details of the construction of consumption data are provided in Appendix A.

4.2 Estimation: Change in the Dynamics of Consumption

The estimation results for the UC model of equations (20) - (26) without a dummy is reported in the first column of Table 1. The basic model without dummy is exactly the same as the UC model of Morley (2007), except that we assume the long-run level of consumption as permanent income while Morley assumes that of real GDP as permanent income. Our results are consistent with Morley’s founding. The estimated correlation ($\hat{\rho}_{vc}$) between the shock to permanent income and the shock to transitory consumption is $-0.993$, and the estimated correlation ($\hat{\rho}_{vy}$) between the shock to permanent income and the shock to transitory income is $-0.878$. The persistence in transitory consumption appears to be higher than that of transitory income.

Table 2 shows the results of the UC model with a dummy. The estimated parameters with their standard errors for the first subsample is shown in the second column and the estimated parameters for the second subsample (Great Moderation Period) is shown in the third column. The estimated standard deviation of the shock to transitory consumption is 1.181 for the period of 1953:Q1 - 1983:Q4 and 0.464 for the period of 1984:Q1 - 2007:Q4. The estimated correlation between the shock to permanent income and the shock to transitory consumption is $-0.993$ for the period of 1953Q1 - 1983Q4 and $-0.904$ for the period of 1984:Q1 - 2007:Q4 and both correlations are statistically significant at the 1% level. In order to investigate whether the magnitude of the correlation changed significantly, we conduct the Wald test. Table 3 shows the test results; the null hypothesis that $\rho_{vc,0} = \rho_{vc,1}$ is rejected at the 5% level ($p - value = 0.026$). In addition, the estimated persistence parameters for transitory consumption are 0.854 for $\hat{\phi}_{c1,0}$ and 0.075 for $\hat{\phi}_{c2,0}$ for the period of 1953:Q1 - 1983:Q4 and 0.777 for $\hat{\phi}_{c1,1}$ and 0.04 for $\hat{\phi}_{c2,1}$ for the period of 1984:Q1-2007:Q4. These results indicate that the persistence of transitory consumption has decreased since 1984. In
order to examine whether the persistence of transitory consumption has changed or not, we
do the Wald test on the null hypothesis that $\phi_{c1,0} + \phi_{c2,0} = \phi_{c1,1} + \phi_{c2,1}$. The hypothesis is
strongly rejected as shown in Table 2.

In order to investigate the speed of adjustment of consumption to the new long-run level
of output in response to a shock to permanent income, we simulate the adjustment path
of consumption when there is a one-unit shock to the common stochastic trend. Figure 2a
displays the simulation results for the consumption adjustment. Given the estimated param-
ters, we plot the adjustment path with the equation (4) along with the one-standard deviation
confidence band (1-SD band hereafter) using the Delta method. As illustrated in Figure 2a,
consumption adjusts to the new level of permanent income faster for the period 1984:Q1 -
2007:Q4 than for the period of 1953:Q1-1983:Q4. We measure the speed of adjustment for
consumption in terms of the half-life of consumption to fully adjust to the new permanent
income level; that is, the time taken for the half-adjustment of consumption to a shock of
one unit to permanent income. The one-SD band for the half-life of consumption adjustment
is 8-13 quarters in the years before 1984, but it becomes 4-6 quarters in the period since
1984. The Wald test of the null hypothesis
$|\rho_{vc,0}\sigma_{v,0} = \rho_{vc,1}\sigma_{v,1}|$ is rejected at the 5% level
as shown in Table 3. Given that $\frac{\hat{\rho}_{vc,0}}{\sigma_{v,0}} = 0.713$ and $\frac{\hat{\rho}_{vc,1}}{\sigma_{v,1}} = 0.717$, equation (4) for the speed
of the adjustment of consumption to permanent income implies that since 1984, the quicker
adjustment of consumption to permanent income has resulted from a reduction of negative
correlation between the shock to permanent income and the shock to transitory consumption
and the decrease in the persistence of transitory consumption. As described in Section 2, we
would like to interpret this to mean the reduction in income uncertainty during the Great
Moderation period led to lower precautionary savings and the lower persistence of transi-
tory consumption, and thus led to the more rapid adjustment of consumption in response to
the shock to permanent income. Consequently, we suggest that the Great Moderation has
contributed to the change in the dynamics of consumption since 1984.
4.3 Estimation: Changes in the Dynamics of Output

The estimated standard deviation of the shock to the permanent component of output is 1.656 for the period of 1953:Q1 - 1983:Q4 and 0.647 for the period of 1984:Q1 - 2007:Q4, implying that the variance in long-run output fluctuation has reduced to 1/6 of previous level. The estimated standard deviation of the shock to the transitory component of output has reduced from 1.307 to 0.294. These results confirm the earlier findings of Kim and Nelson (1999) and McConnell and Quiros (2000).

