Estimating the Japanese Business Cycle Using R

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1 Introduction

The macroeconomy of a country may be considered as a constantly evolving economic system in which consumers, firms, government and other agents respond to changing incentives (McGee, 2015). Aggregate output fluctuates over the short-run as agents adjust their economic activities. Accordingly, the macroeconomy experiences periods of faster, slower and even negative growth. These fluctuations are known as the business cycle.

The precise causes and mechanisms of the business cycle are the source of much analysis and debate amongst academics and practitioners. Many academic articles analyse business cycle fluctuations in macroeconomic time series, for example Stock and Watson (1999) for the United States and Urasawa (2008) for Japan. Illustrating the complex characteristics of business cycles, Zarnowitz (1991) observed:

> *Business cycles have varied greatly over the past 200 years in length, spread, and size. At the same time, they are distinguished by their recurrence, persistence, and pervasiveness. They make up a class of varied, complex, and evolving phenomena of both history and economic dynamics. Theories or models that try to reduce them to a single causal mechanism or shock are unlikely to succeed.*

Figure 1 provides a stylised representation of the business cycle. Gross domestic product (GDP) behaves in a cyclical fashion in the short-run while growing according to a long-run trend. The cycle involves periods of relatively fast economic growth, called expansions, and slowdowns called contractions. The turning point where an expansion changes to a contraction is called a peak. Contractions bottom-out at troughs, after which the economy begins to expand again.

To measure the business cycle accurately, output must be decomposed into separate trend and cycle components. This article shows how to separate Japanese GDP into trend and cycle using the programming language R[1].

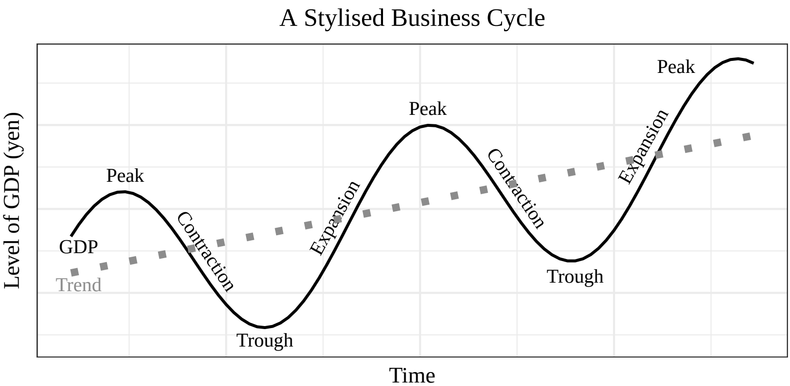

Figure 1

2 Uses of Business Cycle Estimates

There are many uses for business cycle estimates. Three practical applications that I have used in my career as a central bank economist and global macro hedge fund investor include the following.

i) Business cycle estimates may be used to test how well a theoretical macroeconomic model can describe and forecast the business cycle. In this sense, the cycle estimate provides a benchmark to test models against.

ii) Central banks use macroeconomic cycle estimates as a proxy for the output gap. The output gap may be defined as the difference between what the economy is producing and what it can sustainably produce. It is an important indicator of inflationary pressure. A large positive output gap suggests future inflation, while a negative output gap predicts deflation. Central

[1] R is a powerful open-source (free) programming language used for statistical and mathematical computing. Download R from here: `https://cran.r-project.org/`. I recommend RStudio Desktop, which makes using R much more convenient and is also free. Download RStudio from here: `https://www.rstudio.com/products/rstudio/download/`.

bankers use output gap indicators to help determine monetary policy and thus manage inflation (see, for example, Taylor (1993)).

iii) There is evidence that if country A's current business cycle position is relatively strong compared to that of country B, the exchange rate between country A and country B is likely to appreciate (see, for example, Colacito et al. (2018)). Investors use business cycle estimates to forecast exchange rates and make profitable currency trades.

