Fluctuations. Introducing a Leisure/Labor Choice in the Ramsey Model. RBC models.

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The benchmark model had shocks, uncertainty, but no variation in employment. We want to explore what happens if we allow for a leisure/labor choice.

This class of models is known as the RBC model. It does well at explaining many business cycle facts. Procyclical consumption, investment, and employment.

But the hypotheses appear factually wrong (technological shocks, labor/leisure elasticity). Useless? No. Another step on the path to the relevant model.

Organization:

- Set up and solve the model. First order conditions, special cases, and numerical simulations.
- Evidence on technological shocks, and the nature and the dynamic effects of technological progress.
- Evidence on movements in non employment: Unemployment versus non participation.

1 The optimization problem

Again look at a planning problem.

$$\max E[\sum_0^\infty \beta^i \, U(C_{t+i}, L_{t+i})|\Omega_t]$$

subject to:

$$N_{t+i} + L_{t+i} = 1$$

$$C_{t+i} + S_{t+i} = Z_{t+i}F(K_{t+i}, N_{t+i})$$

$$K_{t+i+1} = (1-\delta)K_{t+i} + S_{t+i}$$

The change from the benchmark: L is leisure and N is work. By normalization, total time is equal to one. Utility is a function of both consumption and leisure.

Again I ignore growth. If growth, then the production function would have Harrod neutral technological progress , so $Z_t F(K_t, A_t N_t)$, with $A_t = A^t, A > 1$ for example.

2 The first order conditions

The easiest way to derive them is again using Lagrange multipliers. Put the three constraints together to get:

$$K_{t+i+1} = (1-\delta)K_{t+i} + Z_{t+i}F(K_{t+i}, 1-L_{t+i}) - C_{t+i}$$

Associate $\beta^i \lambda_{t+i}$ with the constraint at time t:

$$E[U(C_t, L_t) + \beta U(C_{t+1}, L_{t+1}) - \lambda_t(K_{t+1} - (1-\delta)K_t - Z_t F(K_t, 1-L_t) + C_t) - \beta\lambda_{t+1}(K_{t+2} - (1-\delta)K_{t+1} - Z_{t+1}F(K_{t+1}, 1-L_{t+1}) + C_{t+1}) + ... \mid \Omega_t]$$

The first order conditions are therefore given by:

$$C_t \ : \ U_C(C_t, L_t) = \lambda_t$$

$$L_t \ : \ U_L(C_t, L_t) = \lambda_t Z_t F_N(K_t, 1-L_t)$$

$$K_{t+1} \ : \ \lambda_t = E[\beta\lambda_{t+1}(1-\delta + Z_{t+1}F_K(K_{t+1}, 1-L_{t+1}) \mid \Omega_t]$$

Define, as before, $R_{t+1} \equiv 1-\delta + Z_{t+1}F_K(K_{t+1}, 1-L_{t+1})$ and define $W_t = Z_t F_N(K_t, 1-L_t)$, so:

$$U_C(C_t, L_t) = \lambda_t$$

$$U_L(C_t, L_t) = \lambda_t W_t$$

$$\lambda_t = E[\beta \lambda_{t+1} R_{t+1} \mid \Omega_t]$$

Interpretation (Optimization problem, consumers in the decentralized economy, taking the wage and the interest rate as given). Combining the first two:

The **intratemporal condition**:

$$U_L(C_t, L_t) = W_t U_C(C_t, L_t)$$

And the **intertemporal condition**:

$$U_C(C_t, L_t) = E[\beta R_{t+1} U_C(C_{t+1}, L_{t+1}) \mid \Omega_t]$$

Before proceeding, we can ask: What restrictions do we want to impose on utility and production so as to have a balanced path in steady state?

(Not a totally convincing exercise:

There is actually a fairly strong downward trend in hours worked (see figure at the end of hand out on hours worked over time for major countries), so not clear that we are on a balanced growth path.

Even if we were, do we really have the same preferences in the short and the long run? Could have all kinds of dynamic specifications of utility with the same implications for the long run.)

- *On the production side, we know that progress has to be Harrod Neutral, say at rate $A > 1$. (Remember we suppressed A_t just for notational convenience.*
- *On the utility side, can use the first order conditions above to derive the restrictions.*

In steady state, leisure is constant. Consumption and the wage increase at rate A, so, from the intratemporal condition:

$$\frac{U_L(CA^t, L)}{U_C(CA^t, L)} = WA^t$$

where C, L and W are constant over time, and A increases. This is true for any A^t, so in particular, for $t = 0$ so $A^t = 1$, so

$$\frac{U_L(C, L)}{U_C(C, L)} = W$$

Using the two relations to eliminate the wage, we can write:

$$\frac{U_L(CA^t, L)}{U_C(CA^t, L)} = A^t \frac{U_L(C, L)}{U_C(C, L)}$$

The marginal rate of substitution between consumption and leisure must increase over time at rate A.

This relation holds for any value of the term A^t So use for example $A^t = 1/C$:

$$\frac{U_L(1, L)}{U_C(1, L)} = \frac{1}{C} \frac{U_L(C, L)}{U_C(C, L)}$$

Or, rearranging:

$$\frac{U_L(C,L)}{U_C(C,L)} = C[\frac{U_L(1,L)}{U_C(1,L)}]$$

The rate of substitution must be equal to C times the term in brackets, which is a function only of L. This in turn implies that the utility function must be of the form:

$$u(C\tilde{v}(L))$$

Now turn to the intertemporal condition. Write it as:

$$U_C(CA^t, L) = (\beta R) U_C(CA^{t+1}, L)$$

Or, given the restrictions above:

$$\frac{u'(CA^t\tilde{v}(L))}{u'(CA^{t+1}\tilde{v}(L))} = \beta R$$

For this condition to be satisfied, $u(.)$ must be of the constant elasticity form:

$$u(C\tilde{v}(L)) = \frac{\sigma}{\sigma-1}(C\tilde{v}(L))^{(\sigma-1)/\sigma}$$

If $\sigma = 1$, then:

$$U(C,L) = \log(C) + v(L)$$

where $v(L) = \log(\tilde{v}(L))$, with $v' > 0, v'' < 0$. (Another way of stating this. If we want to assume separability of leisure and consumption (but there is really no good reason to do that), then the form above is the only one consistent with the existence of a steady state.

Let me use the specification $U(C, L) = \log(C) + v(L)$ and return to the first order conditions.

The **intratemporal condition** becomes:

$$v'(L_t) = W_t/C_t$$

And the **intertemporal condition**:

$$E[\beta R_{t+1} \frac{C_t}{C_{t+1}} \mid \Omega_t] = 1$$

Interpretation. (Note that $U_C = 1/C$ is the marginal value of wealth). So equalize marginal utility of leisure to the wage times the marginal value of wealth. And the Ramsey-Keynes condition for consumption.

So now consider the effects of a favorable technological shock. It increases W and R, both current and prospective.

- Two effects on **consumption**. Smoothing (consumption up) and tilting (consumption down). On net, plausibly up.
- Turn to **leisure/work**. Two effects.
  A substitution effect: Higher W_t leads people to work harder.
  An income/wealth effect. Higher C_t works the other way. As people feel richer (remember that $1/C$ is the marginal value of wealth), they want to consume more and enjoy more leisure.
  Net effect depends on the strength of the two effects. Substitution (elasticity), and wealth (persistence).
- The more transitory the shock, the smaller the increase in C, and so the stronger the substitution effect.
- The more permanent (with C_t increasing as much or more than W_t. Can it? Yes. Think of a permanent shock, plus capital accumulation), the stronger the wealth effect. Employment could decrease.

Another way of looking at the employment effects. An intertemporal condition for leisure (this is the way Lucas and Rapping looked at it):

Replace consumption by its expression from the intratemporal condition. And, just for convenience, use $v(L) = \phi \log(L)$, so $v'(L) = \phi/L$. Then:

$$\phi C_t = W_t L_t$$

So, replacing in the intertemporal condition:

$$E[\beta(R_{t+1}\frac{W_t}{W_{t+1}})\frac{L_t}{L_{t+1}} \mid \Omega_t] = 1$$

What is relevant for the leisure decision is the rate of return "in wage units".