The estimated correlation between the shock to permanent income and the shock to transitory income is \(-0.855\) for the period of 1953:Q1-1983:Q4 and \(-0.899\) for the period of 1984:Q1-2007:Q4 and both correlations are statistically significant at the 1% level. In order to investigate whether the magnitude of the correlation changed significantly, we conduct the Wald test. Table 3 summarizes the test result; the null hypothesis that \(\rho_{vy,0} = \rho_{vy,1}\) is not rejected (\(p - value = 0.630\)). This result implies that a structural change in the correlation between the shock to permanent income and the shock to transitory income since 1984 is uncertain.

The estimated persistence parameters for transitory output are 0.652 for \(\hat{\phi}_{y1,0}\) and 0.045 for \(\hat{\phi}_{y2,0}\) for 1953:Q1-1983:Q4 and 0.500 for \(\hat{\phi}_{y1,1}\) and \(-0.186\) for \(\hat{\phi}_{y2,1}\) for 1984:Q1 - 2007:Q4. The persistence of transitory output thus appears to have decreased greatly since 1984. In order to examine whether the persistence of transitory output has changed or not since 1984, we construct the Wald test for the null hypothesis \(\phi_{y1,0} + \phi_{y2,0} = \phi_{y1,1} + \phi_{y2,1}\); the null hypothesis is rejected at the 5% level as shown in Table 3. The reduced persistence of transitory output possibly implies a “Good policy” story for the source of the Great Moderation.

In order to investigate the changes of adjustment speed of output to the long-run level of output, we simulate the adjustment path of output when there is a one-unit shock to the common stochastic trend. Figure 2b presents the simulation results. Output appears to adjust to the new long-run level of output more quickly for the period of 1984:Q1-2007:Q4.
than for the period of 1953:Q1-1983:Q4. The 1-SD band of the full adjustment of output to its long-run level has reduced from 14-16 quarters to 5-6 quarters. The Wald test indicates that the null hypothesis \( \rho_{vy,0} \frac{\sigma_{x,0}}{\sigma_{v,0}} = \rho_{vy,1} \frac{\sigma_{x,1}}{\sigma_{v,1}} \) is rejected (\( p-value = 0.123 \)).

Given similar estimations for the correlations \( \rho_{vy,0} \) and \( \rho_{vy,1} \), equation (19) indicates that if output adjusted to the new long-run level of output more quickly after 1984, the main reasons are both the reduction in the persistence of transitory output and the decrease in the ratio of the standard deviation \( \frac{\sigma_x}{\sigma_v} \), which changed from 0.789 to 0.454 between the two subsample periods.

Therefore, these results suggest that the reduction in output uncertainty reduced both the persistence of transitory output and the ratio of the standard deviation of the shock to the transitory component to that to the permanent component; From which we conjecture that the development of information technology led to a more rapid adjustment of output to the new long-run level of output in response to a shock to permanent income.

5 Conclusions

Since 1984, the volatility of U.S. real GDP has reduced significantly and this phenomenon, known as the Great Moderation, has received a great deal of attention. A number of studies have addressed the sources of the Great Moderation. To our knowledge, however, no previous study has tried to examine whether this reduction in volatility affected the dynamics of consumption and output during the Great Moderation period. For example, the reduction in output uncertainty tends to reduce precautionary saving and thus change consumers’ behavior, while improvements in the information technology industry may quicken technology diffusion and decrease the persistence of the transitory component of output.

This paper examines whether there has been a structural change in the dynamics of consumption and output during the Great Moderation as a result of the significant reduction in output volatility. From the simulation study, we find that the reduction in precautionary sav-
ing due to more stable income tends to induce a weaker negative correlation between the shock to the permanent component of income and the shock to the transitory consumption, as well as a lower persistence of transitory consumption; both of them cause consumption to adjust more quickly to the long-run level of income. Furthermore, development in the information technology industry may speed up technology diffusion and better inventory management, resulting in the lower persistence of the transitory component of output. Eventually, these may contribute to the more rapid adjustment of output to new long-run level of output over the Great Moderation period.

