August 14, 2006

Why Have Business Cycle Fluctuations Become Less Volatile?

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Abstract

This paper shows that a standard Real Business Cycle model driven by productivity shocks can successfully account for the 50 percent decline in cyclical volatility of output and its components, and labor input that has occurred since 1983. The model is successful because the volatility of productivity shocks has also declined significantly over the same time period. We then investigate whether the decline in the volatility of the Solow Residual is due to changes in the volatility of some other shock operating through a channel that is absent in the standard model. We therefore develop a model with variable capacity and labor utilization. We investigate whether government spending shocks, shocks that affect the household's first order condition for labor, and shocks that affect the household's first order condition for saving can plausibly account for the change in TFP volatility and in the volatility of output, its components, and labor. We find that none of these shocks are able to do this. This suggests that successfully accounting for the post-1983 decline in business cycle volatility requires a change in the volatility of a productivity-like shock operating within a standard growth model.

[*] We thank Stephen Parente, Ed Prescott, John Taylor, and two anonymous referees for helpful comments and suggestions.

1. **Introduction**

Kydland and Prescott (1982) and Prescott (1986) established that productivity shocks could account for most post-World War II business cycle volatility. Business cycle volatility was roughly constant up through the period studied by Kydland and Prescott, but has changed substantially since then. Kim and Nelson (1999), McConnell and Perez-Quiros (2000) and Stock and Watson (2002) all identify a large and statistically significant permanent decline in U.S. GDP volatility beginning in the first quarter of 1984.

This paper examines this decreased volatility through the lens of neoclassical business cycle theory. We focus our analysis on changes in the variance of the Hodrick-Prescott cyclical component of real GDP, its components, labor input, and total factor productivity (TFP). All of these variances are about 30-50 percent smaller in the post-1983 period compared to the 1955-83 period.

Within the neoclassical framework, changes in cyclical volatility are the result of either changes in the volatility of the exogenous shocks that are fed into the model, and/or changes in the structure of the model that maps the exogenous shocks into the endogenous variables. We focus our analysis on changes in the exogenous shock volatility.

We first evaluate the impact of changes in the volatility of TFP shocks. We find that the volatility of this shock declines about 50 percent after 1983. We find that this volatility change reduces the volatility of output and its components, and labor input also by 50 percent in the Hansen (1985) model. This finding suggests that lower productivity shock volatility can be a significant factor underlying lower cyclical volatility. Some economists will question this finding, however, because they argue that TFP shocks are not productivity shocks per se, but rather the endogenous consequence of other shocks operating through unmeasured capital and labor utilization. This “mis-measurement” view of TFP would suggest that the change in TFP volatility is due to the change in the volatility of some other shock, combined with unmeasured changes in factor utilization. We therefore pursue this possibility using the model of Burnside et al. (1996) that features both variable capital and labor utilization. We follow Chari, Kehoe, and McGrattan (2002, 2006) and Cole and Ohanian (2002) who focus on three other shocks for understanding fluctuations in the growth model: a shock to the household’s static first order condition, a shock to the household’s dynamic first order condition, and an additive shock to the resource constraint, such as government spending shocks.

We test whether changes in the volatility of these other shocks can account for both the change in TFP volatility and the change in the volatility of the output, its components and labor. Our main finding is that none of these shocks do this. The volatility of the static preference shocks is roughly unchanged between the two periods. The volatility of the shock to the resource constraint changes significantly, but this change is quantitatively unimportant for the volatility of TFP and the other variables. The volatility of the shock to the Euler equation changes significantly, but generates business cycle statistics that are grossly counterfactual. We conclude that the most promising candidate for understanding lower post-1983 business cycle volatility is a shock that operates like TFP in a standard stochastic growth model. The change in the correlation structure between the two periods provides some additional evidence on this issue.

The paper is organized as follows. Section 2 discusses the literature. Section 3 presents changes in volatility of macroeconomic variables and the impact of lower volatility of technology shocks in a standard real business cycle model. Section 4 describes how we identify multiple shocks in this model and Section 5 studies the change in TFP volatility in the model with variable capital and labor utilization. Section 6 considers the impact of a change in the volatility of technology shocks on business cycle correlations and Section 7 concludes.

