Measurement and business cycle facts

Lecture 11, ECON 4310

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How to build business cycle models?

Main motivation for macroeconomics: The desire to understand economic fluctuations (business cycles). What models are applied?

- RBC
- New Keynesian
- General label: DSGE (dynamic stochastic general equilibrium) models. Almost all business cycle research in academia is currently done using DSGE models. DSGE models have
  - An RBC model in its core
  - Then several 'frictions' are added
  - Example: New Keynesian models are basically just RBC models with monopolistic competition and "sticky" prices

How to build business cycle models? II

What generates business cycles in a DSGE model?

- Stochastic shocks are the drivers behind business cycles
- With no shocks, the economy will be at rest in its (steady state) equilibrium
- As Kydland and Prescott discuss, this is an important difference from 'deterministic' cycle models

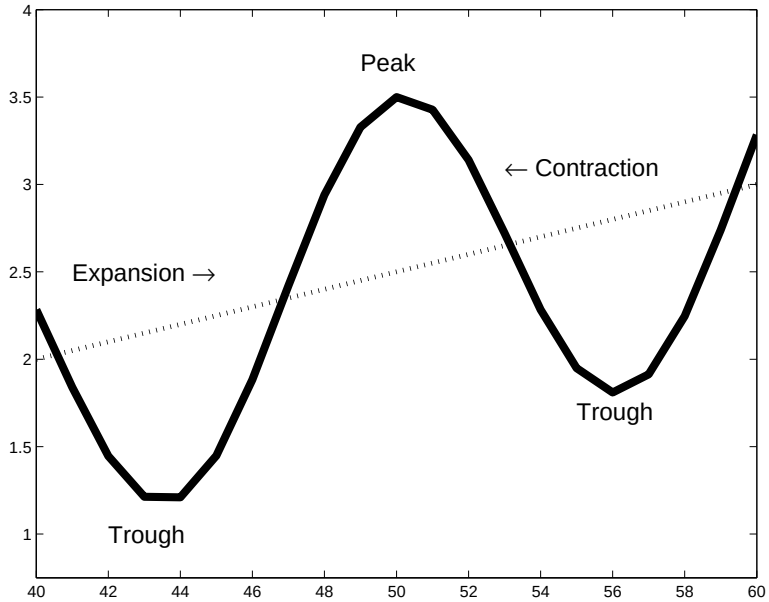
But to say anything about the performance/quality of a model we need to measure real world business cycles.

Outline

What is a business cycle?

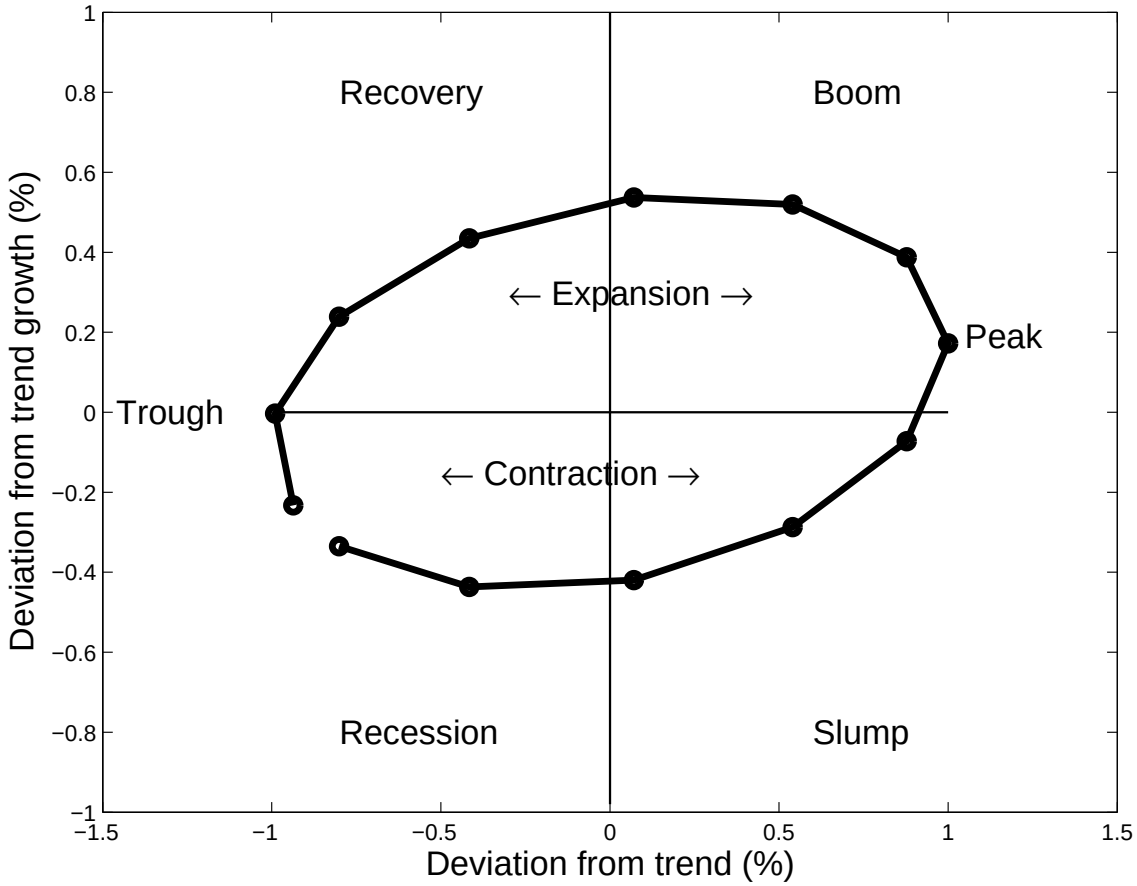
- GDP is a fine measure of economic activity and statistics agencies produce quarterly data on the level of GDP
- GDP in levels can (roughly) be divided into three different components:
  - Long run linear or non-stationary (stochastic) trends and medium run factors
  - Business cycle (cyclical) fluctuations
  - Short run noise

Example of a 'perfect cycle': Dashed line gives the long run trend, solid line the actual development (trend + cyclical, no noise).



What is a business cycle? II

The four phases of a business cycle:



What is a business cycle? III

Real world example: Norwegian mainland real GDP (seasonally adjusted). The data we download from Statistics Norway look like this (in logs):