In our empirical study, we estimate a bivariate UC model which is similar to that of Morley (2007). Our results for U.S. consumption and output from 1953:Q1 to 2007:Q4 show that there has been a significant reduction in the volatility of U.S. real GDP, which confirms previous studies, and consumption adjust to the long-run level of income faster during the Great Moderation, due to the weaker negative correlation between permanent income and transitory consumption and the lower persistence of transitory consumption. Moreover, we find that the speed of output adjustment to the long-run level of output increased during the Great Moderation due to the lower persistence of transitory output. We conjecture that more rapid technology diffusion has contributed to the quicker adjustment of income, while changes in the negative correlation between the shock to the random walk component and the shock to the transitory component of output during the Great Moderation was not certain.

As pointed out in Morley (2007), the slow adjustment of consumption to permanent income is suggestive of habit formation in consumers or the presence of precautionary saving; the suggestion of habit formation in consumer preferences can help explain puzzling economic phenomena, including asset-pricing anomalies and the gradual response of consumption and inflation to monetary policy. Based on these results, this paper highlights the implications of changes in the dynamics of consumption and output over the Great Moderation period and suggests the need for further research on the relationship between changes in the dynamics of consumption and output and monetary policy during the Great Moderation.
Appendix A: Data construction

We follow ? to construct the real per capita consumption of non-durables and services as follows. Denote personal consumption expenditure per capita on nondurable goods as $N_1(t)$ and personal consumption expenditures per capita on Services as $N_2(t)$ and the corresponding chain-type price index as $p_1(t)$ and $p_2(t)$. Then calculate the real per capita consumptions by dividing the nominal values with the price index:

$$q_i(t) = \frac{N_i(t)}{p_i(t)}, \quad i = 1, 2.$$  

Next, use the chain-type quantity index for per capita consumption of non-durables and services which can be calculated using the following Fisher approximation:

$$\frac{Q(t)}{Q(t-1)} = \sqrt{\frac{p_1(t) q_1(t) + p_2(t) q_2(t)}{p_1(t) q_1(t-1) + p_2(t) q_2(t-1)}} \times \sqrt{\frac{p_1(t-1) q_1(t) + p_2(t-1) q_2(t)}{p_1(t-1) q_1(t-1) + p_2(t-1) q_2(t-1)}}$$

The first term on the right side of the equation is called the Paasche index, which uses period $t$ prices as weight and the second term is the Laspeyrex index, which uses period $t-1$ prices as weight. The gross growth rate of the real aggregate at time $t$ is a geometric average of the Paasche and Laspeyrex index.
Appendix B: State-space model with a dummy

The state-space model is as follows:

\[
\begin{bmatrix}
  c_t \\
  y_t
\end{bmatrix} =
\begin{bmatrix}
  0 \\
  a_{st}
\end{bmatrix} +
\begin{bmatrix}
  1 & 1 & 0 & 0 & 0 \\
  b & 0 & 0 & 1 & 0
\end{bmatrix}
\begin{bmatrix}
  x_t \\
  z_{c,t} \\
  z_{c,t-1} \\
  z_{y,t} \\
  z_{y,t-1}
\end{bmatrix}
\]

\[
\dot{Y}_t = A_{st} + H\beta_t
\]

\[R = 0\]

\[
\begin{bmatrix}
  x_t \\
  z_{c,t} \\
  z_{c,t-1} \\
  z_{y,t} \\
  z_{y,t-1}
\end{bmatrix} =
\begin{bmatrix}
  \mu \\
  0 \\
  0 \\
  0 \\
  0
\end{bmatrix} +
\begin{bmatrix}
  1 & 0 & 0 & 0 & 0 \\
  0 & \phi_{c1,S_t} & \phi_{c2,S_t} & 0 & 0 \\
  0 & 0 & 1 & 0 & 0 \\
  0 & 0 & 0 & \phi_{y1,S_t} & \phi_{y2,S_t} \\
  0 & 0 & 0 & 1 & 0
\end{bmatrix}
\begin{bmatrix}
  x_t \\
  z_{c,t} \\
  z_{c,t-1} \\
  z_{y,t} \\
  z_{y,t-1}
\end{bmatrix}
\]

\[
\begin{bmatrix}
  1 & 0 & 0 \\
  0 & 1 & 0 \\
  0 & 0 & 0 \\
  0 & 0 & 1 \\
  0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
  v_t \\
  e_{ct} \\
  e_{yt}
\end{bmatrix}
\]

\[
\beta_t = \bar{\mu}_{S_t} + F\beta_{t-1} + IE_t
\]

\[Cov[e_t] = Q_{S_t}\]

where \(Q_{S_t}\) is given in (26).
Appendix C: Simulation of the adjustment path