3 Setting Up R and Downloading GDP

Eight R packages[2] are required: dynlm, fBasics, ggplot2, mFilter, neverhpfilter, quantmod, scales and xts. Install each package and then load it for use. As an example, execute the following code to install the package dynlm and load it for use. Do this for each package.

```
install.packages("dynlm")
library(dynlm)
```

The quantmod package makes it easy to download economic data from the Federal Reserve Bank of St. Louis economic database. Download quarterly Japanese real GDP data for the sample 1994 to 2018 and calculate its logarithm as follows.

```
gdp <- log(getSymbols('JPNRGDPEXP', src='FRED',
               auto.assign=FALSE))["1994/2018"]
names(gdp) <- "GDP"
```

4 Log-Linear Detrending

The simplest way to estimate trend and cycle is to use linear deterministic detrending, as shown in equation (1). This involves running an ordinary least squares regression of the macroeconomic variable to be detrended (y_t) on a time

[2] R packages are collections of data, code and documentation. These provide functions to perform certain calculations. Look up information regarding packages on `https://cran.r-project.org/`.

trend (tt). In our example, real GDP is in logarithms so the method will produce a log-linear trend estimate[3].

$$y_t = \beta_0 + \beta_1 tt_t + e_t \tag{1}$$

After running the regression, the fitted values ($\hat{y}_t$) give the estimated trend and the residuals ($\hat{e}_t$) give the cycle. The trend and the cycle will be uncorrelated. Run the following code to produce the trend and cycle components.

```
LT <- cbind(gdp, seq(1, dim(gdp)[1], 1))
colnames(LT)[2] <- "TT"
ltm <- dynlm(GDP ~ TT, data = as.zoo(LT))
LT <- cbind(LT, as.xts(ltm$fitted.values),
            as.xts(ltm$residuals))
colnames(LT)[3:4] <- c("LINTREND", "LINCYC")
```

The object "LT" contains the log real GDP data from 1994 to 2018, the time trend used as the explanatory variable in equation (1), the estimate of the log-linear trend (LINTREND) and the estimate of the business cycle component (LINCYC). To view the contents of LT, run the following code.

```
View(LT)
```

To plot log real GDP and the estimated log-linear trend as shown in Figure 2, run the following code[4]. The vertical axis of the chart is in log real GDP (billions of 2011 yen) terms.

```
ggplot(fortify(LT[,c(1,3)],melt=TRUE)) +
  geom_line(aes(x=Index,y=Value, linetype=Series)) +
  scale_linetype_manual(values=c("solid", "dotted"),
       labels=c("GDP", "Log-linear Trend")) + theme_bw() +
  scale_x_date(breaks=pretty_breaks(6)) +
  labs(title="Log GDP and Log-linear Trend for Japan",
       x="", y="") + theme(legend.position=c(0.8, 0.2),
       legend.title=element_blank(),
       legend.key.width=unit(20, 'pt'))
```

[3] A squared time trend term, and potentially higher powers, can be included in the regression.

[4] The format of the figures produced by the code will differ slightly from the figures presented in this article.

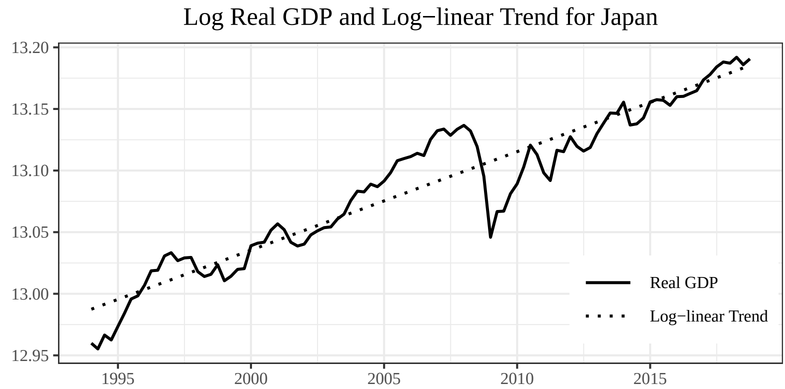

Figure 2

Log-linear detrending is relatively simple. However, the log-linear trend often does not adequately represent the trend in real GDP. Notice in Figure 2 that log real GDP tends to lie above or below the trend for long periods of time. Also, the global financial crisis has made little difference to our estimate of the trend. The residual from the log-linear model is likely to reflect the poor fit of the log-linear detrending model rather than give a good estimate of the business cycle. In the next section, I estimate trend and cycle using the Hodrick-Prescott (HP) filter which allows for a more flexible trend.