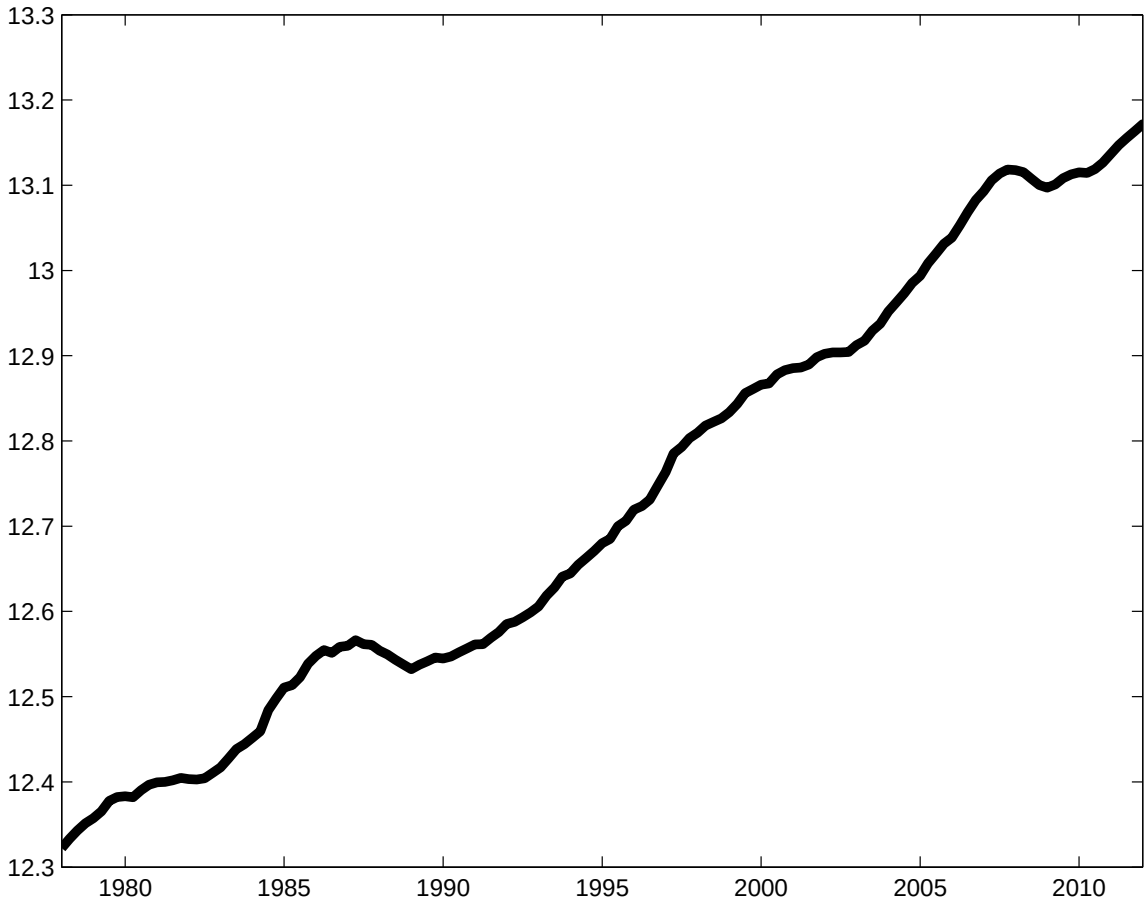


Figure: Norwegian mainland real GDP (smoothed), 1978(1)-2013(2). Source: SSB

What is a business cycle? IV

We will focus at the period 1986-1998. According to Statistics Norway (Eika and Johansen, 2000), Norway experienced:

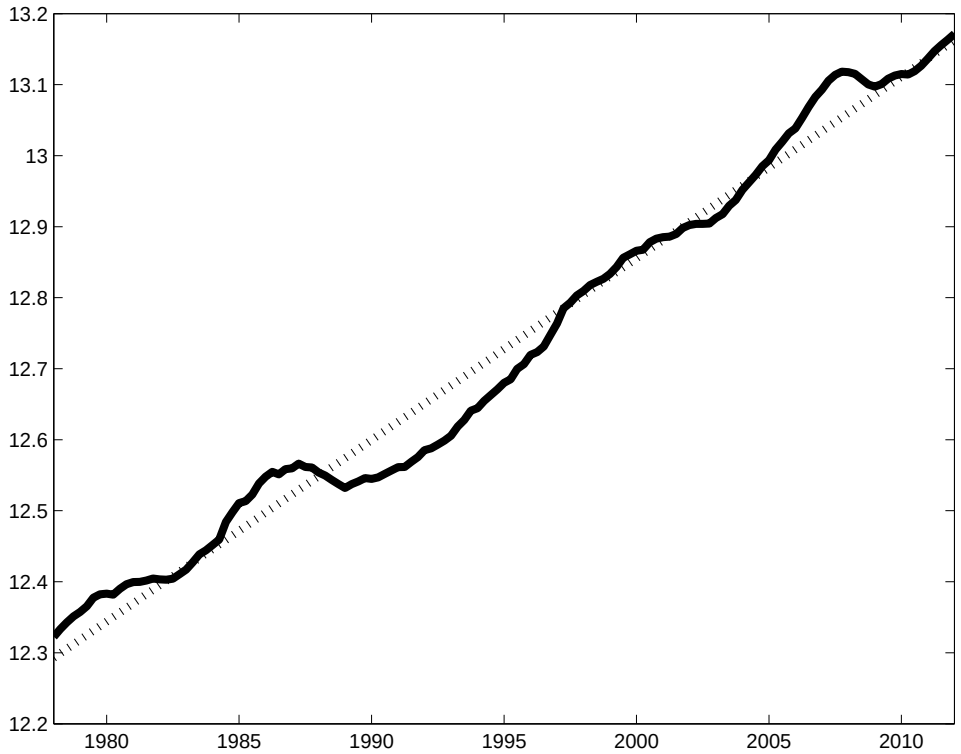
- An expansion in 83-86: Recovery in 83-84 and a boom in 85-86 (peak in Q3-1986)
- A contraction in 86-92: Slump in 86-87, recession in 88-92 (trough in Q4-92)
- Then a new expansion running to 1998. Recovery in 93-96, boom from 96.

Are we able to reach a similar conclusion using our GDP series? We will try three methods: Linear de-trending, HP-filter and BP-filter.

Linear trend

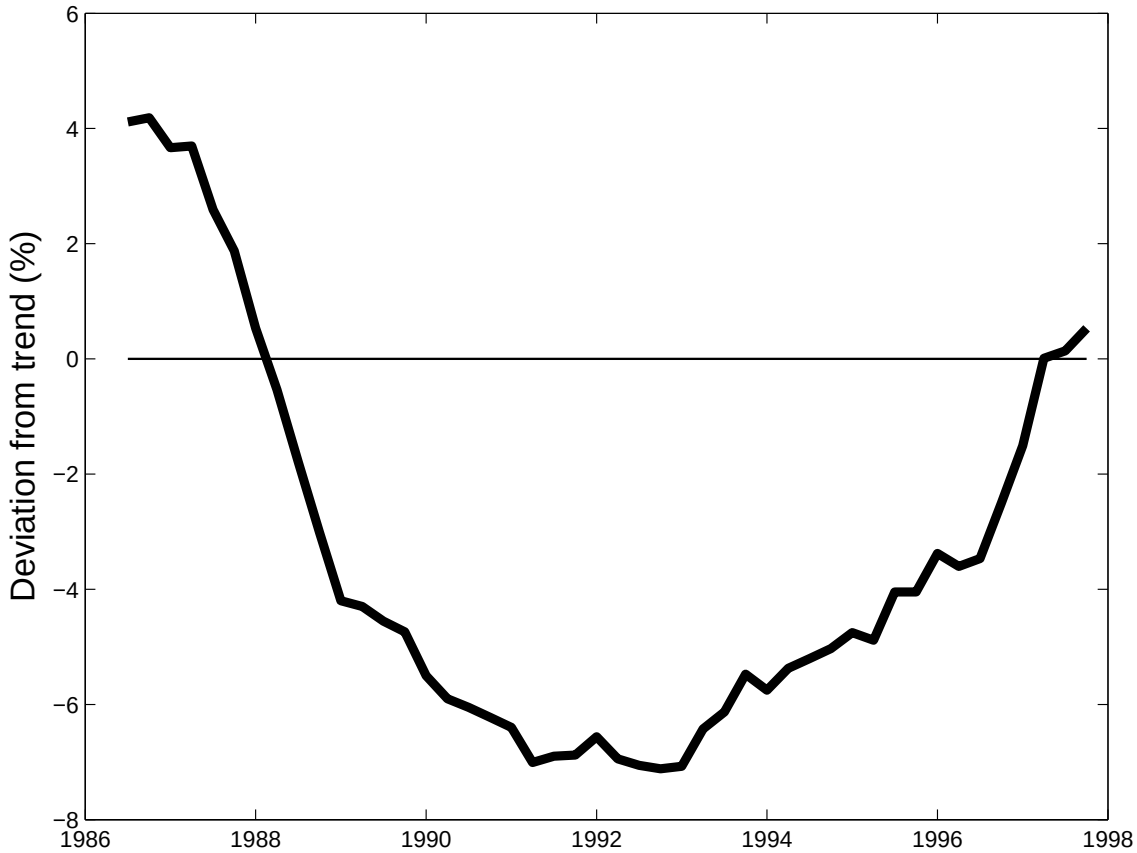
Let y_t be GDP measured in logs. If you use linear de-trending you assume that in the absence of shocks GDP should grow at a constant rate. To de-trend, just regress:

$$y_t = \beta_0 + \beta_1 t + e_t$$



Linear trend II

Cyclical component is $c_t = y_t - \hat{\beta}_0 - \hat{\beta}_1 t$. What we get from this method puts us in the right ballpark (it was indeed a deep recession), but it might be too deep, and the recovery looks too slow at the end.