Here, we will describe the simulation of Figure 2 based on the estimates given in Table 1. The adjustment paths of consumption and output to their long-run levels are given in (4) and (19). We rewrite the adjustment path of consumption and output to a one unit permanent shock as follows:

\[
\frac{\partial c_{t+j}}{\partial v_t} = \frac{\partial x_{t+j}}{\partial v_t} + \frac{\partial z_{c,t+j}}{\partial e_{ct}} \frac{\partial e_{ct}}{\partial v_t}
\]
\[
\frac{\partial y_{t+j}}{\partial v_t} = \frac{\partial b_{x_{t+j}}}{\partial v_t} + \frac{\partial z_{g,t+j}}{\partial e_{yt}} \frac{\partial e_{yt}}{\partial v_t}
\]

The first two terms in the right side of equation are obvious. Since \(x_t\) follows a random walk process, \(\frac{\partial x_{t+j}}{\partial v_t} = 1\). Also \(\frac{\partial z_{c,t+j}}{\partial e_{ct}}\) and \(\frac{\partial z_{g,t+j}}{\partial e_{yt}}\) depend on the Wold coefficients of transitory consumption and output.

In order to get \(\frac{\partial e_{ct}}{\partial v_t}\) and \(\frac{\partial e_{yt}}{\partial v_t}\), we use the following Cholesky decomposition.

\[
\begin{bmatrix}
v_t \\
e_{ct} \\
e_{yt}
\end{bmatrix}
\sim i.i.d., N
\begin{pmatrix}
0 \\
0 \\
0
\end{pmatrix}, Q
\]

where

\[
Q = \begin{bmatrix}
\sigma_v^2 & \rho_{vc} \sigma_v \sigma_c & \rho_{vy} \sigma_v \sigma_y \\
\rho_{vc} \sigma_v \sigma_c & \sigma_c^2 & \rho_{cy} \sigma_c \sigma_y \\
\rho_{vy} \sigma_v \sigma_y & \rho_{cy} \sigma_c \sigma_y & \sigma_y^2
\end{bmatrix}
\]

By defining \(v_t^* = \frac{v_t}{\sigma_v}\), \(e_{ct}^* = \frac{e_{ct}}{\sigma_c}\), \(e_{yt}^* = \frac{e_{yt}}{\sigma_y}\), we can rewrite the original shock vector

\[
\begin{bmatrix}
v_t \\
e_{ct} \\
e_{yt}
\end{bmatrix}
\]
as a linear combination of these standardized shocks:

\[
\begin{bmatrix}
v_t \\
e_{ct} \\
e_{yt}
\end{bmatrix} =
\begin{bmatrix}
\sigma_v & 0 & 0 \\
0 & \sigma_c & 0 \\
0 & 0 & \sigma_y
\end{bmatrix}
\begin{bmatrix}
v_t^* \\
e_{ct}^* \\
e_{yt}^*
\end{bmatrix}
\]

(B-1)

where

\[
\begin{bmatrix}
v_t^* \\
e_{ct}^* \\
e_{yt}^*
\end{bmatrix} \sim \text{i.i.d.} \mathcal{N}
\left(
\begin{bmatrix} 0 \\ 0 \\ 0 
\end{bmatrix}, \Omega
\right)
\]

and \(\Omega = \begin{bmatrix} 1 & \rho_{vc} & \rho_{vy} \\ \rho_{vc} & 1 & \rho_{cy} \\ \rho_{vy} & \rho_{cy} & 1 \end{bmatrix}\) are the correlation matrix.