5 Hodrick-Prescott Filter

The HP filter (Hodrick and Prescott, 1997) is arguably the most popular[5] method of separating the trend and cycle components of macroeconomic time series. Trend and cycle are estimated from the minimisation problem described by equation (2). For a time series y_t where $(t = 1, 2, \ldots T)$, select the trend (y_t^s) and cyclical (y_t^c) components to

[5] Although the HP filter is widely used, there are several criticisms of the method in the literature. Most importantly, the trend estimate is less reliable at the beginning and end of the sample. A number of alternative filter and regression-based methods have been proposed.

$$
\min_{y_t^s, y_t^c} \left[\sum_{t=1}^{T} (y_t^c)^2 + \lambda \sum_{t=2}^{T-1} \left(\left(y_{t+1}^s - y_t^s \right) - \left(y_t^s - y_{t-1}^s \right) \right)^2 \right] \quad \text{subject to} \quad y_t^s + y_t^c = y_t, \tag{2}
$$

where λ determines the smoothness of the trend. A greater λ gives a smoother trend. For quarterly data, λ is usually set to 1600. The method assumes that trend and cycle are uncorrelated, and the trend is a smooth process which is defined by penalizing variations in the second difference of the trend in equation (2).

A package called mFilter is available in R that computes the HP filter. Run the following code to estimate the HP filter trend (HPTREND) and cycle (HP-CYC) components of log real GDP.

```
hp <- hpfilter(gdp$GDP, freq = 1600)
hp_t <- xts(hp$trend, order.by = index(gdp))
hp_c <- xts(hp$cycle, order.by = index(gdp))
HP <- cbind(gdp, hp_t, hp_c)
colnames(HP)[2:3] <- c("HPTREND", "HPCYC")
```

Figure 3 shows the HP filter trend together with log real GDP. Create the plot with the following code.

```
ggplot(fortify(cbind(HP[,1:2]), melt=TRUE)) +
  geom_line(aes(x=Index,y=Value,linetype=Series), na.rm=TRUE) +
  scale_linetype_manual(values=c("solid", "dashed"),
       labels=c("Real GDP", "HP Filter")) +
  scale_x_date(breaks=pretty_breaks(6)) + theme_bw() +
  labs(title=
      "Log Real GDP and HP Filter Trend Estimate for Japan",
       x="", y="") + theme(legend.position=c(0.85, 0.2),
       legend.title=element_blank(),
       legend.key.width=unit(20, 'pt'))
```

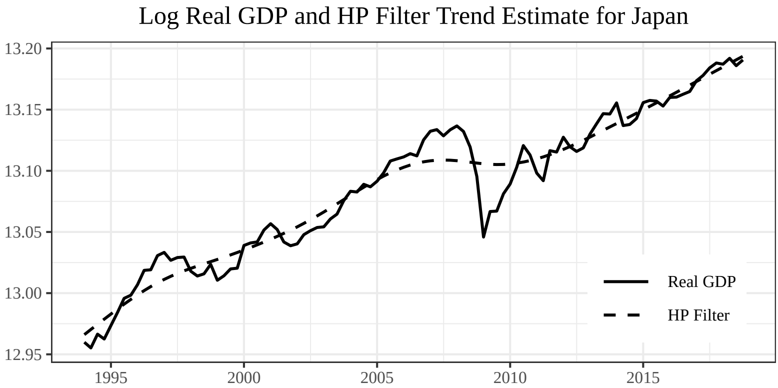

Figure 3

The slope of the HP filter trend responds to long-term changes in the growth of real GDP. Note that the slope of the trend component is flat for around two years following the Lehman shock in 2008. Lower trend growth in real output during this period is reasonable given the disruption to the global economy, decline in the global trade of goods and the weak financial system during the global financial crisis. The HP filter trend appears a better measure of the trend in real GDP. Deviations from the HP filter trend should give a better estimate of the business cycle than the residual of the log-linear model.

The HP filter and log-linear business cycle estimates are shown in Figure 4. The vertical axis of Figure 4 is in deviation from trend terms. For example, positive 0.025 means that real GDP is 2.5 percent above its trend level. The figure can be displayed on one chart using the following code.

```
ggplot(fortify(cbind(HP[,3],LT[,4]), melt=TRUE)) +
  geom_line(aes(x=Index,y=Value,linetype=Series), na.rm=TRUE) +
  scale_linetype_manual(values=c("dashed", "dotted"),
       labels=c("HP Filter", "Log-linear")) +
  theme_bw() + geom_hline(yintercept=0, size=0.1) +
  scale_x_date(breaks = pretty_breaks(6)) +
  labs(title="HP Filter and Log-linear Cycle Estimates",
       x="", y="") + theme(legend.position=c(0.85, 0.2),
       legend.title=element_blank(),
       legend.key.width=unit(20, 'pt'))
```

