# The time-varying correlation between output and prices in the United States over 1800 to 2014

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**Abstract**

In this study, we examine the time-varying correlations between output and prices, while controlling for the impact of monetary policy stance, and output and inflation uncertainties over the period of 1800-2014. The results of the empirical analysis reveal that dynamic correlations of output and prices were typically negative, suggesting a countercyclical behaviour of prices, apart from the early 1840s, and from the beginning till the mid of the 20th century wherein correlation were positive, indicating the procyclicality of prices. A historical decomposition analysis based on a sign-restricted structural vector autoregressive model is able to relate the procyclical and countercyclical behavior to the predominance of aggregate supply, and aggregate demand and/or monetary policy shocks, respectively. Moreover, inflation uncertainty (monetary policy stance) was found to have a positive (negative) effect on inflation over the last 215 years.

*Keywords:* Conditional correlation, GARCH, Price-Output Comovement, US Economy

*JEL codes:* E3; C5

## 1. Introduction

An important question in the business cycle literature is whether prices are procyclical (i.e., output and prices move in the same direction) or countercyclical (i.e., output and

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prices move in the opposite direction). However, this issue has remained unanswered for the US economy, given that, evidence in this regard has been mixed (see Lee, 2006; Konstantakopoulou et al., 2009; Haslag and Hsu, 2012; Brock and Haslag, 2014; Keating and Valcarcel, 2015, and references cited therein for a detailed literature review).

While Friedman and Schwartz (1982) provided evidence that prices are procyclical, this view was challenged by Kydland and Prescott (1990). Cooley and Ohanian (1991), Backus and Kehoe (1992), and Smith (1992) suggests that the contradictory evidence is contingent on the sample period, and hence the nature of the underlying macroeconomic shocks driving the business cycle. Understandably, depending on whether aggregate demand (AD) and/or monetary policy (MP) shocks (aggregate supply (AS) shocks) drive the business cycle, prices would be procyclical (countercyclical). Clearly then, we need to analyse the correlation between prices and output using a time-varying approach, and then, based on a structural framework, determine which shocks were important over time.

Against this backdrop, the objective of our study is to analyse the evolution of the correlation between output and prices for the US economy using Engle's (2002) dynamic conditional correlation (DCC)-GARCH model, over the period of 1800-2014. Besides accounting for time-varying volatility behaviour of the data, a major advantage of the DCC-GARCH approach is its ability to detect changes in the conditional correlation over time. As discussed above, depending on the pre-dominance of the type of shock(s), time-variation in the comovement between output and prices may depend on the state of the economy.

Our paper is related to the work of Lee (2006), who also used the DCC-GARCH model to analyse the dynamic correlation between prices and output for the US economy over the quarterly period of 1900:1-2002:4. However, unlike Lee (2006), we not only consider a longer time-span, but we also analyse the robustness of the conditional correlation between output and prices by incorporating short-term interest rates, output and inflation volatilities in the framework in order to capture the role of monetary policy, output and inflation uncertainties, respectively, in this relationship. More importantly, unlike Lee (2006), using a historical decomposition analysis of the shocks (AS, AD and MP), derived from a sign-restricted Bayesian structural vector autoregression (SVAR), we show that the time-varying correlation can be tied with the dominance of a specific shock(s). To the best of our knowledge, our paper makes the first attempt to provide an in-depth time-varying analysis of the correlation between output and prices of the US economy using over two centuries of data.

The remainder of the paper is organized as follows. Section 2 describes the empirical methodology and Section 3 the data used. While, Section 4 presents the empirical results, with Section 5 summarising the results and offering some concluding remarks.

## 2. Methodology

In order to examine the evolution of co-movements between output and prices, we obtain a time-varying measure of correlation based on the dynamic conditional correlation (DCC) model of Engle (2002).

Let $y_t = [y_{1t}, y_{2t}]'$ be a $2 \times 1$ vector comprising the data series. The conditional mean equations are then represented by:

$$A(L)y_t = B(L)x_t + \varepsilon_t, \quad \text{where} \quad \varepsilon_t|\Omega_{t-1} \sim N(0, H_t), \quad \text{and} \quad t = 1, ..., T \tag{1}$$

where $A$ and $B$ are matrices of endogenous and exogenous variables, respectively, $L$ the lag operator and $\varepsilon_t$ is the vector of innovations based on the information set, $\Omega$, available at time $t-1$. The $\varepsilon_t$ vector has the following conditional variance-covariance matrix:

$$H_t = D_t R_t D_t, \tag{2}$$

where $D_t = diag\sqrt{h_{it}}$ is a $2 \times 2$ matrix containing the time-varying standard deviations obtained from univariate GARCH(p,q) models as:

$$h_{it} = \gamma_i + \sum_{p=1}^{P_i} \alpha_{ip}\varepsilon_{it-ip}^2 + \sum_{q=1}^{Q_i} \beta_{iq} h_{iq-q}, \quad \forall i = 1, 2. \tag{3}$$

The DCC(M,N) model of Engle (2002) comprises the following structure:

$$R_t = Q_t^{*-1} Q_t Q_t^{*-1}, \tag{4}$$

where:

$$Q_t = (1 - \sum_{m=1}^{M} a_m - \sum_{n=1}^{N} b_n)\bar{Q} + \sum_{m=1}^{M} a_m(\varepsilon_{t-m}^2) + \sum_{n=1}^{N} b_n Q_{t-n}. \tag{5}$$

$\bar{Q}$ is the time-invariant variance-covariance matrix retrieved from estimating equation (3), and $Q_t^*$ is a $2{\times}2$ diagonal matrix comprising the square root of the diagonal elements of $Q_t$. Finally, $R_t = \rho_{ij_t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t}q_{jj,t}}}$ where $i, j = 1, 2$ is the $2 \times 2$ matrix comprising the conditional correlations and which are our main focus.