HP-filter

- A problem with linear de-trending is that it is, yes, linear.
- Could be desirable to use methods that allow for a time-varying growth rate of the trend.
- Frequently applied: The Hodrick-Prescott filter (see Krueger for a discussion)

We define the trend component τ_t and cycle component $c_t = y_t - \tau_t$. For a series $\{y_t\}_{t=1}^T$, the HP-filter involves solving:

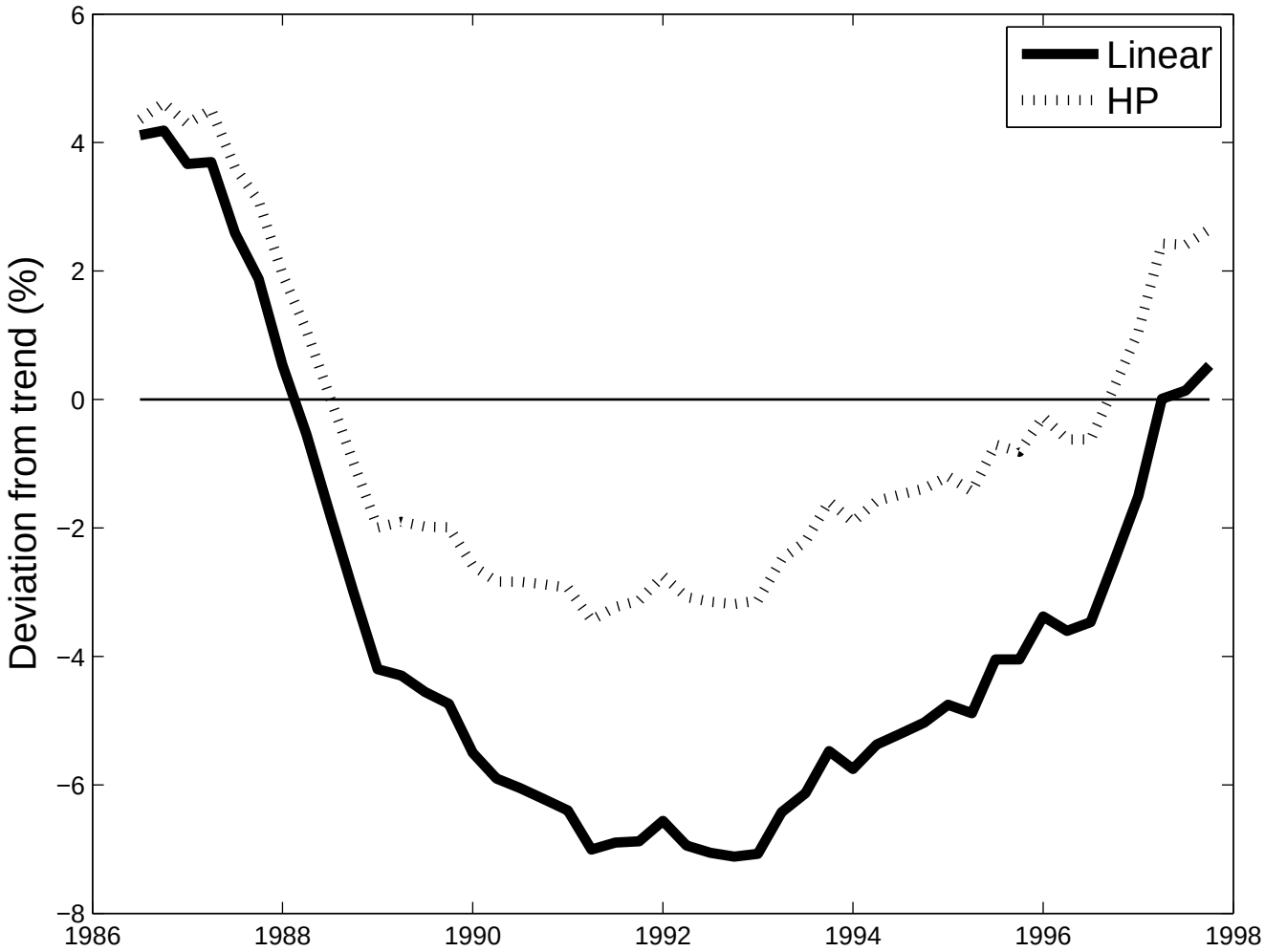
$$\min_{\{\tau_t\}_{t=1}^T} \sum_{t=1}^{T}(y_t - \tau_t)^2 + \lambda \sum_{t=2}^{T-1}(y_t - \tau_t)^2 \left[(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})\right]^2$$

where λ is a parameter you need to choose yourself.

- If $\lambda = 0$, $\tau_t = y_t$, so $c_t = 0$ for all t
- If $\lambda \to \infty$, $\tau_t = y_t^{trend}$ (the linear trend), so c_t is just like in the linear de-trending case
- Default choice for quarterly data: $\lambda = 1600$. (But Statistics Norway often use 40,000 so that is what I use!)
- Can solve for the HP filter by hand: It is only a constrained optimization problem. Most statistics software has a command for the HP-filter.

The HP-filter II

In our case, the HP filter allows the trend to fall compared to the linear trend. The effect is a less severe recession and a quicker recovery. More in line with Statistics Norway.