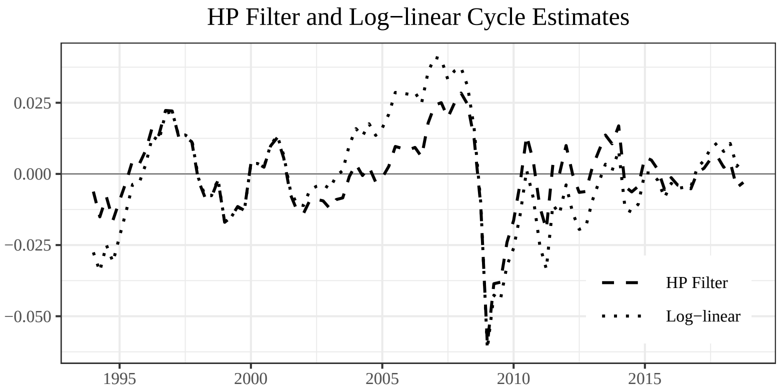

Figure 4

The HP filter cycle estimate appears to be the better business cycle indicator. It generates a more reasonable representation of the early 1990's and early 2000s recessions, the period of expansion during the mid-2000s, and the period of low and variable economic growth in Japan after 2010. However, the severity of the global financial crisis is evident in both indicators from 2008 to 2010.

6 Compare Japan and United States Business Cycles

Comparison can be made between the business cycles of Japan and the United States (U.S.) using the HP filter. The code below downloads U.S. real GDP data, calculates its logarithm, selects the same sample period as used for Japan and runs an HP filter using the same $\lambda = 1600$.

```
usgdp <- log(getSymbols('GDPC1',
            src='FRED', auto.assign=F))["1994/2018"]
names(usgdp) <- "USGDP"
uhp <- hpfilter(usgdp$USGDP, freq = 1600)
uhp_t <- xts(uhp$trend, order.by = index(usgdp))
uhp_c <- xts(uhp$cycle, order.by = index(usgdp))
USHP <- cbind(usgdp, uhp_t, uhp_c)
colnames(USHP)[2:3] <- c("HPTREND", "HPCYC")
```

The code below plots the business cycles for Japan and the U.S. estimated using the HP filter method.

```
ggplot(fortify(cbind(HP[,3], USHP[,3]),melt=T)) +
  geom_line(aes(x=Index,y=Value,linetype=Series), na.rm=T) +
  scale_linetype_manual(values=c("dashed", "solid"),
                         labels=c("Japan", "U.S.")) +
  labs(title="Business Cycles for Japan and the U.S.",
       x="", y="") + theme_bw() +
  geom_hline(yintercept=0, size=0.1) +
  scale_x_date(breaks=pretty_breaks(6)) +
  theme(legend.position=c(0.85, 0.25),
        legend.title=element_blank(),
        legend.key.width=unit(20, 'pt'))
```

Figure 5 shows the business cycles for Japan and the U.S. Between 1994 and 2001, the business cycles of each country follow an opposite pattern. The mid-2000s period shows a synchronised expansion across both countries. 2008 saw the beginning of the global financial crisis which had a substantial and negative impact on the output of Japan and the U.S. The impact of the crisis on Japan was larger in percentage deviation from trend terms. The post-crisis period has been characterised by somewhat variable and close to trend output, consistent with the lack of a strong sustained cyclical macroeconomic recovery in both countries.

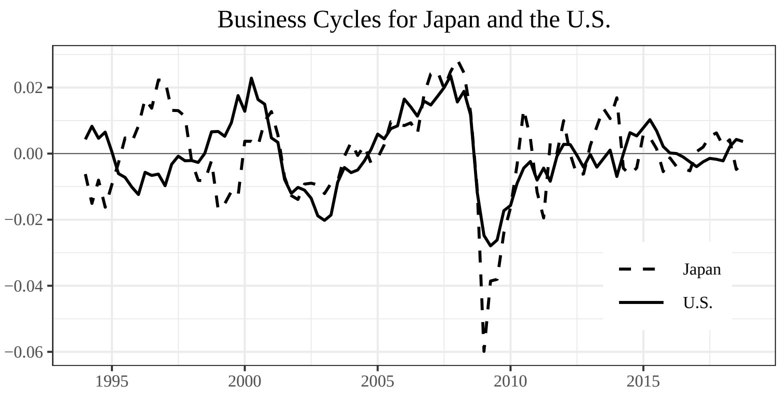

Figure 5

7 Conclusion

Decomposition of aggregate output into trend and cycle components is used in a number of applications such as macroeconomic modelling, monetary policy-making and investment. Producing and plotting trend and cycle estimates is straightforward using a programming language such as R. I hope this simple example is helpful in your studies.

References

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