Now consider a transitory shock, so W_t increases but W_{t+1} does not change much. Then L_t/L_{t+1} will decrease sharply. The increase in the wage will be associated with a strong increase in employment.

Consider a permanent shock: Then W_t/W_{t+1} is roughly constant, and so is L_t/L_{t+1}. (ignoring movements in R). No movement in employment.

3 Solving the model.

The usual battery of methods:

Special cases? The same as before. Assume Cobb Douglas production, assume log–log utility. Assume full depreciation.

$$K_{t+1} = Z_t K_t^{\alpha}(1 - L_t)^{1-\alpha} - C_t$$

and

$$U(C_t, L_t) = \log C_t + \phi \log L_t$$

Then, can solve explicitly. And the solution actually is identical to that of the benchmark model. N is always constant, not by assumption, but by implication now. Substitution and income effects cancel.

$$C_t = (1 - \alpha\beta) Y_t$$

$$N \mid \frac{\phi}{1-N} = \frac{1-\alpha}{1-\alpha\beta} \frac{1}{N}$$

So, nice, but not useful if we want to think about fluctuations in employment.

So need to go to **numerical simulations**. SDP, or log linearization. Campbell gives a full analytical characterization. On the web page, you can find a Matlab program written by Thomas Philippon and Ruben Segura-Cayuela for the log linearized model (with Cobb Douglas production and log-log preferences). ("RBC.m" and associated programs give the impulse responses, and the moments, and correlations of the variables with output. Play with it).

The effects of different persistence parameters for the technological shocks. See figures from RBC.m for three values of ρ. Could do the same for different elasticities of labor supply, or different intertemporal elasticities. But in these two cases, you need to modify the matrices a bit. You may want to do it.

(See also results from King Rebello. Tables 1, 3. And their figure 7.)

Success? Not yet:

- Labor supply elasticities: plausible?
- Technological shocks. Are they really there?

4 Movements in employment and the labor/leisure choice

Within the logic of the model: Under the log-log assumption used by King and Rebello and others, the elasticity of employment with respect to the wage, controlling for consumption (so as to eliminate the income/wealth effect) is given by:

$$\frac{dN}{N} = -\frac{dL}{L}\frac{1-N}{N} = \frac{1-N}{N}\frac{dw}{w}$$

So, if we assume, like King-Rebello, that $\bar{N} = .2$ (that we spend 20% of our time working), then the elasticity of employment with respect to the wage is 4.

Empirical estimates (of which there are many in the micro-labor lit) are all much lower, below 1. If we assume an elasticity of 1 in the RBC model, then, as shown in Figure 8 of King-Rebello, we do not get much action in employment relative to the data.

Is this deadly? Not necessarily. It suggests that the competitive spot market characterization of the labor market has to be replaced by something else.

This is the approach which has been explored by the "flows and bargaining" line of research. This approach thinks of and formalizes the labor market as a market characterized by flows of workers in and out of jobs, and of wages being set by bargaining between firms and workers. You will see it in detail in 454.

In this approach, the causal relation between wages and employment runs from employment (or unemployment, or in general, any variable characterizing the state of the labor market) to (bargained) wages: How much does a change in employment (unemployment) affect bargained wages? (Contrast this with the competitive labor market formalization in the RBC model above, where the causal relation runs from wages to employment: How much do wages affect employment (labor supply)?)

And the question becomes: Do we have a convincing explanation for why changes in employment lead to a small response of wages? This is the subject of much current research. The answer is not yet in.

But the answer is central, not only for RBC models, but, as we shall see, in New Keynesian models. All these models generate plausible responses of the economy to shocks only if the elasticity of wages to employment is small (equivalently, if the elasticity of employment to wages is high).

5 Technological shocks. Evidence

A priori, the notion that there would be sharp movements in the production frontier from quarter to quarter, highly correlated across sectors, is not plausible. The diffusion of technology is steady. Breakthroughs are rare, and unlikely to be in all sectors at once.

(Exceptions:

For example, a breakdown in the rule of law. Then, suddenly, many relations come to an end, and the effective production frontier shrinks. Relevant for example in Eastern Europe in the early 1990s

And relevant at slightly lower frequencies. Clear that technological shocks (the high tech boom) had something to do with the expansion of the second half of the 1990s, and the subsequent recession. Perhaps not however through the RBC channels).

So second look:

5.1 The measurement of technological shocks

One way to measure technological progress was suggested by Solow. The construction of the Solow residual goes like this:

Suppose the production function is of the form:

$$Y = F(K, N, A)$$

A is the index of technological level, and enters the production function without restrictions. We want to measure the contribution of A to Y.

Differentiate and rearrange to get:

$$\frac{dY}{Y} = \frac{F_K K}{Y}\frac{dK}{K} + \frac{F_N N}{Y}\frac{dN}{N} + \frac{F_A A}{Y}\frac{dA}{A}$$

Suppose now that firms price according to marginal cost. Let W be the price of labor services, and R be the rental price of capital services. Assume no costs of adjustment for either labor or capital. Then:

$$P = \mathrm{MC} = W/F_N = R/F_K$$

Replacing:

$$\frac{dY}{Y} = \frac{RK}{PY}\frac{dK}{K} + \frac{WN}{PY}\frac{dN}{N} + \frac{F_A A}{Y}\frac{dA}{A}$$

Define the Solow residual as $S \equiv (F_A A/Y)(dA/A)$. Let α_K be the share of capital costs in output, and α_N be the share of labor costs in output. Then:

$$S = \frac{dY}{Y} - \frac{dX}{X}$$

where

$$\frac{dX}{X} \equiv \alpha_K \frac{dK}{K} + \alpha_N \frac{dN}{N}$$

The Solow residual is equal to output growth minus weighted input growth, where the weights are shares (and time varying). No need for estimation, or to know anything about the production function.

If we construct the residual in this way:

- Get a highly procyclical Solow residual. Figure 1 from Basu.
- Get a very good fit with output: From annual data from 1960 to 1998 (different time period from Basu graph):

$$\frac{dY}{Y} = 1.16\ S + 0.36\ S(-1) + \epsilon \qquad \bar{R}^2 = .82$$

Solow used this approach to compute S over long periods of time. Is it reasonable to construct it to estimate technological change from year to year, or quarter to quarter? The answer is: Probably not.

A number of serious problems. Among them:

- Costs of adjustment. If costs of adjustment to capital, then the shadow rental cost is higher/lower than the rental price R. Same if costs of adjustment to labor. So shares using rental prices or wages may not be right.
- Non marginal cost pricing. Firms may have monopoly power, in which case, markup μ will be different from one.
- Unobserved movements in N or K. Effort? Capacity utilization?

Examine the effects of the last two (On costs of adjustment just to capital, no problem. Condition still holds for labor, so use the share of labor to weight the change in employment. And use one minus the share of labor to weight the change in capital. More of an issue if costs of adjustment to both.)

Markup pricing

Suppose

$$P = (1+\mu)\ \mathrm{MC}$$

Then: $P = (1+\mu)W/F_N$ or $F_N = (1+\mu)W/P$. Similarly $F_K = (1+\mu)R/P$. So:

$$S = \frac{dY}{Y} - (1+\mu)\frac{dX}{X}$$

Let the measured Solow residual be $\hat{S}$, and true Solow residual be S. Then, if $\mu > 0$ and we construct the Solow residual in the standard way, then we shall overestimate the Solow residual when output growth/input growth is high. :

$$S = \hat{S} - \mu\frac{dX}{X}$$

Figure, for $\mu = 0.1, 0.2$, from Basu. Adjusted Solow Residual much less procyclical. But have to go to high values of μ, say 0.5 to eliminate procyclicality.

Unobserved inputs

Suppose for example that $N = BHE$, where B is number of workers, H is hours per worker, and E is effort. Going through the same steps as before, leaving markup pricing aside:

$$S \equiv \frac{dY}{Y} - [\alpha_K \frac{dK}{K} + \alpha_N (\frac{dB}{B} + \frac{dH}{H} + \frac{dE}{E})]$$

Suppose we observe B and H but not E, so measure labor (incorrectly) by BH. Then, again, we shall tend to overestimate the Solow residual in booms:

$$S = \hat{S} - \alpha_N \frac{dE}{E}$$

Similar issues with capacity utilization on the capital side.

Are there ways around it?