2. Connection with the Literature

The existing literature offers several explanations for the fall in business cycle volatility, though currently there is no generally accepted explanation of lower cyclical volatility. Kahn, McConnell and Perez-Quiros (2002) argue that the "information revolution" has changed the way shocks are propagated. In particular, they argue that the volatility reduction resulting largely from improvements in inventory management techniques, using a model that differs substantially from the standard neoclassical model**.** Their approach thus focuses on changes in a specific model's propagation mechanism with a focus on inventory management. More recently, Campbell and Hercowitz (2005) argue that financial reforms of the early 1980's have changed the propagation mechanism by relaxing collateral constraints on household borrowing. Other authors, for example Clarida, Galí and Gertler (2000), maintain that improved monetary policy since the early 1980's has stabilized the U.S. economy. Blanchard and Simon (2001) argue that changes in inventory management techniques, monetary policy, and also the volatility of government spending all have been significant contributing factors to lower volatility.

In contrast, Stock and Watson (2002) conduct a comprehensive statistical examination and find that the volatility reduction is primarily due to "good luck." That is, there has been a fall in the variance of the structural shocks that impact the economy, rather than improved monetary policy or improved inventory control techniques. Ahmed, Levin, and Wilson (2002) also conclude that lower volatility is largely a matter of "good luck" in the post-1983 period. Finally, Gordon (2005) also finds that the reduced variance of shocks was the dominant source of reduced business cycle volatility. We accept the "good luck" conclusions of these papers, that the shocks hitting the U.S. economy since 1984 have been smaller. Our paper complements these latter three studies by providing an assessment of the contribution of lower shock volatility to the business cycle using a DSGE framework. Our DSGE analysis allows us to make progress on understanding which shocks are important for the change in cyclical volatility, and on understanding the structural mechanisms through which these shocks operate. We therefore develop a simple RBC model and we evaluate how changes in the volatility of different shocks affect business cycle volatility. Comin and Phillipon (2005) argue that microeconomic volatility (among listed corporations) has increased recently, and Phillipon (2003) argues that increases in competition can jointly account for higher microeconomic volatility and lower macroeconomic volatility.[1] The closest study to ours is by Leduc and Sill (2005) who study the contribution of TFP shocks and monetary shocks to lower volatility. They find that changes in monetary policy are relatively unimportant.[2]

3. Volatility in a Basic Real Business Cycle Model

In Table 1, we present a measure of business cycle volatility for a variety of U.S. aggregate time series.[3] Here, the business cycle is defined by deviations from a Hodrick-Prescott

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[1] We do not address the possible increase in firm-level volatility, as this is beyond the scope of this paper. It is worth noting, however, that within our framework, improved access to asset markets would tend to increase microeconomic volatility. There is evidence that asset markets have become more efficient (see Krueger and Perri (2006)).

[2] Other analyses of changes in volatility within a fully articulated model include Posch and Waelde (2005), and Justiano and Primiceri (2005). Both analyses differ considerably from this analysis. Posch and Waelde find that changes in tax rates can be stability-enhancing in a model with endogenous cycles, while Justiano and Primiceri find that changes in the variance of investment-specific technological change is key in a Bayesian analysis of a model with time-varying mark-ups, sticky prices and wages, habit formation, investment-specific technological change, and investment adjustment costs.

[3] We use quarterly data from 1955:3 – 2003:2. The beginning date is the first for which hours based on the household survey are available. Data has been logged before applying the Hodrick-Prescott filter. All National Income and Product Account data is in 1996 dollars. Hours (HS) is total hours worked based on data from the

trend. We report the percent standard deviation of quarterly data from 1955:3 to 2003:2 in the first column of the table. In the second and third columns, the same statistic is reported for the pre-1984 and post-1984 subperiods. In the last column, the ratio of the volatility measure for the late subperiod to the early subperiod is given.

This table shows that volatilities of all series in the later subperiod are significantly smaller than in the earlier subperiod. Output and TFP are about half as volatile, while the labor input is 70 percent as volatile. This fall in volatility of the labor input is essentially identical in both hours worked measured using the household survey as well as hours from the establishment survey. A component of GNP on which we focus particular attention is consumption of services and nondurables, since this corresponds conceptually to consumption in a stochastic growth model. Similarly, consumer durables plus fixed investment corresponds to investment in our theoretical model. We find that investment is 58 percent as volatile, and consumption 65 percent, in the later subperiod as compared with the early subperiod. Government spending is 55 percent as volatile. Overall, these statistics show that volatility declined 30-50 percent in these variables after 1983.

Current Population Survey and available on the Bureau of Labor Statistics website. The BLS data has been seasonally adjusted prior to computing our volatility statistics. Hours (ES) is based on data from establishment payrolls and is also available on the BLS website. Measured total factor productivity (TFP) is computed as $\log(TFP_t) = \log(GNP_t) - .6\log(Hours_t)$. We have ignored the stock of capital because it does not vary much over the business cycle following Prescott (1986).