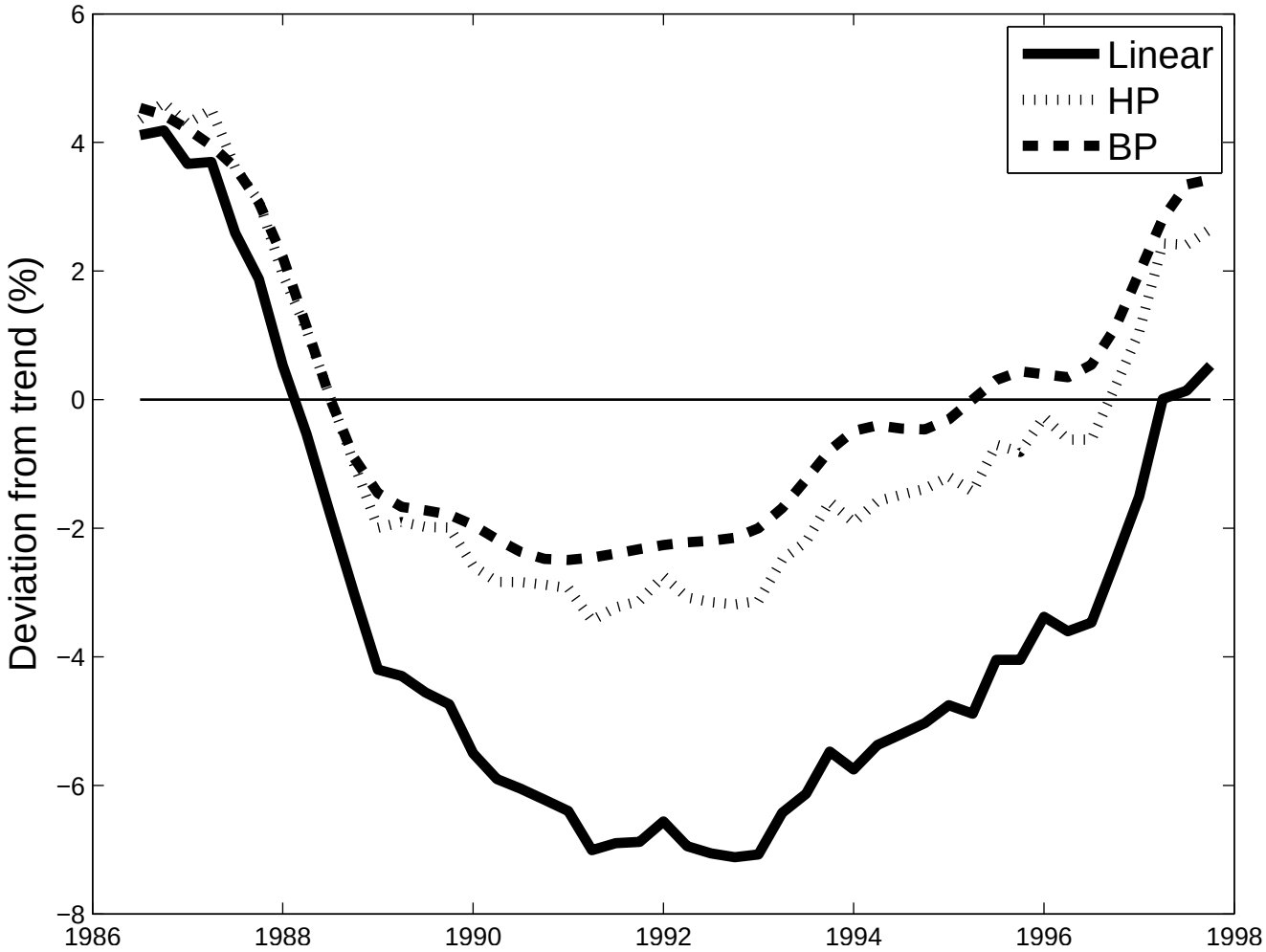
BP-filter

Now, what linear de-trending and the HP-filter do is to remove the *trend*. But since we only care about the cyclical component, we should ideally also remove short term noise. For this purpose we can use the band pass (BP) filter (Reference: "The Band Pass Filter" by Lawrence J. Christiano and Terry J. Fitzgerald (1999), NBER working paper.).

- This is a filter based on *spectral analysis*
- Idea: A statistical process (such as GDP) can be represented on the time series domain but also along the *frequency domain*
- For the latter, the process is thought of as a function of lots of different *cos* and *sin* waves
- Allows you to identify the part of GDP that reflects the *business cycle frequency*, lets say between 6 and 64 quarters. (This allows for long cycles)
- We take out the part of GDP at longer frequencies (i.e. the trend) and higher frequencies (i.e. noise).

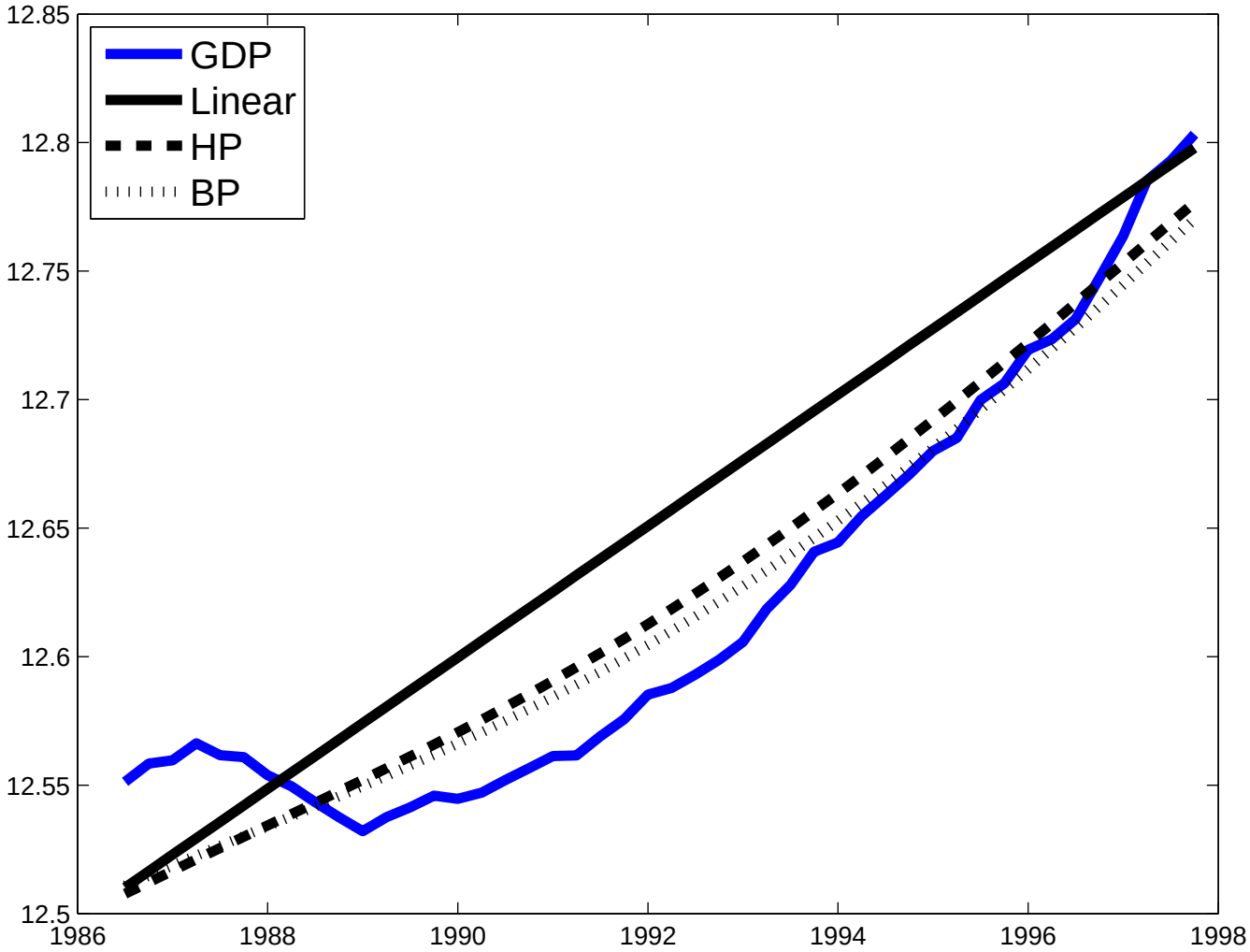
BP-filter II

Comparing the cyclical components based on linear trend, HP filter and BP filter.