Suppose that we allow for markup pricing and unobserved effort. Then:

$$S = \frac{dY}{Y} - (1+\mu)\frac{dX}{X} - (1+\mu)\alpha_N \frac{dE}{E}$$

Or, equivalently:

$$\frac{dY}{Y} = (1+\mu)\frac{dX}{X} + (1+\mu)\alpha_N \frac{dE}{E} + S$$

Can we estimate it and get a series for the residual? There are two problems:

- Unobservable effort dE/E ? Part of the error term, likely to be correlated with dX/X.
  If firms cost minimize at all margins and can freely adjust effort and hours, then, under reasonable assumptions, dE/E and dH/H will move together. So will capacity utilization. So can estimate:

$$\frac{dY}{Y} = (1+\mu)\frac{dX}{X} + \beta\alpha_N \frac{dH}{H} + S$$

- S correlated with dX/X? Likely as well. Surely under RBC hypotheses. So, need to use instruments: Government spending on defense, oil price, federal funds innovation... Good instruments? Might be easier in a small economy: World GDP.

Results. Basu and Fernald. Find markup around 1, so that correction makes little difference. But the correction for hours makes the estimated Solow residual nearly a-cyclical. See their Figure 3.

Role of technological shocks? Variance decomposition of a bivariate VAR in the estimated residual and the usual Solow residual:

Contribution of technological shock to Solow residual, 5% on impact, 38% after a year, 59% after 3 years, 66% after 10 years.

Having constructed an adjusted series, can look at the dynamic effects on output, employment, and so on. This is done by Basu, Fernald, and Kimball (NBER WP 10592)

5.2 An alternative way of identifying technological shocks

An alternative construction of shocks, and the results. Gali 2004, expanding on Blanchard Quah, 1989.

Identify the technological shocks as those shocks with a long term effect on productivity, and then trace their short run effects on output, employment, productivity.

Technically:

- Estimate a bivariate VAR in $\Delta \log(Y/N)$ and $\Delta \log(N)$. Stationary. So no effect of shocks on productivity growth and employment growth. But potential effects on level of productivity, and level of employment.

- Assume two types of shocks. Shocks with permanent effects on level of productivity. Shocks with no permanent effects on level of productivity. This is sufficient for identification.
- Call the first "technological shocks." Impulse responses (get the impulse responses for productivity growth and employment growth. Easy to then get impulse responses for output, employment and productivity levels (how?) . Figure 2 in Gali.

  Find an increase in output, but less than productivity. So a (small) decrease in employment (measured by total hours worked).

  By constructing the movements in Y due to the technological shocks, can see how much of the cyclical movements in Y are explained by these shocks. This is done in Figure 3 in Gali. The answer: not much. (An alternative measure would be to show variance decompositions at various forecast horizons.)
- Blanchard Quah differs in the two variables looked at: log output, and unemployment rate. Less appealing: output may be affected by more than technological shocks in the long run.

  Impulse responses: technological shocks on output build up slowly. Variance decomposition: Tables 2 to 2B. Due to technological shocks: 1% to 16% at one quarter, 20 to 50% at 8 quarters.
- How robust? My reading: fairly robust. See discussion in Gali. (As was pointed out in the lecture, earlier Gali 1992 (problem set 1) finds a larger role for technological shocks at cyclical frequencies).
- An independent confirmation. Basu et al (2004) trace the effects of their constructed measure of technological shocks on output, employment. They find an initially negative effect of the shocks on employment.

5.3 Technological progress and fluctuations

Other relevant papers/approaches. In no particularly tight order.

- One reason for doubting the existence of large aggregate technological shocks is the law of large numbers. Technological shocks may be large in the short run in one firm, perhaps one sector, but likely to wash out for the economy as a whole.

  This is questioned by Gabaix (on the reading list) who argues, theoretically and empirically, that idiosyncratic shocks may be large enough to explain a good part of aggregate fluctuations (so the law of large numbers fails).
- Along related lines, one would expect to see potentially large technological shocks at the firm or sectoral level, but largely washing out in the aggregate.

  Franco and Philippon (not on the reading list, "Firms and aggregate dynamics", http://ssrn.com/abstract=640584), look at a panel of firm, allowing firms to be affected by permanent shocks to technology, permanent shocks to relative demand, and common aggregate (demand?) shocks. They find a large role for permanent shocks to technology at the firm level, largely washing out in the aggregate.
- Sector specific innovations are unlikely to show up as large movements in the economy's production frontier from year to year. They are likely to be implemented over time, and to be largely uncorrelated over time.

  Some technological changes however can shift the production frontier in many sectors. These are known as general purpose technologies, and run from electricity to computers. They are likely to diffuse over time to many sectors. This appears to have been for example the case in the second half of the 1990s in the United States.

  During that time, there appears to have an increase in tfp growth in IT producing sectors, and an increase in both capital intensity and tfp growth in the other (IT using) sectors. The decrease in capital intensity is plausibly attributed to the decrease in the price of IT capital goods. The (small) increase in tfp growth in the IT using sectors is plausibly attributed to changes in organization facilitated by the installation of IT capital. (See Jorgenson and Stiroh article on RL).

Such periods are likely to be characterized by higher growth for some time. (During those periods, consumption and investment demand may also boom, leading to an increase in aggregate demand which leads to even more output growth than warranted by the increase in tfp on the supply side. This is for example Greenspan's interpretation of that half decade).

- Another hypothesis is that the introduction of GPTs may be associated with lower measured tfp growth for some time.

  Initially, the introduction of new technologies may require firms to reorganize, or put another to invest in organization capital. During that time, measured output may well decline. (When we learn to use a new program, our measured productivity goes down).

  This could provide an explanation for Solow's paradox, the remark in the early 1990s that computers could be seen everywhere except in productivity statistics. Under that explanation, lower productivity growth in the 1980s and early 1990s reflected investment and learning. We are now seeing the positive effects in the form of higher measured tfp growth. (See work by Greenwood)

  The hypothesis is appealing, and surely relevant in many cases at the micro level. Whether it can explain the slowdown in tfp growth after the mid 1970s remains an open issue. It does not seem to have much to say about recessions.

- Reverse causality: Fluctuations due to other shocks are likely to have some lasting effects on total factor productivity.

  On the one hand, recessions are likely to lead to the closing of the least productive firms. In this sense, recessions may "cleanse" the economy, leading to higher productivity, at least for some time.

On the other, in the presence of imperfections in credit markets, recessions may lead to inefficient cleansing, the closing of efficient, but credit constrained firms. (see work by Ricardo Caballero)

Which way it goes appears empirically ambiguous. There is some (but only mildly convincing) evidence that recessions due to non technological shocks are followed by permanently higher productivity.

- One hypothesis, explored by Lilien in the 1980s, is that variations in unemployment may be due to higher reallocation across firms, coming from a higher pace on technological progress. In that case, higher technological progress could be associated with higher unemployment.

  The empirical evidence does not support this view. Under that view, one would expect fluctuations to be associated with positive co movements between unemployment (workers looking for jobs) and vacancies (jobs looking for workers). Exactly the opposite holds. Fluctuations are associated with opposite movements in vacancies and unemployment. (This negative relation between vacancies and unemployment is known as the Beveridge curve).

- An attractive story for why technological progress might lead to cycles was developed by Shleifer (see RL).