Table 1—Volatility of U.S. Data

Series	1955:3-2003:2	1955:3-1983:4	1984:1-2003:2	Late/Early
	Percent Standard Deviation			
GNP	1.59	1.78	0.93	0.53
Hours (HS)	1.51	1.58	1.12	0.71
Employment	1.02	1.08	0.73	0.68
Hours per worker	0.69	0.74	0.58	0.79
Hours (ES)	1.72	1.82	1.29	0.71
Labor Productivity (HS)	1.01	1.15	0.75	0.65
Labor Productivity (ES)	0.79	0.86	0.67	0.78
TFP (HS) $(= GNP/Hours^{0.6})$	1.04	1.21	0.62	0.51
TFP (ES)	0.83	0.95	0.46	0.49
Consumption Expenditures	1.23	1.38	0.80	0.57
Nondurables	1.10	1.23	0.79	0.64
Services	0.71	0.74	0.54	0.74
Durables	4.54	5.08	3.07	0.60
Nondurables + Services	0.80	0.88	0.57	0.65
Investment Expenditures	7.06	7.66	4.41	0.58
Fixed Investment	4.87	5.29	3.20	0.61
Fixed Investment + Consumer Durables	4.53	4.97	2.88	0.58
Government Expenditures	1.50	1.73	0.96	0.55

We first assess the impact of lower TFP volatility on output and its components, and labor. We do this using the following real business cycle model. The equilibrium of this model economy is characterized by the solution to a social planner's problem (where the initial capital stock, k_0, is given):

$$\max_{k_{t+1},h_t} E\sum_{t=0}^{\infty}\beta^t\left[\log c_t + \theta h_t \frac{\log(1-\bar{h})}{\bar{h}}\right]$$

subject to

$$c_t + k_{t+1} = e^{z_t}k_t^{1-\alpha}h_t^{\alpha} + (1-\delta)k_t$$

$$z_{t+1} = \rho_1 z_t + \varepsilon_{1,t+1}, \ \ \varepsilon_1 \sim N(0,\sigma_1^2)$$

In this economy, labor is indivisible (individuals work $\bar{h}$ or not at all), and the labor market allows trade in employment lotteries—contracts that specify a probability of working $\bar{h}$ hours (see Hansen (1985) for details). In this problem, z_t is the log of TFP, c_t is consumption, and h_t is aggregate hours worked. The log of TFP follows a first order autoregressive process.

The model is calibrated in way that is standard in the real business cycle literature (see Cooley and Prescott (1995)). In particular, the value of the discount factor, β, is determined so that the average quarterly *k/y* ratio for the model is the same as in U.S. data. The depreciation rate is calibrated to the average investment to output ratio and the reduced form preference parameter, $\frac{\theta\log(1-\bar{h})}{\bar{h}}$, is chosen so that individuals spend on average 31 percent of their substitutable time working. The parameter α is set equal to average labor's share in the U.S. national income accounts, and ρ_1 is set close to one in order to match the autocorrelation of measured TFP (additional details provided in the next section). These criteria lead us to assign the following parameter values: β = .988, δ = 0.018, $\frac{\theta \log(1-\bar{h})}{\bar{h}}$ = 2.547, α = 0.6, and

$\rho_1 = .95$.

We now use the model to quantify the contribution of changes in TFP volatility to the volatility of the other variables. We first calculate the volatility of the endogenous variables when σ_1 is set to its value over the entire 1955:1 – 2003:2 period. We then calculate the volatilities for the endogenous variables for the 1955-1983 subperiod when σ_1 is calibrated so that TFP volatility in the model is equal to actual TFP volatility in that subperiod , and we analogously do this for the 1984-2003 subperiod. The TFP volatilities we calibrate to are listed in Table 1[4].

The results of this experiment are shown in Table 2.

Table 2—Volatility in a Standard Real Business Cycle Economy

Percent Standard Deviations

Series	*Entire Period*	*Early Subperiod*	*Late Subperiod*	*Late/Early*
Output	1.57	1.80	0.87	0.49
Hours	1.25	1.43	0.69	0.49
Capital	0.36	0.40	0.19	0.49
Investment	5.61	6.45	3.07	0.49
Consumption	0.40	0.46	0.22	0.49
Labor Productivity	0.40	0.45	0.22	0.49
TFP	0.83	0.95	0.46	0.49
Calibrated σ_1	0.0065	0.0075	0.0037	

The fall in the volatility of GNP and other aggregate variables is not a puzzle from perspective of "pure" real business cycle theory. In addition, because there is only one shock in

[4] We use the establishment survey measure of hours worked for calibrating TFP in our model.

this model and the propagation mechanism is close to linear, the volatility of all variables falls by the same amount. This would not be the case if we introduced additional shocks to the model.