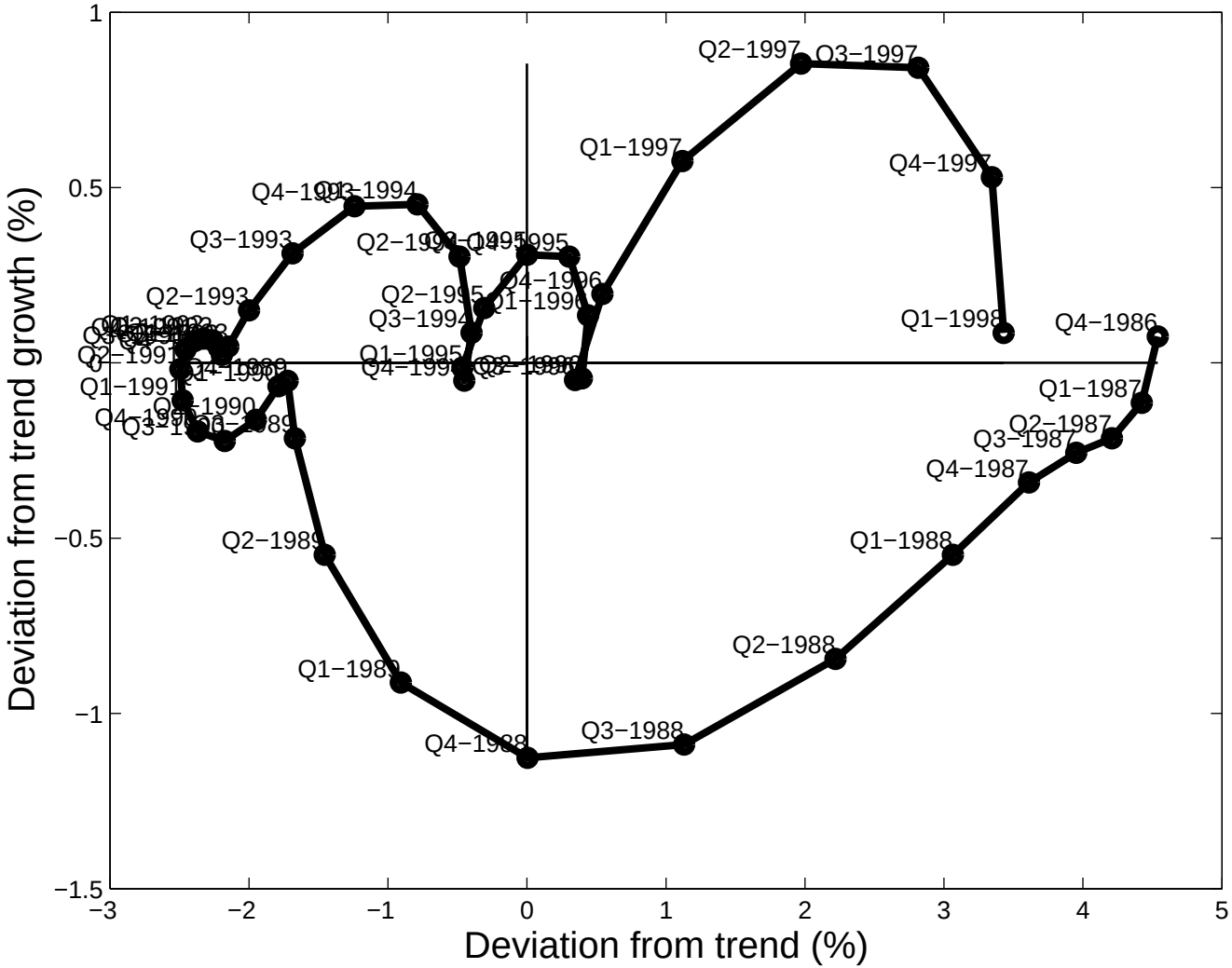
BP-filter III

Comparing the trends:



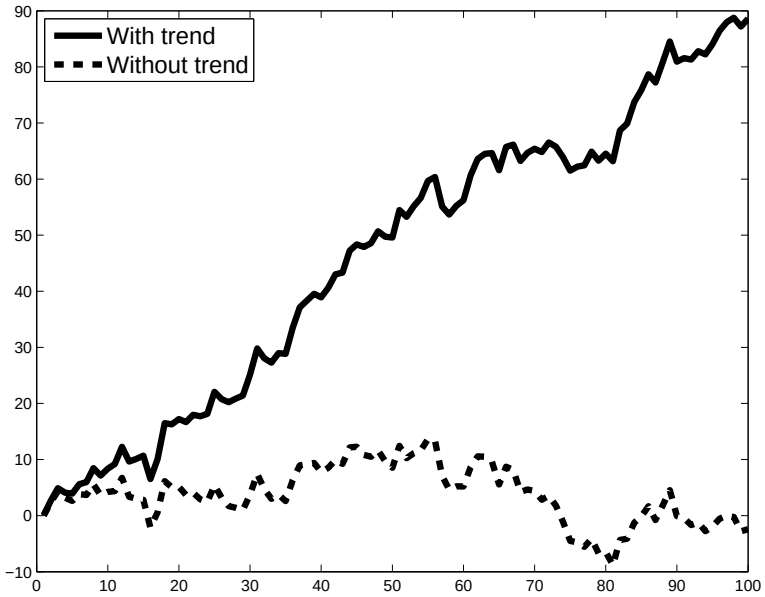
Phases of the cycle

Then we can draw a diagram that represents the four phases of the cycle again. x-axis: Deviation from trend. y-axis: $\Delta c_t = \Delta y_t - \Delta \tau_t$. Figure is based on the results from the band pass filter. Gives a pretty good match to Statistics Norway's description.



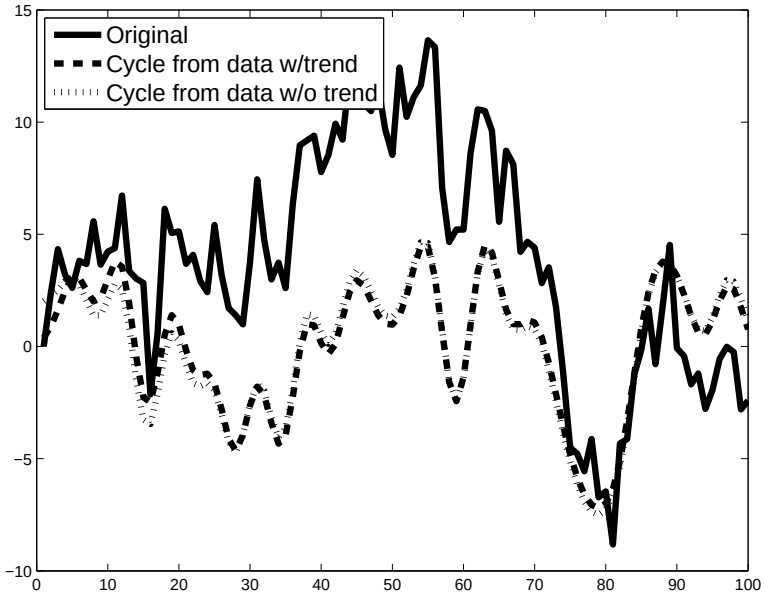
More on filtering

- We've seen that applying either the HP or BP filter (which is simple to implement – you should do it!) will give us the cyclical component of a time series
- Since these techniques allow for a non-linear trend, you should remember that we also take out 'medium run' trends.
- Example: These data-series are identical, except that in the solid line I have added a linear trend.



More on filtering II

- When we filter, two things happen:
- First, the linear trend is taken out (giving the series almost identical cyclical components!)
- Second, the 'medium-run' movements in the series are also taken to be part of the trend.



More on filtering III

Then let us ask: How do we interpret the cyclical component?

- We have already implicitly interpreted the cyclical GDP componenet for Norway as a measure of the output gap – the difference between current output and 'sustainable'/long-run output
- But how we interpret it depends on what economic model you have in mind
- In the RBC model (which we come to), all fluctuations in GDP reflect changes in sustainable output. The output gap (as defined above) is therefore zero. The cyclical component then reflects changes in sustainable output.
- In an old-school Keynesian model, fluctuations in GDP reflect demand shocks, animal spirits, etc.
- How useful these filters are also depends on the economic model you have for long and medium run changes in the economy
- Example: During the last years it has been debated whether potential output in the US has fallen or not.
  - Some authors argue that the cyclical component of US GDP is already positive since the long-run trend has flattened.
  - Others argue that filtering techniques have problems during persistent events. Large and prolonged drops in output are attributed to the trend, while it really is a cyclical thing.

Outline

Measuring business cycle facts

- We have seen how to use filters to go from econonomic data in *levels* to the *cyclical* components
- These cyclical components can then be used to create business cycle 'facts'
- A criterion for macro models should then be that if we produce data from the model and filter it with the same technique as applied to real data, or model should match these business cycle facts!
- A typical strategy for measuring the relevant 'business cycle facts' is to:
  - Collect data for a set of variables Z_t
  - Compute deviations from trend (using e.g. the HP-filter)
  - Find variances and correlations

Measuring business cycle facts II

The tables reported by Kydland and Prescott (1990) have the common format. For the series y_t, q_t and z_t they report:

		Cross-correlation of y_t with:				
Variable x_t	Volatility	x_{t-2}	x_{t-1}	x_t	x_{t+1}	x_{t+2}
y_t	σ_y	$\rho(y_t, y_{t-2})$	$\rho(y_t, y_{t-1})$	$\rho(y_t, y_t)$	$\rho(y_t, y_{t+1})$	$\rho(y_t, y_{t+2})$
q_t	σ_q	$\rho(y_t, q_{t-2})$	$\rho(y_t, q_{t-1})$	$\rho(y_t, q_t)$	$\rho(y_t, q_{t+1})$	$\rho(y_t, q_{t+2})$
z_t	σ_z	$\rho(y_t, z_{t-2})$	$\rho(y_t, z_{t-1})$	$\rho(y_t, z_t)$	$\rho(y_t, z_{t+1})$	$\rho(y_t, z_{t+2})$

[the variables have been de-trended]

Measuring business cycle facts III

Labels:

- If the contemporaneous correlation coefficient of a variable with real GDP is positive (negative), we say it is *procyclical* (*countercyclical*)
- A variable *leads* the cycle if correlation coefficient of the series which is shifted *forward* wrt real GDP is greatest
- A variable *lags* the cycle if correlation coefficient of the series when shifted *backward* wrt real GDP is greatest

Measuring business cycle facts III

Imagine that we have the following numbers:

		Cross-correlation of y_t with:				
Variable x_t	Volatility	x_{t-2}	x_{t-1}	x_t	x_{t+1}	x_{t+2}
y_t	1.5	0.4	0.7	1	0.7	0.4
q_t	0.8	0.2	0.3	0.5	**0.8**	0.6
z_t	2	-0.6	**-0.7**	-0.5	-0.1	0.2

For each variable we care about (i) amplitude, (ii) degree of comovement with the business cycle and (iii) the phase shift relative to the business cycle.