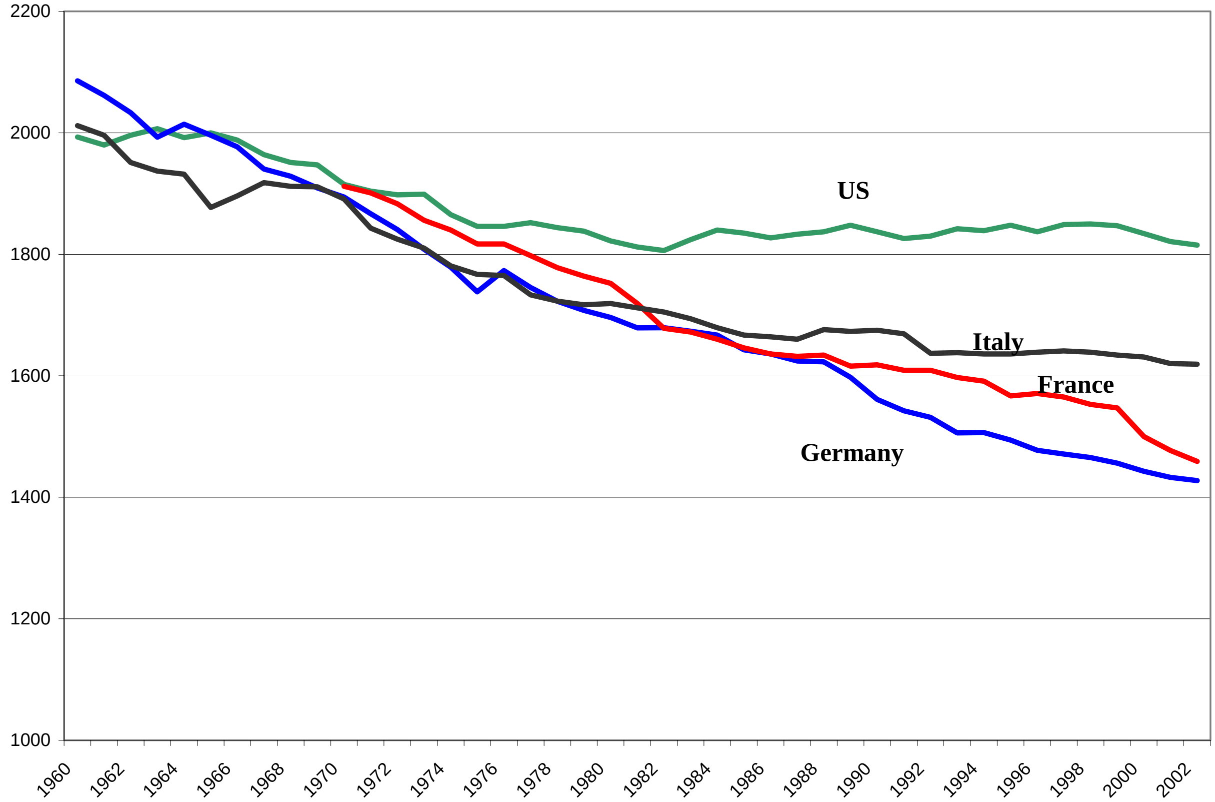
  Suppose the rate of innovation is constant, but firms can decide about the timing of implementation of their innovation. Suppose that firms get rents from the introduction of a new product, but these rents disappear over time due to entry of competitors.

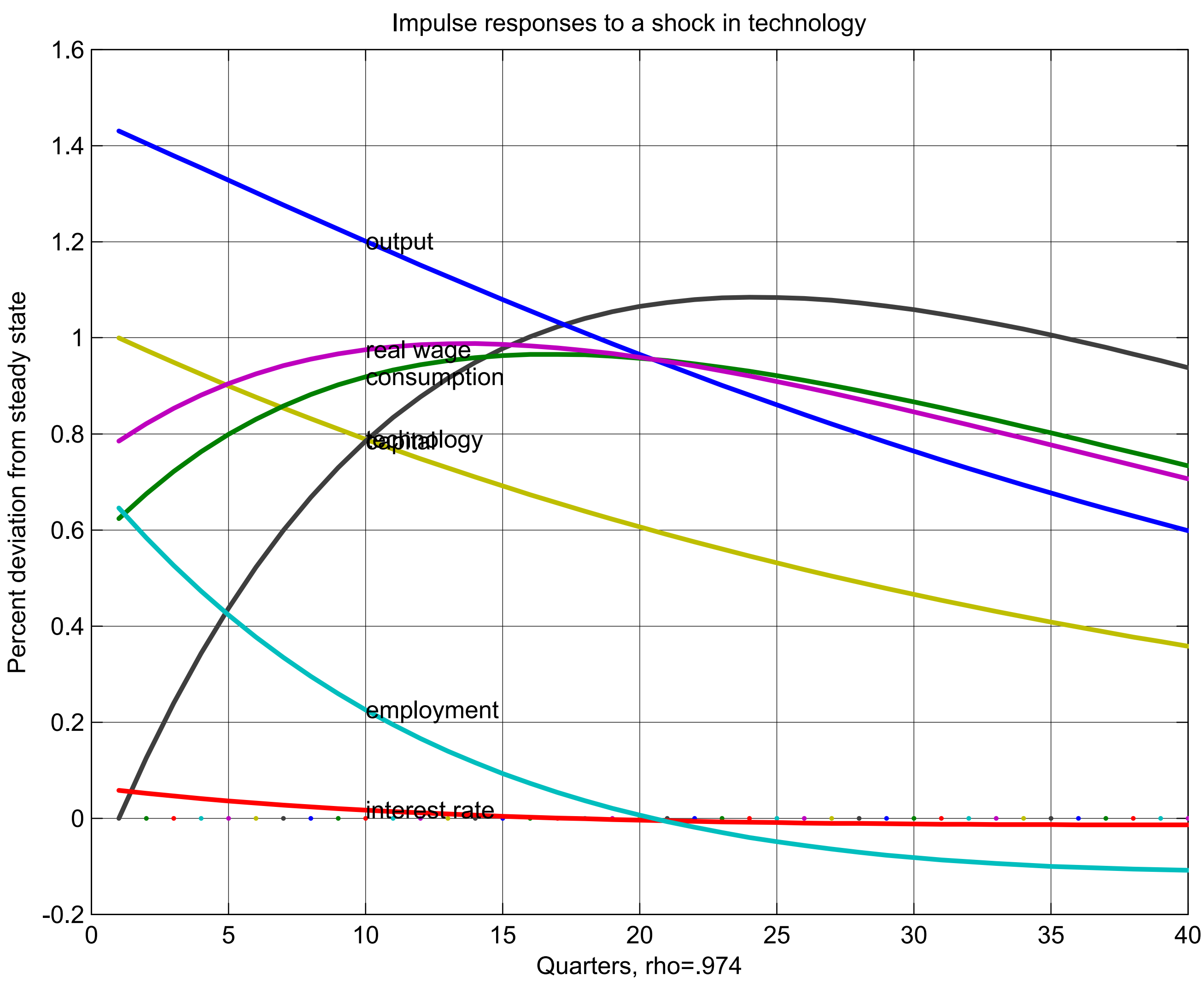
  Then firms will want to introduce their products when rents are largest, thus when aggregate demand is highest. Aggregate demand will be highest when many firms introduce their products, leading to an increase in aggregate income. Thus, the economy will exhibit implementation cycles, times when many firms introduce new products,

followed by quiet times, and a new burst of implementation.
How relevant? It appears to fit aspects of the 1990s. It provides perhaps the most plausible account of why smooth discoveries may lead to sharper aggregate cycles.