Several researchers, however, [Basu (1996) and Burnside, Eichenbaum and Rebelo (1995)] have argued that aggregate procyclical TFP fluctuations are due primarily to unmeasured changes in factor utilization. According to these studies, once unmeasured utilization is taken into account, there is little in the way of exogenous technology shocks to be accounted for by exogenous shocks. Hence, in Section 5, we consider the impact of changes in the volatility of shocks other than technology shocks in a model with endogenous movements in TFP due to labor hording and capital utilization. Before doing that, we describe how we identify these other shock in the following section.

4. Identifying Multiple Shocks

Our approach for identifying shocks is similar to that of Chari, Kehoe, and McGrattan (2004) and Cole and Ohanian (2001) in that fluctuations in the endogenous variables from their steady state values is due to one or more deviations in the equations that characterize the solution to the planner's problem. In both our case, and in the case of these other papers, the goal is to determine which deviations are central for understanding the fluctuations in the endogenous variables. It is worth noting that there is a slight difference in terminology, however, but not in substance. Whereas Chari *et.al.* refer to these deviations as "wedges" which can be mapped into a variety of shocks, we refer to these deviations as shocks: a technology shock, a government expenditure shock, a shock to preference for leisure, and a shock to the discount factor. Note that as in the case of Chari *et.al.*, the deviations (shocks) that we specify can be mapped into different classes of deeper shocks. For example, the shock to the preference for leisure can be modeled more deeply as a shock to home production, or a shock to changes in union power. The key point is that our investigation, as in the case of Chari *et.al.*, identifies plausible broad classes of shocks that may—or may not—be important for the question of interest.

The following planner's problem incorporates all of shocks considered in this paper:

$$\max_{k_{t+1},h_t} E\sum_{t=0}^{\infty}\beta_t\left[\log c_t + \theta_t h_t \frac{\log(1-\bar{h})}{\bar{h}}\right]$$

subject to

$$c_t + k_{t+1} + g_t = e^{z_{1t}} k_t^{1-\alpha} h_t^{\alpha} + (1-\delta)k_t$$

$$g_t = \bar{g}e^{z_{2t}}$$

$$\theta_t = \bar{\theta}e^{z_{3t}}$$

$$\beta_{t+1} = \beta_t\,\bar{\beta}\,e^{z_{4t}} \;,\; \beta_0 = 1$$

$$\log z_{i,t+1} = \rho_i \log z_{i,t} + \varepsilon_{i,t+1},\; \varepsilon_i \sim N(0,\sigma_i^2) \text{ for } i = 1-4$$

k_0 given.

There are four types of stochastic shocks in this economy, which we denote by z_1 to z_4. The first is the same technology shock as in the previous section. The second shock is an additive shock to the resource constraint. Following Christiano and Eichenbaum (1992), we measure this as a government spending shock. The third shock is a preference shock that distorts the labor-leisure decision. The importance of this class of shocks for business cycles has been argued by Hall (1997) and a number of others. The last is a shock to the subjective discount factor and introduces a stochastic wedge in the intertemporal Euler equation.

Each of these shocks is identified from the data as follows:

$$z_{1t} = \log y_t - \alpha \log h_t$$

$$z_{2t} = \log g_t$$

$$z_{3t} = \log y_t - \log c_t - \log h_t$$

$$z_{4t} = Ac_t + B_1 z_{1t} + B_2 z_{2t} + B_3 z_{3t}$$

The first equation is the log of TFP, measured using establishment hours. As in Table 1, since we are interested in cyclical fluctuations, we ignore capital because it does not vary significantly over the business cycle. The second shock is computed from the log of government expenditures.[5] To compute the third shock, we take the first order condition for hours worked, $\bar{\theta} e^{z_{3t}} \frac{-\log(1-\bar{h})}{\bar{h}} = \frac{\alpha y_t}{c_t h_t}$, and solve for z_{3t} (ignoring constants). Finally, the fourth shock is computed from the intertemporal first order condition, $\frac{1}{c_t} = \bar{\beta} e^{z_{4t}} E_t \left[\frac{(1-\alpha)(y_{t+1}/k_{t+1}) + 1 - \delta}{c_{t+1}} \right]$. Solving a log-linearized version of this model enables us to express the conditional expectation on the right hand side as a linear function of z_{it} (i = 1,..,4) and $\log k_t$. Next, this linearized first order condition can be solved for z_{4t}, where A, B_1, B_2, and B_3 are the resulting coefficients. Again, as in the case of z_1, our empirical measure of z_4 ignores capital (the coefficient on $\log k_t$ is set equal to zero).