- In this case q is less volatile than y and a **procyclical** variable. It **lags** the business cycle by one quarter.
- z is more volatile then y and a **countercyclical** variable. It **leads** the business cycle by one quarter.

Note an implicit assumption: Movements in y represent the business cycle

Business cycle facts

Kydland and Prescott (1990) argue that

- Economic theory is an important guide for which economic facts to look at
- But one should be allowed to report facts without putting it into the context of a complete model

Their paper is therefore all about reporting stylized business cycle facts for the US. Hopefully, such facts will be helpful in the process of writing new and improved models.

Business cycle facts II

- KP follow Lucas in defining business cycles as the deviations of aggregate real output from trend
- Trend is measured using the HP-filter
- Variables selected for inspection are those central in neoclassical models

Business cycle facts III

Table 1

Cyclical Behavior of U.S. Production Inputs

Deviations From Trend of Input Variables
Quarterly, 1954–1989

Variable x	Volatility (% Std. Dev.)	Cross Correlation of Real GNP With										
		$x(t-5)$	$x(t-4)$	$x(t-3)$	$x(t-2)$	$x(t-1)$	$x(t)$	$x(t+1)$	$x(t+2)$	$x(t+3)$	$x(t+4)$	$x(t+5)$
Real Gross National Product	1.71	−0.03	0.15	0.38	0.63	0.85	1.00	0.85	0.63	0.38	0.15	−0.03
Labor Input												
Hours (Household Survey)	1.47	−0.10	0.05	0.23	0.44	0.69	0.86	0.86	0.75	0.59	0.38	0.18
Employment	1.06	−0.18	−0.04	0.14	0.36	0.61	0.82	0.89	0.82	0.67	0.47	0.25
Hours per Worker	0.54	0.08	0.21	0.35	0.49	0.66	0.71	0.59	0.43	0.29	0.11	−0.02
Hours (Establishment Survey)	1.65	−0.23	−0.07	0.14	0.39	0.66	0.88	0.92	0.81	0.64	0.42	0.21
GNP/Hours (Household Survey)	0.88	0.11	0.21	0.34	0.48	0.50	0.51	0.21	−0.02	−0.25	−0.34	−0.36
GNP/Hours (Establishment Survey)	0.83	0.40	0.46	0.49	0.53	0.43	0.31	−0.07	−0.31	−0.49	−0.52	−0.50
Average Hourly Real Compensation (Business Sector)	0.91	0.30	0.37	0.40	0.42	0.40	0.35	0.26	0.17	0.05	−0.08	−0.20
Capital Input												
Nonresidental Capital Stock*	0.62	−0.58	−0.61	−0.51	−0.48	−0.31	−0.08	0.16	0.39	0.56	0.66	0.70
Structures	0.37	−0.45	−0.51	−0.55	−0.53	−0.44	−0.29	−0.10	0.09	0.25	0.38	0.45
Producers' Durable Equipment	0.99	−0.57	−0.58	−0.53	−0.41	−0.22	0.02	0.26	0.47	0.62	0.70	0.71
Inventory Stock (Nonfarm)	1.65	−0.37	−0.33	−0.23	−0.05	0.19	0.50	0.72	0.83	0.81	0.71	0.53

*Based on quarterly data, 1954:1–1984:2.
Source of basic data: Citicorp's Citibase data bank

Business cycle facts IV

Table 1 deals with production inputs. What do we observe?

- Hours worked are about as volatile as output, highly procyclical and is contemporaneously correlated with the cycle (or slightly lagging)
- Most of the volatility of hours is due to the *extensive*, not the *intensive* margin (i.e. employment, not hours per worker)
- The lag in correlation is more due to employment than hours per worker
- The capital stock seems acyclical, but is strongly lagging the cycle.
- Inventories are almost as volatile as output, procyclical, and lags the cycle.

Business cycle facts V

Variable x	Volatility (% Std. Dev.)	Cross Correlation of Real GNP With										
		$x(t-5)$	$x(t-4)$	$x(t-3)$	$x(t-2)$	$x(t-1)$	$x(t)$	$x(t+1)$	$x(t+2)$	$x(t+3)$	$x(t+4)$	$x(t+5)$
Real Gross National Product	1.71	−0.03	0.15	0.38	0.63	0.85	1.00	0.85	0.63	0.38	0.15	−0.03
Consumption Expenditures	1.25	0.25	0.41	0.56	0.71	0.81	0.82	0.66	0.45	0.21	−0.02	−0.21
Nondurables & Services	0.84	0.20	0.38	0.53	0.67	0.77	0.76	0.63	0.46	0.27	0.06	−0.12
Nondurables	1.23	0.29	0.42	0.52	0.62	0.69	0.69	0.57	0.38	0.16	−0.05	−0.22
Services	0.63	0.03	0.25	0.46	0.63	0.73	0.71	0.60	0.49	0.39	0.23	0.07
Durables	4.99	0.25	0.38	0.50	0.64	0.74	0.77	0.60	0.37	0.10	−0.14	−0.32
Investment Expenditures	8.30	0.04	0.19	0.39	0.60	0.79	0.91	0.75	0.50	0.21	−0.05	−0.26
Fixed Investment	5.38	0.09	0.25	0.44	0.64	0.83	0.90	0.81	0.60	0.35	0.08	−0.14
Nonresidential	5.18	−0.26	−0.13	0.05	0.31	0.57	0.80	0.88	0.83	0.68	0.46	0.23
Structures	4.75	−0.40	−0.31	−0.17	0.03	0.29	0.52	0.65	0.69	0.63	0.50	0.34
Equipment	6.21	−0.18	−0.04	0.14	0.39	0.65	0.85	0.90	0.81	0.62	0.38	0.15
Residential	10.89	0.42	0.56	0.66	0.73	0.73	0.62	0.37	0.10	−0.15	−0.34	−0.45
Government Purchases	2.07	0.00	−0.03	−0.03	−0.01	−0.01	0.05	0.09	0.12	0.17	0.27	0.34
Federal	3.68	0.00	−0.05	−0.08	−0.09	−0.09	−0.02	0.03	0.06	0.10	0.19	0.24
State & Local	1.19	0.06	0.10	0.17	0.25	0.26	0.25	0.20	0.16	0.19	0.27	0.36
Exports	5.53	−0.50	−0.46	−0.34	−0.14	0.11	0.34	0.48	0.53	0.53	0.53	0.45
Imports	4.92	0.11	0.18	0.30	0.45	0.61	0.71	0.71	0.51	0.28	0.03	−0.19
Real Net National Income												
Labor Income*	1.58	−0.18	−0.02	0.18	0.42	0.68	0.88	0.90	0.80	0.62	0.40	0.19
Capital Income**	2.93	0.10	0.24	0.44	0.63	0.79	0.84	0.60	0.30	0.02	−0.19	−0.29
Proprietors' Income & Misc.†	2.70	0.11	0.24	0.38	0.55	0.62	0.68	0.46	0.29	0.11	0.02	−0.10

Business cycle facts VI

Table 2 contains the output components.

- We see that consumption is overall a procyclical variable, contemporaneously correlated with the cycle, almost leading.
- The volatility differs greatly across consumption goods: Durables are more than twice as volatile as output, while services are only a third as volatile as output
- Investment expenditures is another strongly procyclical variable contemporaneously correlated with the cycle.
- Investment is even more volatile than durables consumption, for any subcategory. Residential investments are more than 5 times as volatile as output
- Government purchases seem to be completely uncorrelated with the cycle
- Exports and imports are as volatile as consumption of durables and procyclical. Exports lag the cycle, while imports are contemporaneously correlated.