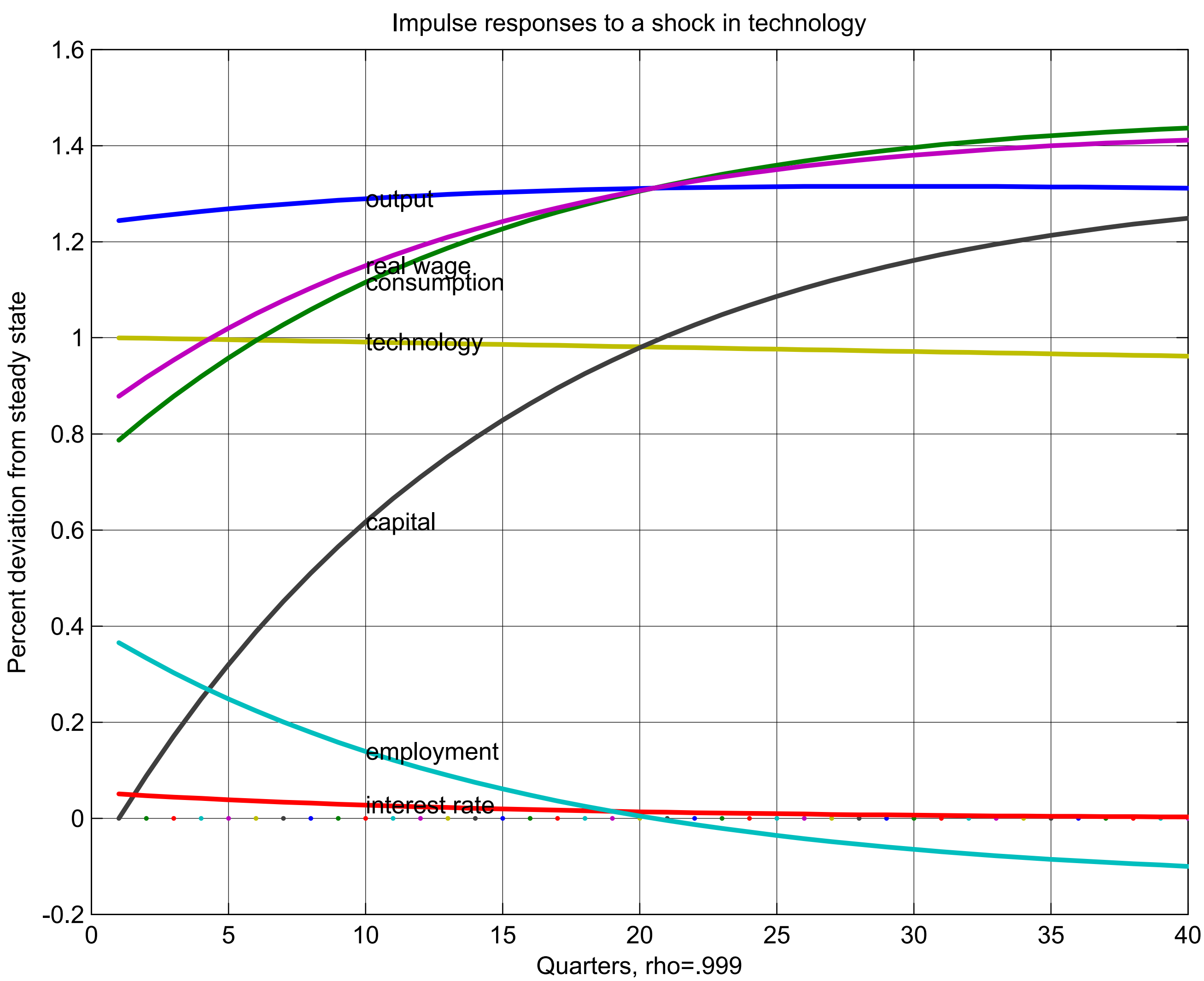
Figure 1
Annual Hours Worked Over Time

OECD data. Annual hours per employed person. Annual hours are equivalent to 52*usual weekly hours minus holidays, vacations, sick leave.





Impulse responses to a shock in technology
Percent deviation from steady state
Quarters, rho=.974
output
real wage
consumption
technology
capital
employment
interest rate
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
5
10
15
20
25
30
35
40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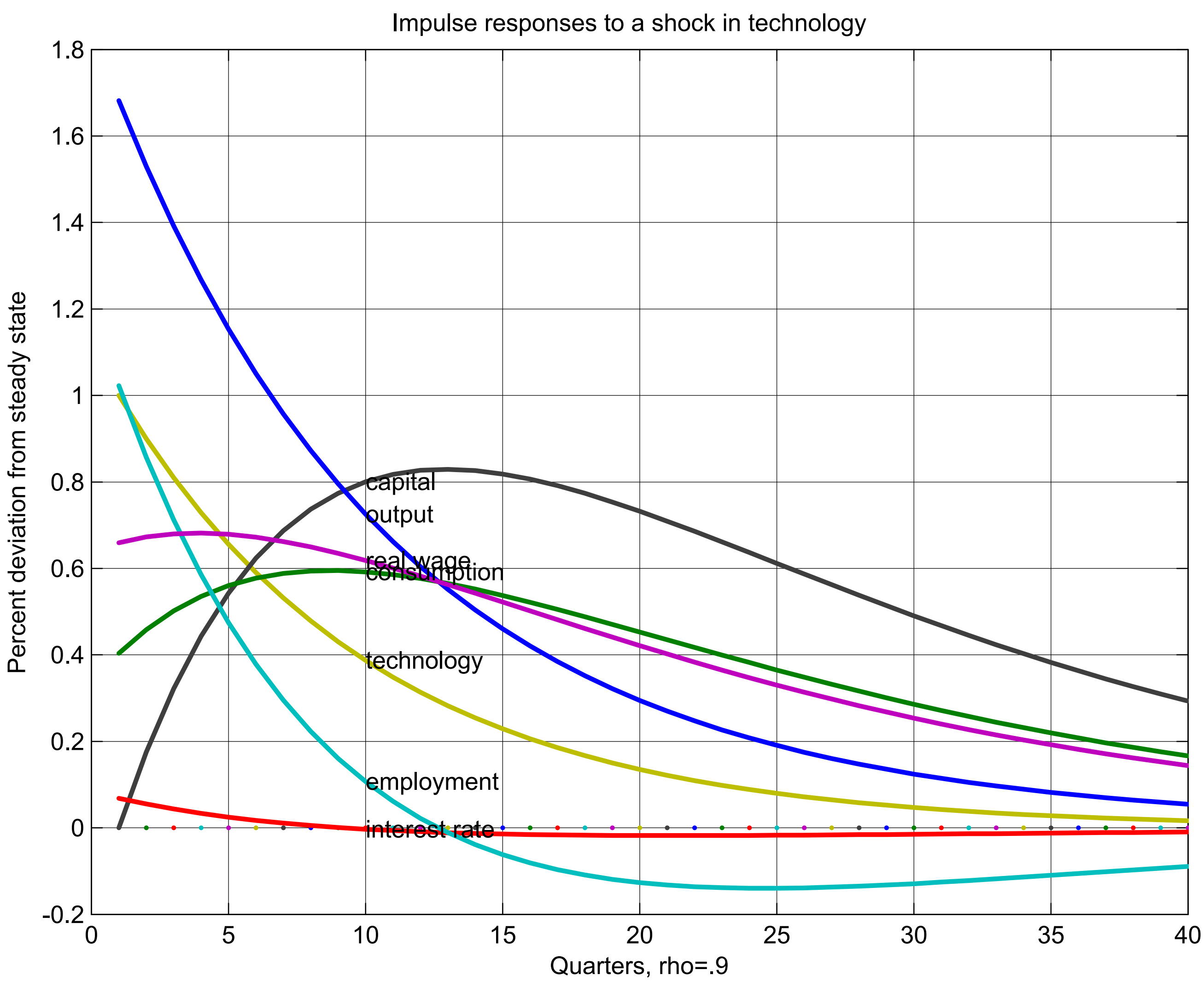
Percent deviation from steady state
output
real wage
consumption
technology
capital
employment
interest rate
0
5
10
15
20
25
30
35
40
Quarters, rho=.999



Impulse responses to a shock in technology
Percent deviation from steady state
Quarters, rho=.9
capital
output
real wage
consumption
technology
employment
interest rate
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
5
10
15
20
25
30
35
40

of 0.9. This high serial correlation is the reason why there is some predictability to the business cycle.

Table 1
Business Cycle Statistics for the U.S. Economy

	Standard Deviation	Relative Standard Deviation	First Order Auto-correlation	Contemporaneous Correlation with Output
Y	1.81	1.00	0.84	1.00
C	1.35	0.74	0.80	0.88
I	5.30	2.93	0.87	0.80
N	1.79	0.99	0.88	0.88
Y/N	1.02	0.56	0.74	0.55
w	0.68	0.38	0.66	0.12
r	0.30	0.16	0.60	-0.35
A	0.98	0.54	0.74	0.78

Note: All variables are in logarithms (with the exception of the real interest rate) and have been detrended with the HP filter. Data sources are described in Stock and Watson [1998], who created the real rate using VAR inflation expectations. Our notation in this table corresponds to that in the text, so that Y is per capita output, C is per capita consumption, I is per capita investment, N is per capita hours, w is the real wage (compensation per hour), r is the real interest rate, and A is total factor productivity.