The autoregressive parameters of the first three shocks (ρ_1, ρ_2, and ρ_3) are estimated by removing a linear time trend from our measures of z_1, z_2, z_3 and computing an autoregression using OLS. From this, we obtained $\rho_1 = .95$, $\rho_2 = .98$, and $\rho_3 = .99$. In order to compute the empirical counterpart to the fourth shock, we needed to guess a value for ρ_4 so that we could solve for the conditional expectation. Using this value, we constructed a time series for z_4 and estimated ρ_4 from this time series. We solve for the fixed point where the guessed value for ρ_4

[5] As pointed out by a referee, we are ignoring net exports in this identification of the additive shock.

used to compute the z_4 time series and the autoregressive coefficient estimated from this time series are identical. This procedure led us to set $\rho_4 = .99$.

5. Volatility in Model with Endogenous Factor Utilization

In this section, we use the model of Burnside and Eichenbaum (1996) to study the impact of changes in the size of alternative shocks on business cycle volatility in a model with unmeasured factor utilization. This model incorporates two sources of factor utilization in a real business cycle model similar to the one studied in the previous section. These include labor hording as modeled in Burnside, Eichenbaum and Rebelo (1993) and capital utilization as modeled in Greenwood, Hercowitz and Huffman (1988) and Taubman and Wilkinson (1970).

The equilibrium of this model is characterized by the solution to a social planner's problem like the one in the previous section except with two additional choice variables: labor effort, *e*, and the rate of capital utilization, *u*. Labor hording is introduced by assuming that employment (n_t) is chosen before period *t* shocks are observed. The remaining choices (k_{t+1}, u_t, and e_t) are made after the shocks are observed. The planner's problem is the following subject to this timing restriction:

$$\max_{k_{t+1}, n_t, e_t, u_t} E \sum_{t=0}^{\infty} \beta_t \left[\log c_t + \theta_t n_t \log(1 - \omega - \bar{h} e_t) \right]$$

subject to

$$c_t + k_{t+1} + g_t = e^{z_{1t}} \left(u_t k_t \right)^{1-\alpha} \left(e_t n_t \bar{h} \right)^{\alpha} + (1 - \delta(u_t)) k_t$$

$$\delta(u_t) = \gamma u_t^{\phi}, \ \ \phi > 1$$

$$g_t = \bar{g} e^{z_{2t}}$$

$$\theta_t = \bar{\theta} e^{z_{3t}}$$

$$\beta_{t+1} = \beta_t \bar{\beta} e^{z_{4t}} \ , \ \beta_0 = 1$$

$$\log z_{i,t+1} = \rho_i \log z_{i,t} + \varepsilon_{i,t+1} , \ \varepsilon_i \sim N(0,\sigma_i^2) \ \text{for } i = 1-4$$

k_0 given.

Capital utilization, u_t, affects both production and the rate of depreciation. The higher capital is utilized in production, the larger is the rate of depreciation. As discussed in Burnside and Eichenbaum (1996), this feature and labor hoarding have important implication for the way shocks are propagated.

The model is calibrated in a similar manner as in the previous section. In particular, the value of $\bar{\beta}$ is chosen to target the *k/y* ratio, ϕ chosen to target the *i/y* ratio, and $\bar{g}$ chosen to target the *g/y* ratio. The parameter $\bar{\theta}$ is chosen so that the average time devoted to market activities, $n_t(\omega + \bar{h})$, is equal to 0.31 and γ is chosen so that the average utilization rate is 0.9.[6] The length of a work shift, $\bar{h}$, is set so that effort (*e*) is 1 in steady state. Labor's share is set equal to 0.6 and the fraction of time spent commuting (ω) is set equal to 6/98. The autoregressive coefficients for the shock processes are not re-estimated for this model and are the same as reported in the pervious section: $\rho_1 = .95$; $\rho_2 = .98$; $\rho_3 = .99$, and $\rho_4 = .99$.

Our goal in the following three experiments is to determine if changes in the volatility of (i) the government spending shock, (ii), the static preference shock, and (iii), the intertemporal preference shock, can plausibly account for both the change in the volatility of TFP and the change in the volatility of output and its components, and labor. We begin with the government spending shock. The volatility of government spending in the data falls by almost half after

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[6] The cyclical properties of the model do not depend on the value of the parameter γ.

1983. To measure the impact of reducing the volatility of government spending, we simulate the model as follows, setting $\sigma_3 = \sigma_4 = 0$ ($\theta_t = \bar{\theta}$ and $\beta_t = \bar{\beta}$):

1. Set σ_1 and σ_2 to match the volatility of TFP and government spending for the entire 1955-2003 period shown in Table 1.
2. Keep σ_1 at the same value, but choose σ_2 to match the volatility of *g* during the early subperiod.
3. Keep σ_1 at the same value, but choose σ_2 to match the volatility of *g* during the late subperiod.