Business cycle facts VII

Table 4

Cyclical Behavior of U.S. Monetary Aggregates and the Price Level

Deviations From Trend of Money Stock, Velocity, and Price Level
Quarterly, 1954–1989

Variable x	Volatility (% Std. Dev.)	Cross Correlation of Real GNP With										
		$x(t-5)$	$x(t-4)$	$x(t-3)$	$x(t-2)$	$x(t-1)$	$x(t)$	$x(t+1)$	$x(t+2)$	$x(t+3)$	$x(t+4)$	$x(t+5)$
Nominal Money Stock*												
Monetary Base	0.88	−0.12	0.02	0.14	0.25	0.36	0.41	0.40	0.37	0.32	0.28	0.26
M1	1.68	0.01	0.12	0.23	0.33	0.35	0.31	0.22	0.15	0.09	0.07	0.07
M2	1.51	0.48	0.60	0.67	0.68	0.61	0.46	0.26	0.05	−0.15	−0.33	−0.46
M2 – M1	1.91	0.53	0.63	0.67	0.65	0.56	0.40	0.20	−0.01	−0.21	−0.39	−0.53
Velocity*												
Monetary Base	1.33	−0.26	−0.15	0.00	0.22	0.40	0.59	0.50	0.37	0.22	0.08	−0.08
M1	2.02	−0.24	−0.19	−0.12	−0.01	0.14	0.31	0.32	0.27	0.20	0.10	0.00
M2	1.84	−0.63	−0.59	−0.48	−0.29	−0.05	0.24	0.34	0.40	0.43	0.44	0.43
Price Level												
Implicit GNP Deflator	0.89	−0.50	−0.61	−0.68	−0.69	−0.64	−0.55	−0.43	−0.31	−0.17	−0.04	0.09
Consumer Price Index	1.41	−0.52	−0.63	−0.70	−0.72	−0.68	−0.57	−0.41	−0.24	−0.05	0.14	0.30

*Based on quarterly data, 1959:1–1989:4.
Source of basic data: Citicorp's Citibase data bank

Business cycle facts VIII

Table 4 illustrates the nominal side of the story.

- The money stock is procyclical and M_1 and M_2 are about as volatile as production
- M_2 seems to lead the cycle, but not M_1
- The velocities are not leading the cycle
- **The price level is countercyclical and leading the cycle**. The CPI is almost as volatile as output.

The last observation leads KP to reject what they refer to as a "monetary myth" (that the price level is procyclical).

Business cycle facts IX

This persepective, that Kydland and Prescott, pioneered gave macro researchers a road map to see in what directions models should be improved. As mentioned, the driving force behind business cycles in DSGE models is a range of stochastic shocks that are put into the models. General challenge:

- Real-world business are very persistent
- Often difficult to generate sufficiently inherent persistence in DSGE models
- Therefore necessary to have quite persistent shocks

An example of a shock would be productivity. In the first RBC models, Kydland and Prescott, among others, showed how a simple neoclassical model with technology shocks could account for a large part of the business cycle variation in the US (a heavily debated claim).

AR processes

The shocks (or the log of the shocks) are usually modeled as *AR(1)* processes. What is an AR(1) process? We define an autoregressive process of order 1 as:

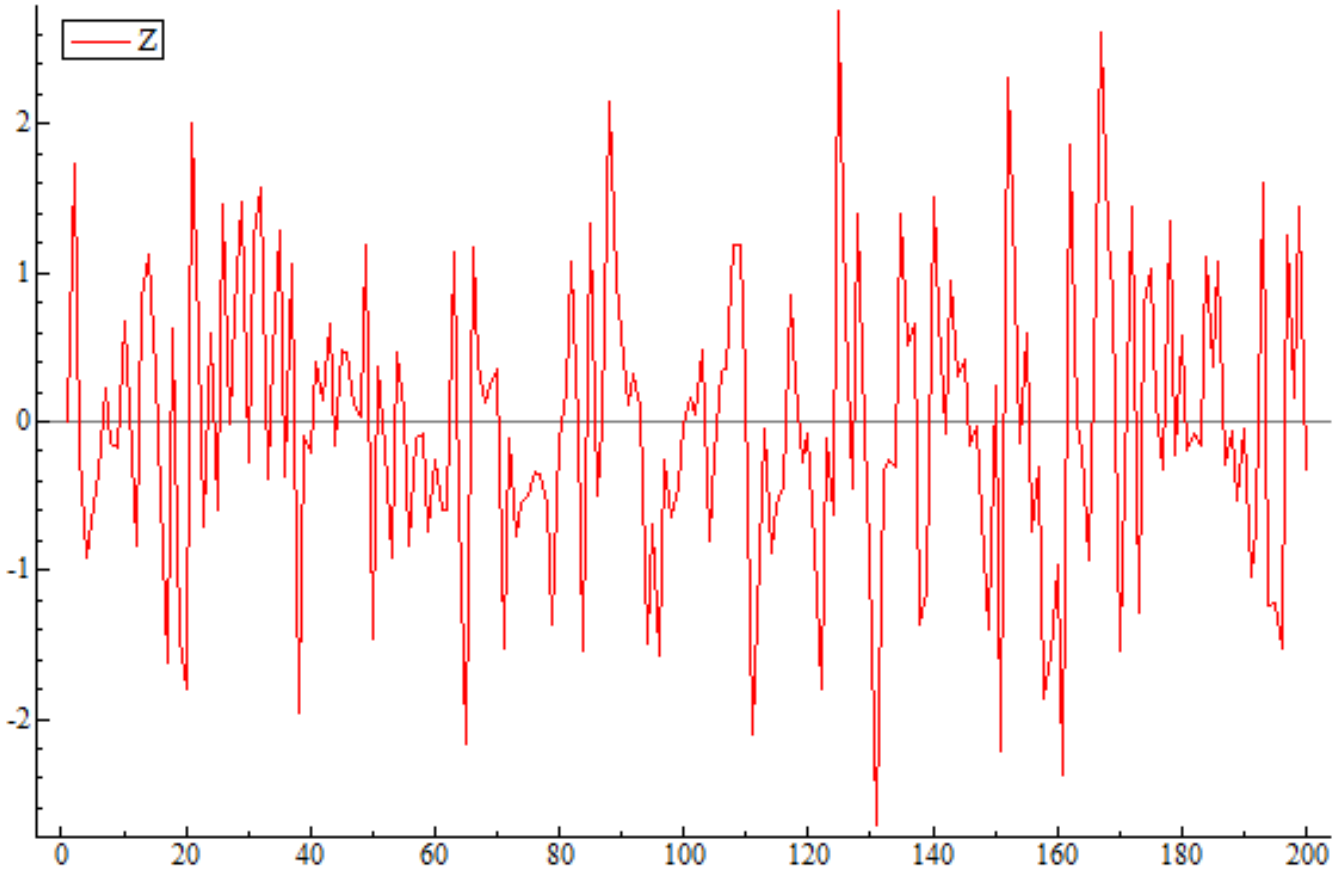
$$Z_t = \rho Z_{t-1} + \varepsilon_t$$

ε_t is usually assumed to be iid $N(0, \sigma^2)$, while $0 \leq \rho \leq 1$. The AR-parameter ρ measures how persistent the process is.

- If $\rho = 0$, then Z_t will vary randomly around its mean
- If $0 < \rho < 1$, then Z_t may deviate persistently away from its mean, but it will always return to it.