In presenting these business cycle facts, we are focusing on a small number of empirical features that have been extensively discussed in recent work on real business cycles. For example, in the interest of brevity, we have not discussed the lead-lag relations between our variables. In choosing the series to study, we have also left out nominal variables, whose cyclical behavior is at the heart of many controversies over the nature of business cycles.[13] However, we do report the

[13]See Stock and Watson [1998, sections 3(d), 3(f), and 4.1] for a discussion of literature and empirical results.

reported in the second columns of Tables 1 and 3. In particular, investment is about three times more volatile than output in both the actual economy (where the ratio of standard deviations is 5.30/1.81=2.93) and the model economy (where the ratio of standard deviations is 2.95). Consumption is substantially smoother than output in both the model and actual economies. In our basic model, however, consumption is only about one-third as volatile as output while it is over two thirds as volatile as output in the U.S. economy. We return to discussion of this feature of the economy in section 6 below.

Table 3
Business Cycle Statistics for Basic RBC Model[35]

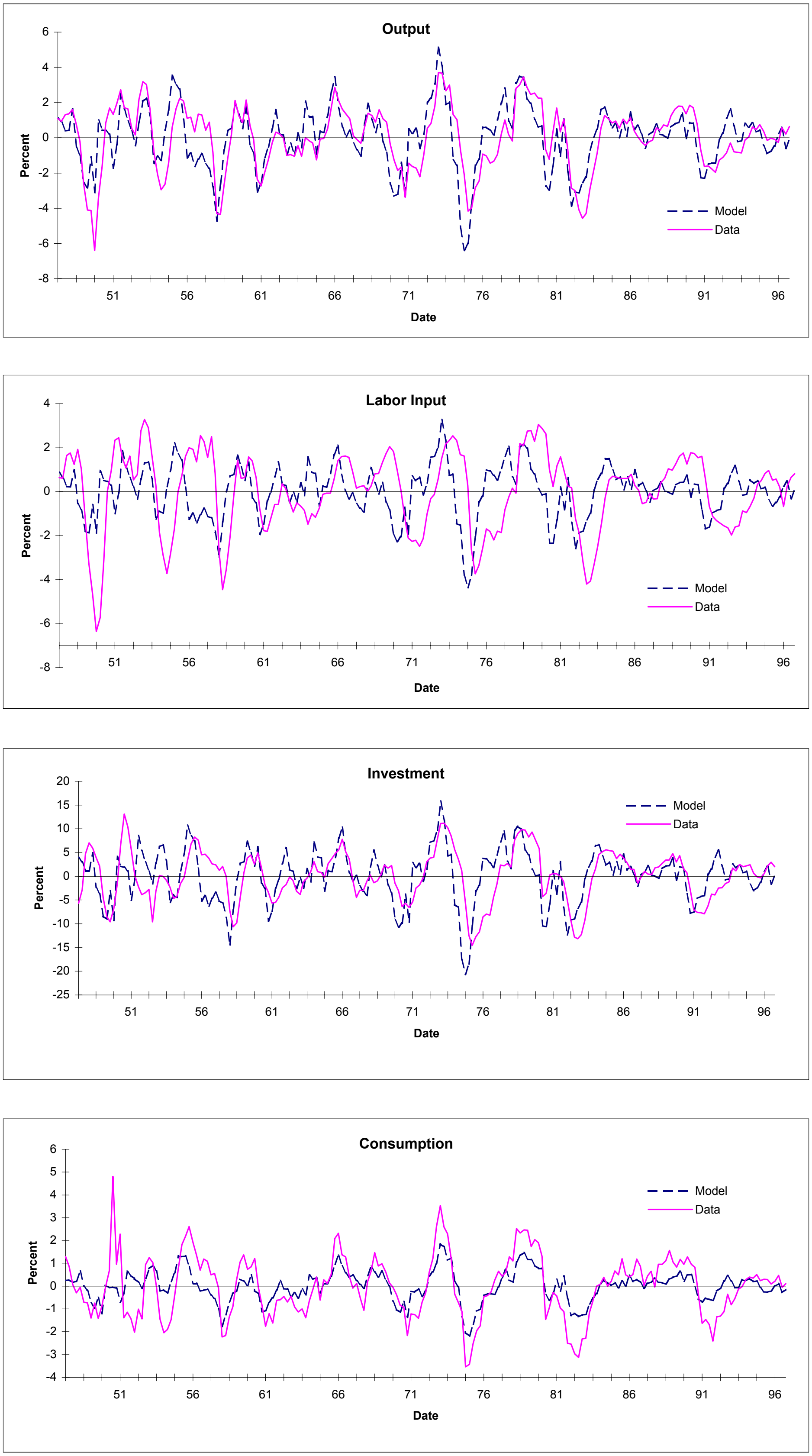
	Standard Deviation	Relative Standard Deviation	First Order Auto-correlation	Contemporaneous Correlation with Output
Y	1.39	1.00	0.72	1.00
C	0.61	0.44	0.79	0.94
I	4.09	2.95	0.71	0.99
N	0.67	0.48	0.71	0.97
Y/N	0.75	0.54	0.76	0.98
w	0.75	0.54	0.76	0.98
r	0.05	0.04	0.71	0.95
A	0.94	0.68	0.72	1.00

Note: All variables have been logged (with the exception of the real interest rate)and detrended with the HP filter.

Persistence and comovement with output. Business cycles are persistently high or low levels of economic activity: one measure of this persistence is the first-order serial correlation coefficient. Table 3 shows that the persistence generated by the basic model is generally high, but weaker than in the data (see Table 1). The relative standard deviations also provide a measure of the limited extent to which

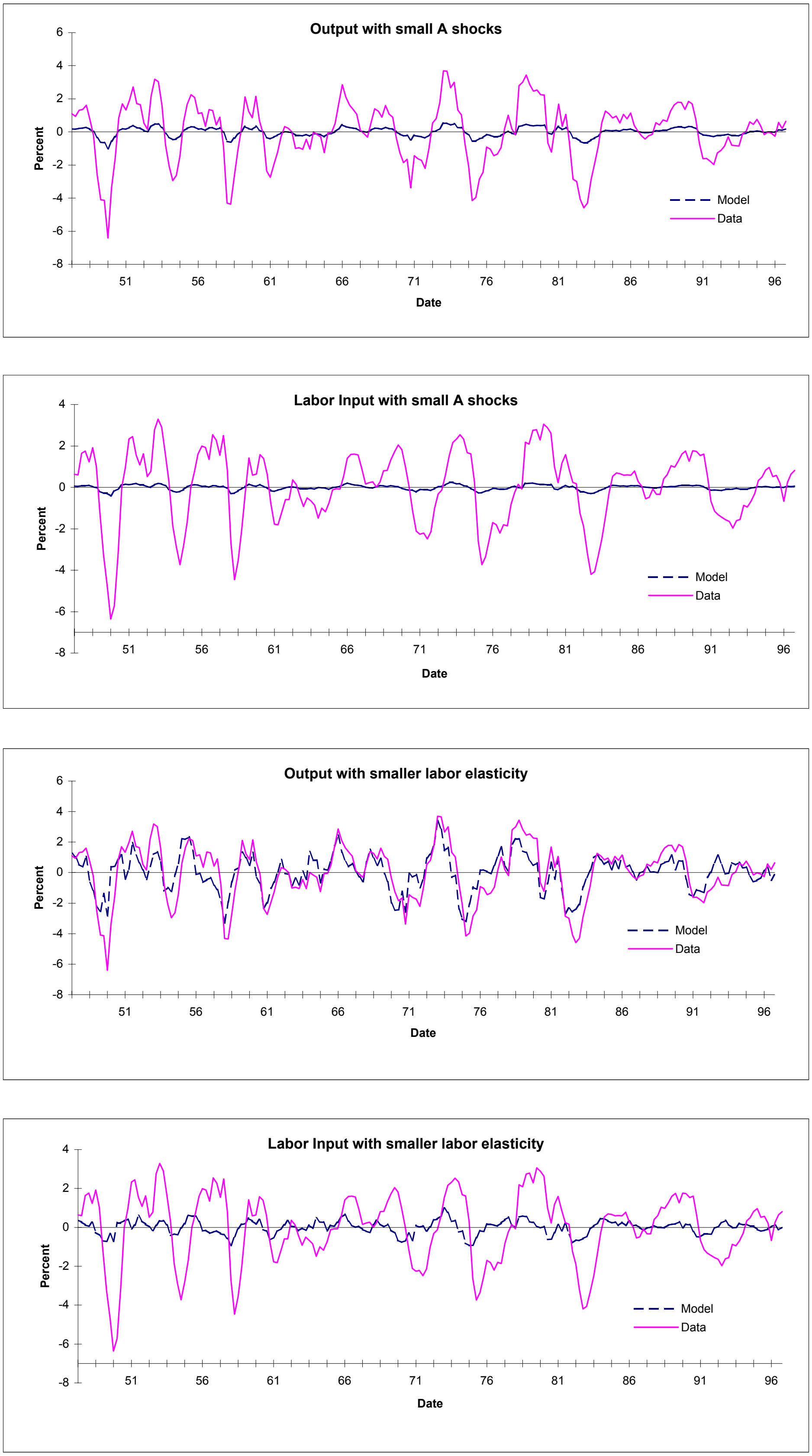
[35]The moments in this table are population moments computed from the solution of the model. Prescott [1986] produced multiple simulations, each with the same number of observations available in the data, and reported the average HP-filtered moments across these simulations.