The percent standard deviations associated with each of these parameterizations are given in the first three columns of Table 3.

Table 3—Volatility in a Model with Variable Factor Utilization
The Role of Government Spending Shocks ($\sigma_3 = \sigma_4 = 0$)

Series	*Percent Standard Deviations* Entire Period	Early Subperiod	Late Subperiod	Late/Early
Output	1.40	1.40	1.32	0.94
Hours	1.26	1.29	1.15	0.89
Capital	0.25	0.25	0.24	0.98
Investment	5.17	5.11	4.94	0.97
Consumption	0.31	0.31	0.28	0.90
Labor Productivity	0.65	0.66	0.62	0.94
TFP	0.83	0.82	0.80	0.97
Government Expenditure	1.50	1.73	0.96	0.55
Calibrated σ_1	0.00311	0.00311	0.00311	
Calibrated σ_2	0.01173	0.01378	0.00773	

The key finding from Table 3 is that, although government spending is 55 percent as volatile in the second subperiod as the first, this has relatively little effect on the volatility of any of the endogenous variables. Thus the impact of an additive resource constraint shock is quantitatively much too small to account for changes in the volatility of the other variables in the model.

Perhaps a reduction in the variance of the preference shock will have a more important quantitative effect on business cycle volatility. In order to conduct an empirically relevant experiment, we need to calibrate σ_3. To do so, we use the first order condition for choosing e_t (labor effort), which can be written as follows:

$$\frac{y_t}{c_t\, n_t\, \bar{h}} = \frac{\theta_t\, e_t}{\alpha(1-\omega-\bar{h}e_t)} \tag{1}$$

The volatility of the left hand side can be computed from data, but the right hand side is a function of unobservable effort. This is not a problem, because we can choose σ_3 so that simulations of the model imply volatility of the left hand side of this equation that is the same as that measured in U.S. data.

More precisely, Table 4 gives results from the following experiment (assume $\sigma_2 = \sigma_4 = 0$):

1. Set σ_1 and σ_3 to match the volatility of TFP and the "theta target" for the entire 1955-2003 period shown in Table 1.
2. Keep σ_1 at the same value, but choose σ_3 to match the volatility of the target during the early subperiod.
3. Keep σ_1 at the same value, but choose σ_3 to match the volatility of the target during the late subperiod.

Table 4—Volatility in a Model with Variable Factor Utilization
The Role of Taste Shocks ($\sigma_2 = \sigma_4 = 0$)

Percent Standard Deviations

Series	*Entire Period*	*Early Subperiod*	*Late Subperiod*	*Late/Early*
Output	1.78	1.77	1.67	0.94
Hours	2.10	2.10	1.96	0.94
Capital	0.30	0.30	0.28	0.94
Investment	6.34	6.25	5.94	0.95
Consumption	0.68	0.68	0.63	0.93
Labor Productivity	0.85	0.85	0.81	0.95
TFP	0.83	0.82	0.79	0.96
Theta target	1.10	1.10	1.03	0.93
Calibrated σ_1	0.00258	0.00258	0.00258	
Calibrated σ_3	0.00822	0.00834	0.00784	

Table 4 shows very little change in business cycle volatility from the calibrated change in the variance of the taste shock. The volatility in the model variables falls between 4 and 7 percent, compared to the 30-50 percent declines in the data. This finding that the change in the shock volatility cannot account for the volatility changes in the other variables is similar to the first case of the resource constraint shock in table 3, but for a very different reason. Here, the volatility of the left hand side of (1) falls by only 7 percent from the early to the late subperiod. This implies relatively little change in the value of σ_3. If the variance of the left hand side of (1) had fallen more substantially, we would find a bigger change in business cycle volatility between the early and late subperiods. Thus, the taste shock is not a useful candidate factor for understanding changing cyclical volatility in the indivisible labor model because its volatility is similar between the two periods.[7]

Our next experiment considers the potential of the intertemporal shock to account for the change in volatility. This shock enters the intertemporal first order condition, which can be written as follows:

$$\frac{1}{c_t} = \bar{\beta}\, e^{z_{4t}} E\left[\frac{(1-\alpha)(y_{t+1}/k_{t+1}) + 1 - \gamma\, u_{t+1}^{\phi}}{c_{t+1}} \right].$$

A natural way to calibrate the standard deviation of this shock is to target the volatility of consumption. If we employ this criterion, the value of σ_4 we obtain using data for the entire period, turns out to be 0.000403. While this is a considerably smaller value than our estimates of the other shock volatilities, it turns out to imply considerable volatility in the endogenous variables. In particular, the percent volatility of TFP implied by our model turns out to be 0.85. This is actually *larger* than TFP volatility computed from U.S. data for this same period (0.83).