Suppose that the technology shock is the most exogenous and not is affected by the transitory consumption and output shocks, and suppose that the transitory output shock is the most endogenous; we can then decompose the three shocks into a linear combination of independent shocks. According to the Cholesky decomposition, we have a unique lower triangular \(P\) such that \(PP^T = \Omega\) and

\[
P = 
\begin{bmatrix}
1 & 0 & 0 \\
\rho_{vc} & \sqrt{1 - \rho_{vc}^2} & 0 \\
\rho_{vy} & \frac{1}{\sqrt{1 - \rho_{vc}^2}} (\rho_{cy} - \rho_{vc}\rho_{vy}) & \sqrt{\frac{1}{\rho_{vc}^2 - 1}} (\rho_{cy} - \rho_{vc}\rho_{vy})^2 - \rho_{vy}^2 + 1 \\
p_{11} & 0 & 0 \\
p_{21} & p_{22} & 0 \\
p_{31} & p_{32} & p_{33}
\end{bmatrix}
\]

(B-2)

The standardized shock vector

\[
\begin{bmatrix}
v_t^* \\
e_{ct}^* \\
e_{yt}^*
\end{bmatrix}
\]

can be represented as the product of \(P\) and a tri-
variate standard normal distribution:

\[
\begin{bmatrix}
\mathbf{v}_t^* \\
\mathbf{e}_{ct}^* \\
\mathbf{e}_{yt}^*
\end{bmatrix} =
\begin{bmatrix}
p_{11} & 0 & 0 \\
p_{21} & p_{22} & 0 \\
p_{31} & p_{32} & p_{33}
\end{bmatrix}
\begin{bmatrix}
\omega_{1t} \\
\omega_{2t} \\
\omega_{3t}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\omega_{1t} \\
\omega_{2t} \\
\omega_{3t}
\end{bmatrix} \sim i.i.d. \mathcal{N}
\begin{bmatrix}
0 \\
0 \\
0
\end{bmatrix},
\begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

Thus by combining (B-1) and (B-2) we can decompose into the linear combinations of those standard normal shocks:

\[
\begin{bmatrix}
\mathbf{v}_t \\
\mathbf{e}_{ct} \\
\mathbf{e}_{yt}
\end{bmatrix} =
\begin{bmatrix}
\sigma_v & 0 & 0 \\
0 & \sigma_c & 0 \\
0 & 0 & \sigma_y
\end{bmatrix}
\begin{bmatrix}
p_{11} & 0 & 0 \\
p_{21} & p_{22} & 0 \\
p_{31} & p_{32} & p_{33}
\end{bmatrix}
\begin{bmatrix}
\omega_{1t} \\
\omega_{2t} \\
\omega_{3t}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\sigma_v p_{11} \omega_{1t} \\
\sigma_c p_{21} \omega_{1t} + \sigma_c p_{22} \omega_{2t} \\
\sigma_y p_{31} \omega_{1t} + \sigma_y p_{32} \omega_{2t} + \sigma_y p_{33} \omega_{3t}
\end{bmatrix}
\]

Thus using the chain-rule and replace \(p_{ij}s\) in (B-2) we get the following:

\[
\frac{\partial \mathbf{e}_{ct}}{\partial \mathbf{v}_t} = \frac{\partial \mathbf{e}_{ct}}{\partial \omega_{1t}} \frac{\partial \omega_{1t}}{\partial \mathbf{v}_t} = \frac{\sigma_c}{\sigma_v} \rho_{vc}
\]

\[
\frac{\partial \mathbf{e}_{yt}}{\partial \mathbf{v}_t} = \frac{\partial \mathbf{e}_{yt}}{\partial \omega_{1t}} \frac{\partial \omega_{1t}}{\partial \mathbf{v}_t} = \frac{\sigma_y}{\sigma_v} \rho_{vy}
\]
References