Figure 7



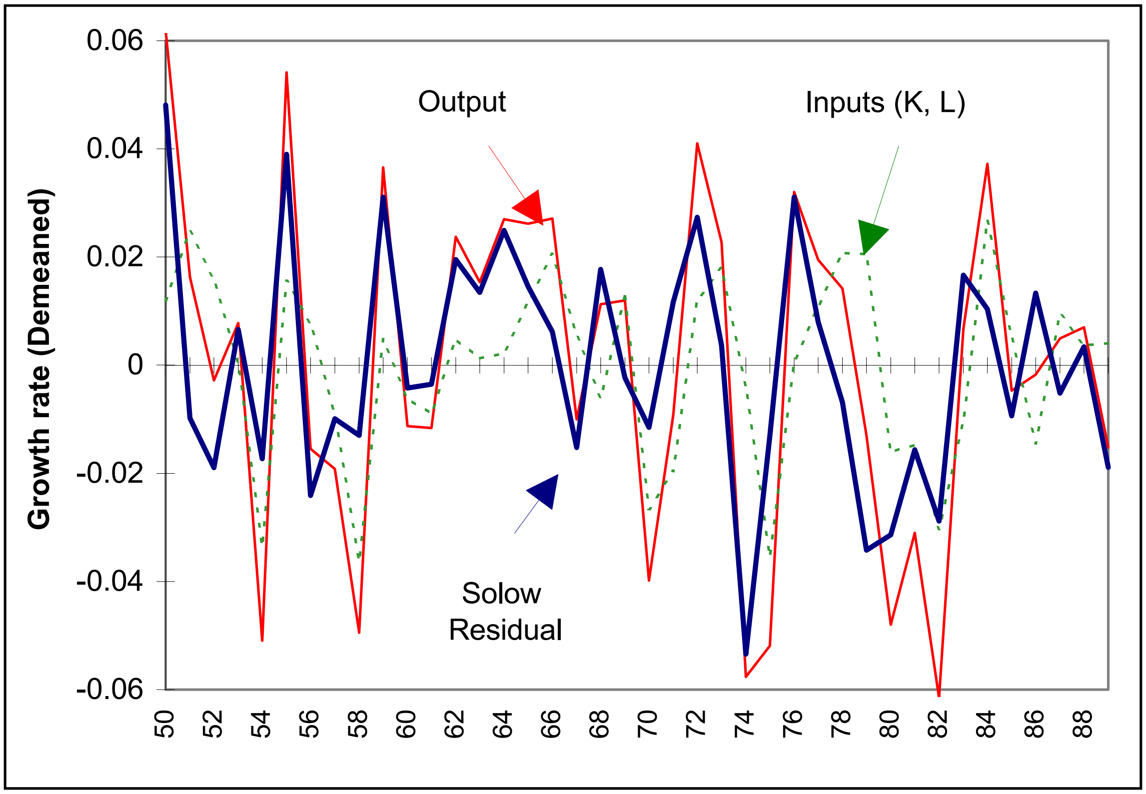
Note: Sample period is 1947:2 - 1996:4. All variables are detrended using the Hodrick-Prescott filter.

Figure 8



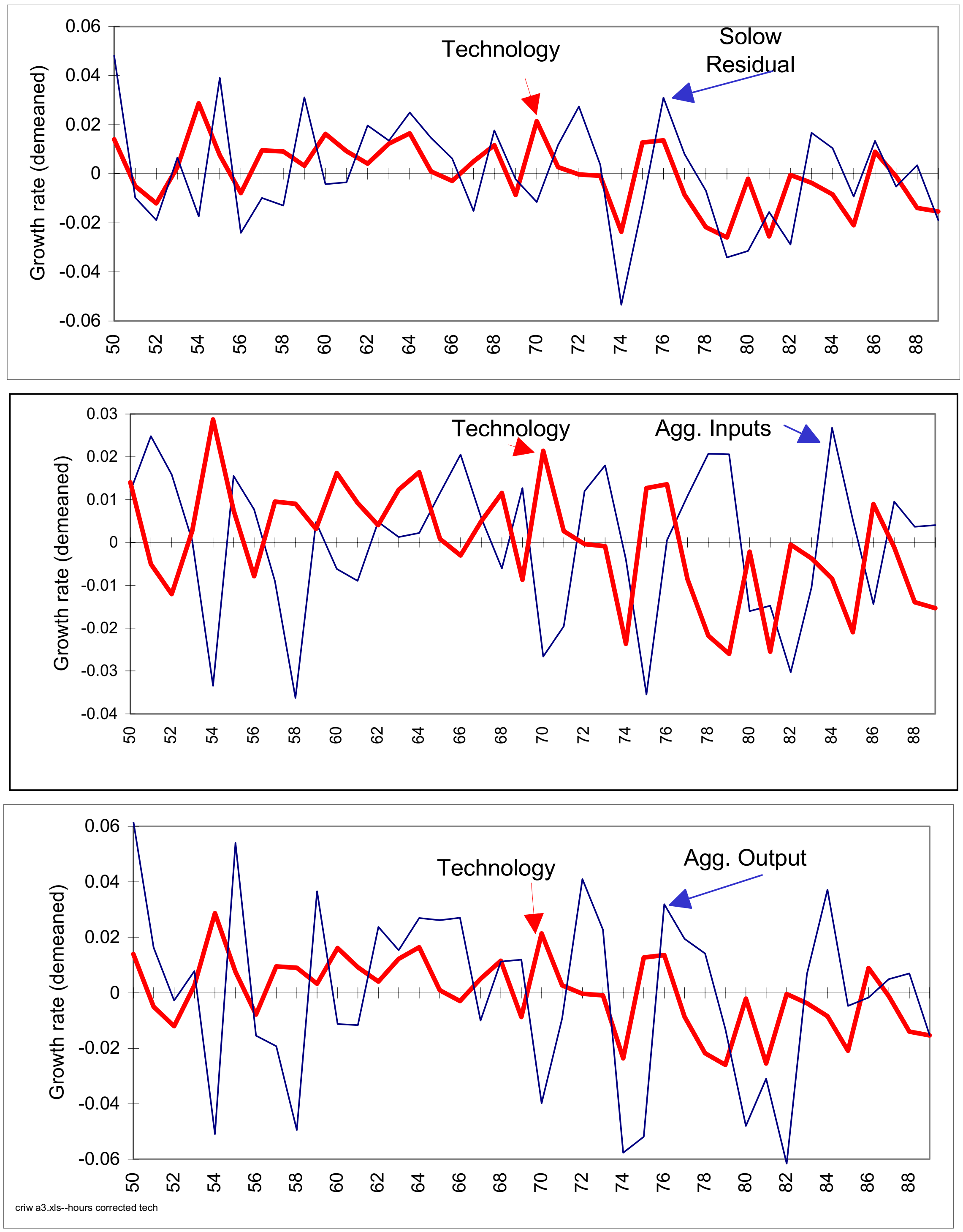
Note: Sample period is 1947:2 - 1996:4. All variables are detrended using the Hodrick-Prescott filter.

Figure 1. Aggregate Solow Residual, Input Growth, and Output Growth



Note: All series are demeaned. Sample period in 1950-89. Data are from Jorgenson, Gollop, and Fraumeni for the non-farm private business economy. Inputs are a share-weighted average of capital and labor growth.