Because of the considerable volatility generated by this shock, we report results for an experiment where the other shock volatilities are set equal to zero. That is, Table 6 gives results from the following experiment (assume $\sigma_1 = \sigma_2 = \sigma_3 = 0$):

1. Set σ_4 to match the volatility of consumption for the entire 1955-2003 period shown in Table 1.
2. Choose σ_4 to match the volatility of consumption during the early subperiod.
3. Choose σ_4 to match the volatility of consumption during the late subperiod.

[7] We stress that this finding is for the indivisible labor model, and may be sensitive to alternative formulations. This is because the household static first order condition which we used to identify the variance of the shock depends on the preference specification that is used.

Table 6—Volatility in a Model with Variable Factor Utilization
The Role of Intertemporal Shocks ($\sigma_1 = \sigma_2 = \sigma_3 = 0$)

Percent Standard Deviations

Series	*Entire Period*	*Early Subperiod*	*Late Subperiod*	*Late/Early*
Output	2.49	2.73	1.77	0.65
Hours	3.34	3.67	2.38	0.65
Capital	0.67	0.73	0.47	0.64
Investment	16.58	17.90	9.04	0.50
Consumption	0.80	0.88	0.57	0.65
Labor Productivity	1.15	1.29	0.84	0.65
TFP	0.85	0.94	0.61	0.65
Calibrated σ_4	0.000403	0.000453	0.000296	

We find that considerable volatility reduction can be accounted for by the intertemporal shock. In particular, unlike the government spending or preference shock, this shock appears to be able to account for the reduction in volatility of TFP and other endogenous variables once endogenous factor utilization is taken into account.

While this intertemporal shock may be capable of potentially accounting for much of the change in the volatility of TFP and the other variables, its contribution in this one-shock model is flawed, because with only this one shock the model is seriously deficient as a positive business cycle model. Specifically, it generates several business cycle statistics that are grossly counterfactual. For example, as shown in Table 6, the fluctuations in hours worked are significantly larger than the output fluctuations, and investment is much too volatile. An even more striking shortcoming of this model is the fact that consumption in this model economy is counter-cyclical, while it is highly pro-cyclical in the U.S. economy. These findings indicate that this one-shock model is not a reasonable specification for evaluating the potential contribution of the change in the volatility of the intertemporal shock. Doing this requires adding productivity shocks, as it is well known that models with productivity shocks tend to produce reasonable volatility and co-movement patterns compared to actual data.

We now consider the contribution of the change in the volatility of the intertemporal shock in an economy where technology shocks are important. Specifically, to generate a model with potentially reasonable business cycle properties, we maximize the possible contribution of technology shocks as follows. The value of σ_1 is chosen so that it completely accounts for TFP volatility in the second (low volatility) subperiod. The same value of σ_1 is used in the first (high volatility) subperiod, and we choose σ_4 in the first subperiod to account for the change in the volatility of σ_1 between the two subperiods. Specifically, the experiment is conducted as follows:

1. Set $\sigma_4 = 0$ and choose σ_1 to match the volatility of TFP in later subperiod (results are shown in the second column of Table 7).
2. For the early subperiod, maintain the same value of σ_1 as in step 1. Choose σ_4 to match the much higher volatility of TFP during the early subperiod.

Hence, in this experiment, we are allowing for a significant role for technology shocks in both subperiods, but we are allowing a change in the volatility of the intertemporal shock (σ_4) to account for one hundred percent of the change in the TFP volatility between the two subperiods.

Table 7—Volatility in a Model with Variable Factor Utilization
The Role of Intertemporal Shocks ($\sigma_2 = \sigma_3 = 0$)

Percent Standard Deviations

Series	*Early Subperiod*	*Late Subperiod*	*Late/Early*
Output	2.51	0.75	0.30
Hours	3.29	0.64	0.19
Capital	0.66	0.14	0.21
Investment	14.38	2.83	0.20
Consumption	0.79	0.16	0.20
Labor Productivity	1.18	0.84	0.30
TFP	0.95	0.46	0.48
Calibrated σ_1	0.00183	0.00183	
Calibrated σ_4	0.000398	0	

The results of this experiment tell basically the same story as Table 6. A change in the variance of the intertemporal shock can account for the reduced variance of TFP, but the implied business cycle properties when the intertemporal shock is active (the early subperiod in Table 7) are substantially at variance with the business cycle properties of the U.S. economy. Specifically, hours worked fluctuates more than output, and consumption is highly counter-cyclical (the correlation of output and consumption is -0.7).