# Table 1: The Estimates of the UC Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Full Sample</th>
<th>Pre 1984</th>
<th>Post 1984</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_{c1}$</td>
<td>0.8568***</td>
<td>0.854***</td>
<td>0.7769***</td>
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<td>[0.026]</td>
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<td>0.0464*</td>
<td>0.0747**</td>
<td>0.04</td>
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<tr>
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<td>[0.033]</td>
<td>[0.063]</td>
</tr>
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<td>$\phi_{y1}$</td>
<td>0.689***</td>
<td>0.6521***</td>
<td>0.4999***</td>
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<td>[0.048]</td>
<td>[0.065]</td>
<td>[0.133]</td>
</tr>
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<td>$\phi_{y2}$</td>
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<td>0.0454**</td>
<td>-0.1863**</td>
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<tr>
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<td>$\mu$</td>
<td>0.5294***</td>
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<td>[0.094]</td>
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<td>[0.066]</td>
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<td>1.1808***</td>
<td>0.4636***</td>
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<td>[0.028]</td>
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<td>0.294***</td>
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<td>0.6469***</td>
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<td>[0.09]</td>
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<td>0.8147***</td>
<td>0.7887***</td>
<td>0.6253***</td>
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<td>[0.062]</td>
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<td>-0.9928***</td>
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<td>-0.9039***</td>
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<tr>
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<td>[0.005]</td>
<td>[0.007]</td>
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<td>$\alpha$</td>
<td>17.806**</td>
<td>-4.7818</td>
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<td>[5.213]</td>
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<td>$b$</td>
<td>1.0328***</td>
<td>1.0559***</td>
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<tr>
<td></td>
<td>[0.007]</td>
<td>[0.005]</td>
<td></td>
</tr>
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<td>Null Hypothesis $H_0$</td>
<td>Pre 1984</td>
<td>Post 1984</td>
<td>Wald Test Statistics</td>
</tr>
<tr>
<td>-----------------------</td>
<td>----------</td>
<td>-----------</td>
<td>----------------------</td>
</tr>
<tr>
<td>$\phi_{c1,\text{pre}} + \phi_{c2,\text{pre}} = \phi_{c1,\text{post}} + \phi_{c2,\text{post}}$</td>
<td>0.9287</td>
<td>0.8168</td>
<td>10.685 ***</td>
</tr>
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<td>0.3136</td>
<td>5.8759 **</td>
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<td>$\sigma_{c,\text{pre}} = \sigma_{c,\text{post}}$</td>
<td>1.1808</td>
<td>0.4636</td>
<td>14.2608 ***</td>
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<td>1.3067</td>
<td>0.294</td>
<td>17.2687 ***</td>
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<td>1.6559</td>
<td>0.6469</td>
<td>24.7046 ***</td>
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<td>$\rho_{cy,\text{pre}} = \rho_{cy,\text{post}}$</td>
<td>0.7887</td>
<td>0.6253</td>
<td>0.7332</td>
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<td>$\rho_{vc,\text{pre}} = \rho_{vc,\text{post}}$</td>
<td>-0.9931</td>
<td>-0.9039</td>
<td>4.9675 **</td>
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<td>-0.899</td>
<td>0.2326</td>
</tr>
<tr>
<td>$\frac{\sigma_{c,\text{pre}}}{\sigma_{v,\text{pre}}} = \frac{\sigma_{c,\text{post}}}{\sigma_{v,\text{post}}}$</td>
<td>0.7131</td>
<td>0.7166</td>
<td>0.0024</td>
</tr>
<tr>
<td>$\frac{\sigma_{c,\text{pre}}}{\sigma_{v,\text{pre}}} = \frac{\sigma_{y,\text{post}}}{\sigma_{v,\text{post}}}$</td>
<td>0.7891</td>
<td>0.4544</td>
<td>6.8733 ***</td>
</tr>
<tr>
<td>$\rho_{vc,\text{pre}} \frac{\sigma_{c,\text{pre}}}{\sigma_{v,\text{pre}}} = \rho_{vc,\text{post}} \frac{\sigma_{c,\text{post}}}{\sigma_{v,\text{post}}}$</td>
<td>-0.7082</td>
<td>-0.6478</td>
<td>0.7059</td>
</tr>
<tr>
<td>$\rho_{vy,\text{pre}} \frac{\sigma_{y,\text{pre}}}{\sigma_{v,\text{pre}}} = \rho_{vy,\text{post}} \frac{\sigma_{y,\text{post}}}{\sigma_{v,\text{post}}}$</td>
<td>-0.675</td>
<td>-0.4085</td>
<td>4.613 **</td>
</tr>
</tbody>
</table>
Figure 1. The path of Consumption Given a One-Time Shock to Permanent Income

(a) Adjustment path of consumption corresponding to different persistence of transitory consumption (when $\rho = -0.9$)

(b) Adjustment path of consumption corresponding to different negative correlation (when $\phi_{c1} = 0.9$)
Figure 2. The Paths of Consumption and Income Given a One-Time Shock to Permanent Income

Adjustment path of consumption

Adjustment path of output

Legend:
- Blue: PERMANENT INCOME
- Red dashed: Consumption Pre 1984
- Green dashed: Consumption Post 1984

Legend:
- Blue: Long-run Output Level
- Red dashed: Output Pre 1984
- Green dashed: Output Post 1984