Figure 3. Technology Residual, Solow Residual, Output and Input Growth



Note: The technology series is the hours-adjusted aggregate residual, which measures technology change (adjusted for variations in utilization) for the non-farm business economy. Aggregate inputs are a share-weighted average of capital and labor growth. All series are demeaned. Entries are log changes. Sample period is 1950-89.

Figure 2. The Estimated Effects of Technology Shocks

Difference Specification , 1948:01-2002:04

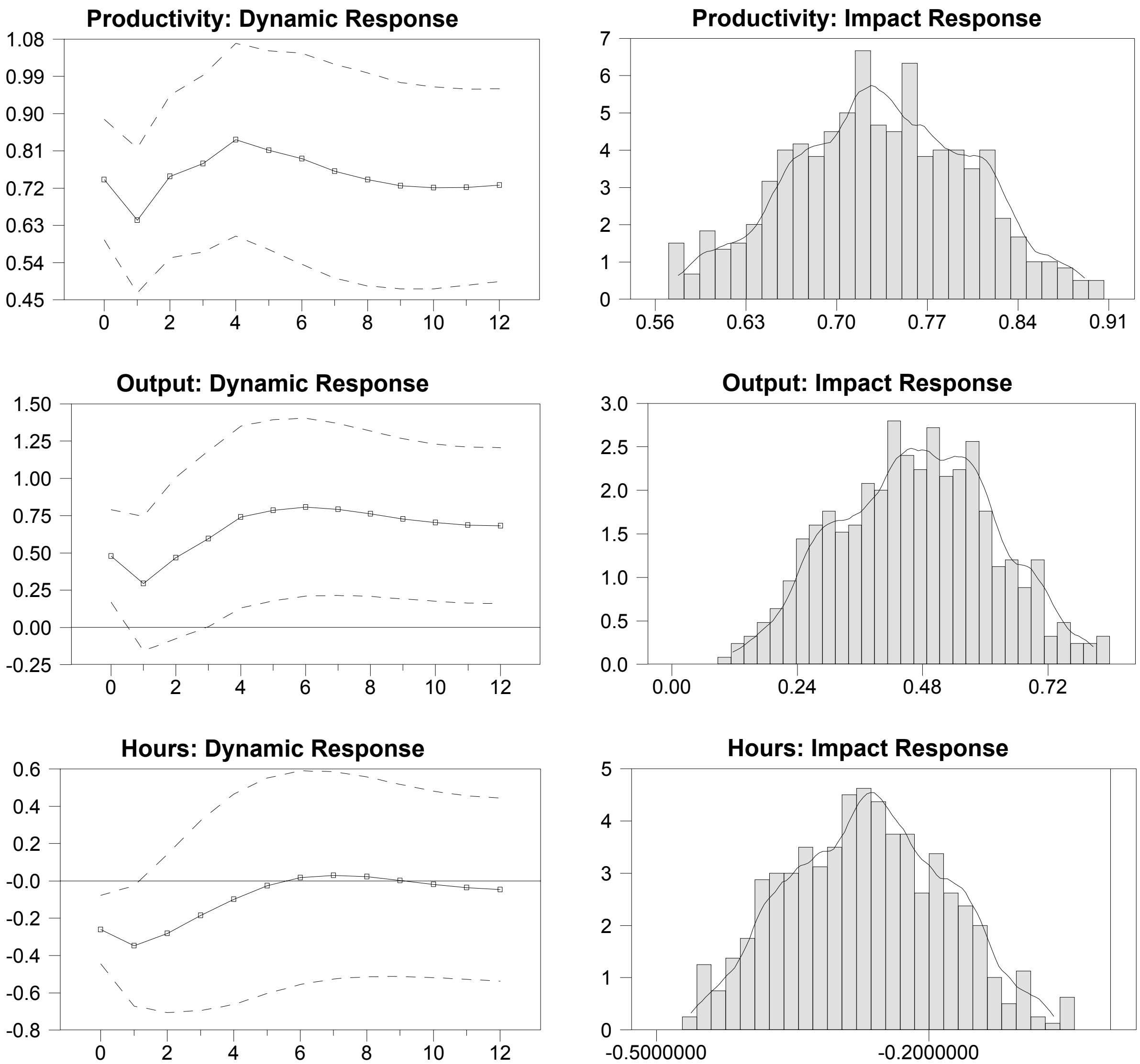


Figure 3: Sources of U.S. Business Cycle Fluctuations

Difference Specification , Sample Period:1948:01-2002:04

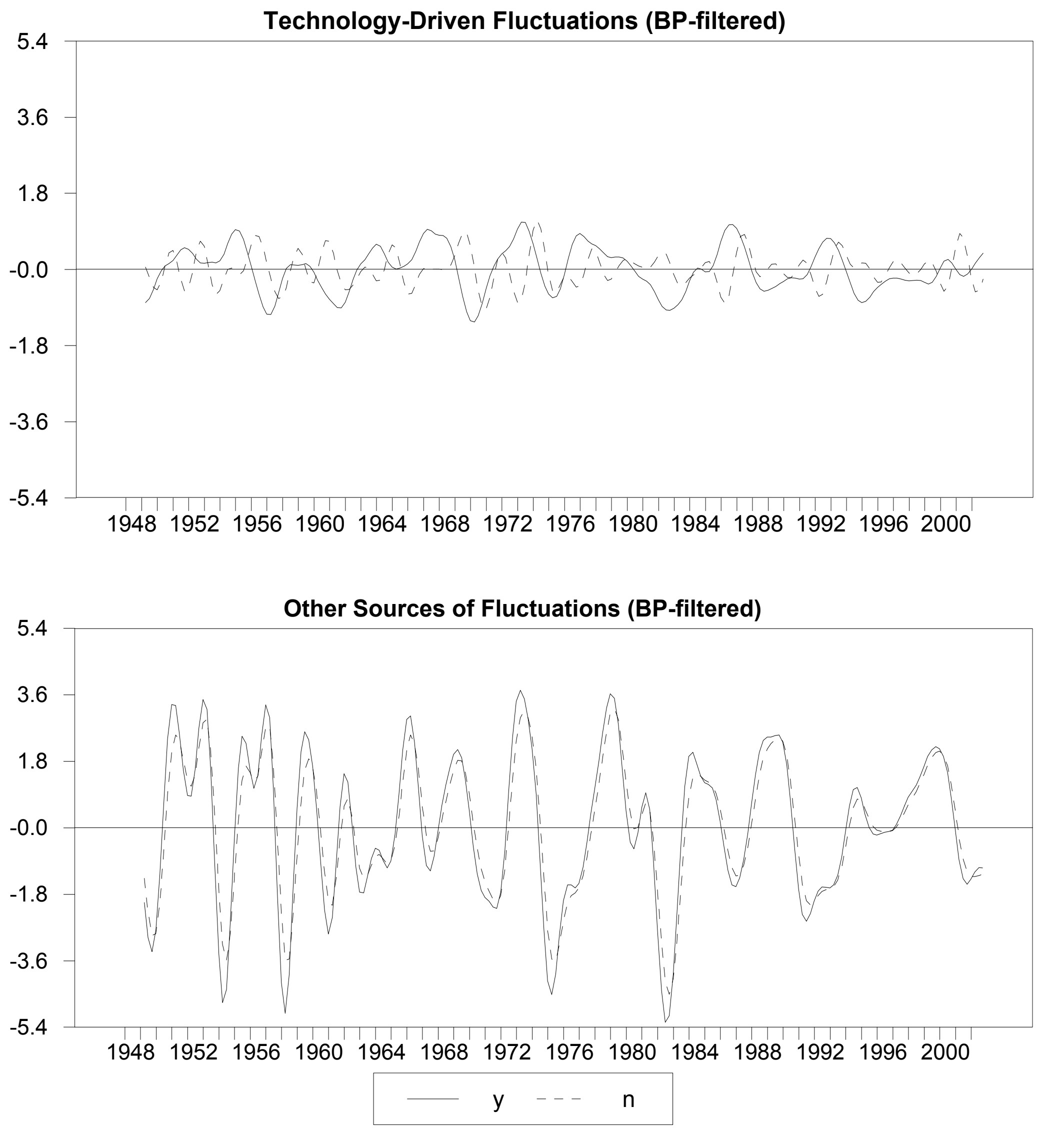


Figure 5. Technology Shocks: VAR vs. BFK