This experiment indicates that a change in the volatility of an intertemporal shock that shifts the Euler equation is a very unlikely candidate for understanding changing cyclical volatility because the business cycle properties in this model are significantly at variance with the data. This suggests that investigating this shock seems to require a model which deviates considerably from the growth model.

6. Changes in Correlations

In the experiments carried out in this paper, we have focused on changes in volatility of macroeconomic variables before and after 1984. We now examine changes in the correlations between these variables over these periods. The tables below show the correlations between the Hodrick-Prescott filtered time series from Table 1 for the early and late subperiods. These data suggest that the size of technology shocks fell in the latter subperiod.

Table 8—Business Cycle Correlations for U.S. Data

Early Subperiod (1955:3-1983:4)	GNP	Consumption of Services + Nondurables	Fixed Investment+ Consumer Durables	Hours (ES)	Prod (ES)	TFP (ES)
GNP	1.00	0.80	0.91	0.89	0.19	0.85
Services + Nondurables		1.00	0.80	0.69	0.20	0.70
Fixed Investment + Durables			1.00	0.83	0.13	0.75
Hours (ES)				1.00	-0.29	0.50
Prod (ES)					1.00	0.68
TFP (ES)						1.00

Late Subperiod (1984:1-2003:2)	GNP	Consumption of Services + Nondurables	Fixed Investment+ Consumer Durables	Hours (ES)	Prod (ES)	TFP (ES)
GNP	1.00	0.84	0.85	0.87	-0.28	0.56
Services + Nondurables		1.00	0.82	0.81	-0.38	0.34
Fixed Investment + Durables			1.00	0.78	-0.33	0.40
Hours (ES)				1.00	-0.72	0.07
Prod (ES)					1.00	0.64
TFP (ES)						1.00

The table shows that labor productivity becomes countercyclical, and that the correlation between TFP and the other variables declines considerably, in the second sub-period.

To assess the extent that declining TFP volatility can shed light on these correlation changes, we performed the following experiment. We abstract from the government spending shock (since its volatility change doesn't have much of an impact) and the intertemporal shock (since it generates counterfactual business cycle properties in our model).

1. Set $\sigma_2 = \sigma_4 = 0$ and $\sigma_3 = 0.00822$. The latter is the value of σ_3 required to match the volatility of the "theta target" for the entire sample (see Table 4). Set σ_1 to match the volatility of TFP for the early subperiod.
2. Hold $\sigma_2, \sigma_3,$ and σ_4 constant and set σ_1 to match the volatility of TFP for the later subperiod.

The following table shows the correlation matrix corresponding to each of the two cases described above:

Table 9—Correlations in a Model with Variable Factor Utilization
The Role of Technology Shocks ($\sigma_2 = \sigma_4 = 0$)

Early Subperiod	Output	Consumption	Investment	Hours	Labor Productivity	TFP
Output	1.00	0.83	0.98	0.90	-0.05	0.79
Consumption		1.00	0.74	0.71	0.05	0.69
Investment			1.00	0.90	-0.07	0.77
Hours				1.00	-0.46	0.47
Labor Productivity					1.00	0.55
TFP						1.00

Late Subperiod	Output	Consumption	Investment	Hours	Labor Productivity	TFP
Output	1.00	0.87	0.98	0.95	-0.60	0.67
Consumption		1.00	0.79	0.71	-0.19	0.86
Investment			1.00	0.98	-0.69	0.57
Hours				1.00	-0.81	0.42
Labor Productivity					1.00	0.18
TFP						1.00

We see that our model with the change in TFP volatility, and the volatility of the taste shock held constant, indeed generates countercyclical labor productivity in the later subperiod. It does not, however, predict the large changes in the correlations with TFP seen in Table 8.

7. Conclusion

We find that the approximately 50 percent decline in business cycle volatility that has occurred since 1983 can be accounted for by the observed decline in the volatility of productivity shocks. This finding is robust to allowing for endogenous TFP volatility operating in a model with variable capital and labor utilization. In particular, we found that neither changes in the volatility of an additive resource constraint shock, changes in the volatility of a static taste shock, nor changes in the volatility of a dynamic taste shock can plausibly account for the change in TFP volatility, the change in the volatility of output and its components, and labor. We see two avenues for future research in this area. One is to develop theories for why the TFP shock volatility had declined so much. Another is to test whether other plausible modifications to the model generate very different results.

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