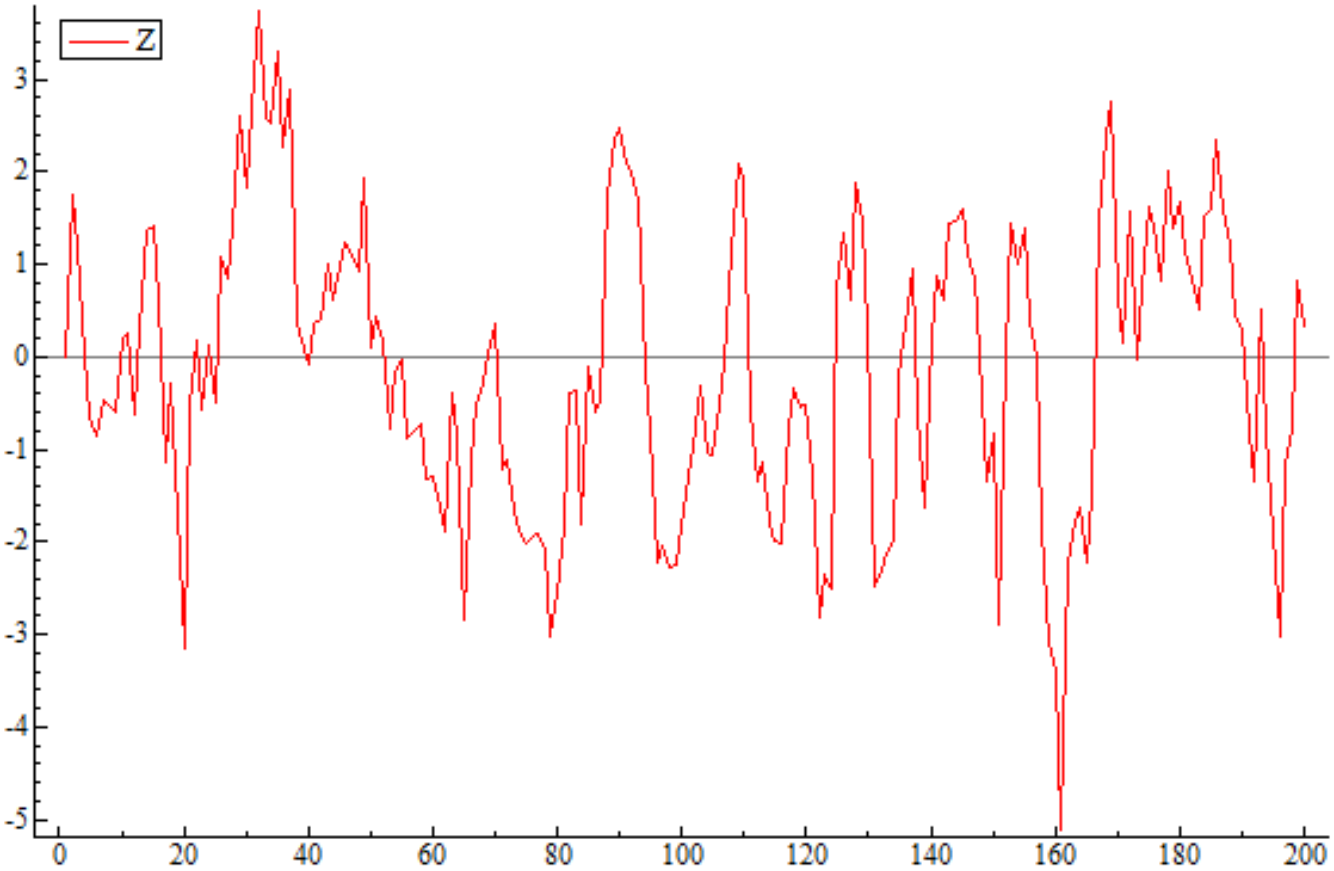
AR processes II

When $\rho = 0$:



AR processes III

When $\rho = 0.8$:



AR processes IV

In the special case of $\rho = 1$, we see that

$$Z_t = Z_{t-1} + \varepsilon_t$$

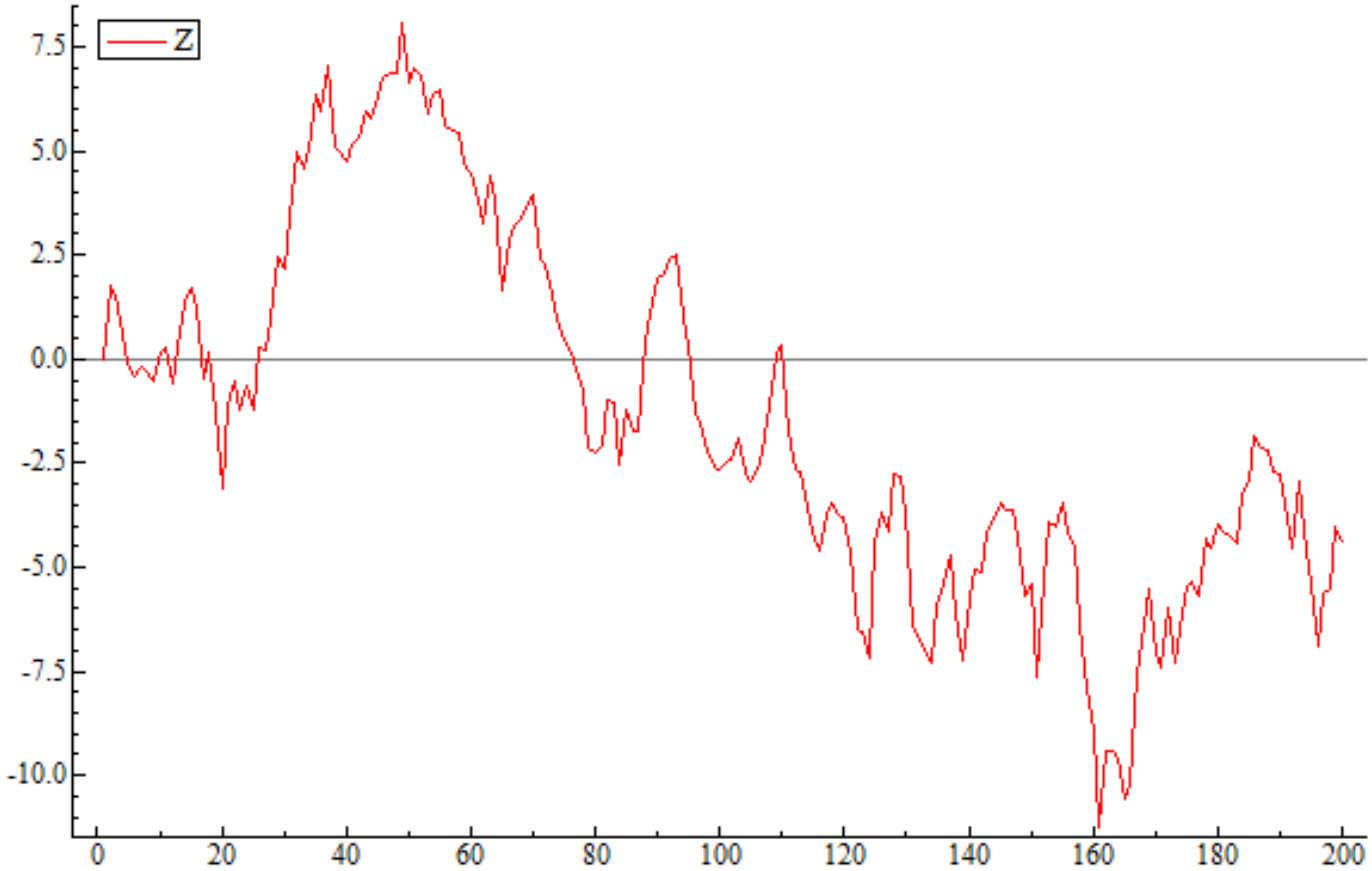
which after iterating backwards will give us

$$Z_t = Z_0 + \sum_{s=1}^{t} \varepsilon_s$$

Hence any shock to Z_t is permanent, and the process is accumulating shocks over time. This is a **random walk**.

AR processes V

When $\rho = 1$:



AR processes VI

In the example I gave you on filtering of a time series with and without a linear trend, the process was AR(1).

- When you feed a persistent AR process into a filter, you will find that some of the movements are attributed to the trend
- So a model that is driven by persistent AR processes should be filtered before you compare the business cycle facts of your model with the real facts
- (This is what Kydland and Prescott do)