## 3. Data

The two main variables of interest in this paper are output and prices in the US over the period of 1800-2014, i.e., 215 observations. Output is measured by the real gross domestic product (GDP) at constant 2009 prices, and prices by the consumer price index (CPI). The series have been obtained from the Global financial Database and the website of Professor Robert Sahr (http://liberalarts.oregonstate.edu/spp/polisci/research/inflation-conversion-factors-convert-dollars-1774-estimated-2024-dollars-recent-year), respectively. As the DCC analysis to be valid has to be performed on stationary variables, we convert the real GDP series to real GDP growth and CPI series to inflation by taking the first difference of the natural logarithm of each series.[1]

We also control for (1) the short-tem interest rates, obtained over the period of 1800-1870 from Homer and Sylla (2005), and beyond that from the data segment of the website of Professor Robert J. Shiller (http://www.econ.yale.edu/∼shiller/data.htm), and (2) output

[1]However, as discussed below, different transformation of these series does not affect our main results.

growth uncertainty and inflation uncertainty as exogenous variables in the conditional mean equations of output growth and inflation, respectively. Interest rates are accounted for so as to capture any potential impact of US monetary policy on the output growth-inflation relationship. Output growth uncertainty, which is proxied by the conditional volatility of output growth, is included in the conditional mean equation of output growth. The motivation for this is based on the vast, albeit ambiguous, theoretical literature on the relationship between economic growth and its volatility.[2] Inflation uncertainty, proxied by the conditional volatility of inflation, is included in the conditional mean equation of inflation due to the fact that the literature suggests that high levels of inflation uncertainty lead to higher inflation rates (see, e.g. Cukierman and Meltzer, 1986).

Figure 1 presents the evolution of output growth, inflation and the interest rate. According to upper part of this figure, we observe the existence of periods wherein output growth and inflation moved in the same direction, followed by periods wherein the two series moved in opposite directions. Put differently, the unconditional correlations between the two series are not stable overtime. In addition, in the lower part of the Figure 1, we observe that interest rates reach a peak shortly before or during recessions.

[Insert Figure 1 here]

Table 1 presents the descriptive statistics of our data. According to this table, we observe large variability in our main variables. Over the last 215 years, economic growth in the United States averaged at 3.65%, inflation at 1.37% and interest rates at 5.49%. The augmented Dickey-Fuller (ADF) test with just a constant indicates that all series are stationary.[3] The fact that the ARCH-LM test rejects the null hypothesis of homoskedasticity for each series indicates the appropriateness of modelling our series of interest as an ARCH-type process. Finally, the unconditional correlation among output growth, inflation and the interest rate are presented in the lower panel of Table 1. The unconditional correlation between the main two series of interest, i.e. output growth and inflation, is negative and equal to -0.15166. However, as seen in Figure 1 this negative relation is not constant overtime. Thus, the dynamic conditional correlation model, which takes into account of that and has several additional good features discussed above, seems appropriate for our empirical analysis.

[Insert Table 1 here]

[2] According to Bernanke (1983), output volatility raises economic uncertainty and thus hampers investment due to its irreversible nature, which in turn leads to lower economic growth. Aghion and Howitt (2006) argue that volatility has a negative effect on growth under credit market imperfections that constrain investments during recessions. On the contrary, higher volatility (economic uncertainty) could increase precautionary saving and therefore lead to higher growth rates (Mirman, 1971; Lensink et al., 1999). Optimal portfolio theory suggests that volatile sectors command high investment rates (Imbs, 2007). Finally, a positive effect of volatility on growth could also be due to a Schumpeterian 'cleansing effect' of recessions (Caballero, 1991). See Imbs (2007) for an extended discussion of the link between volatility and growth.

[3] In the analysis below, we use the the interest rate series in the levels as it does not contain a unit-root.

## 4. Estimation Results

Table 2 reports the results of the DCC model. Panels A and B present the conditional mean and variance results, respectively, while Panel C contains the Ljung-Box Q-Statistics on the standardized and squared standardized residuals up to 10 lags. The choice of the lag-length of the autoregressive process of the conditional mean, which is equal to one, is based on the Akaike information criterion (AIC) and Schwarz Bayesian criterion (BIC).

[Insert Table 2 here]

According to the conditional mean results of model 1 in Table 2 (which does not control for interest rates), we find that past real GDP growth is associated with significant increases in the current real GDP growth and inflation, while past inflation is significantly associated with lower current economic growth and higher current inflation. Also in line with the literature, inflation uncertainty (proxied by inflation volatility, $h\pi_t$) leads to higher rates of inflation (see, e.g. Cukierman and Meltzer, 1986), while output growth uncertainty (proxied by output growth volatility, $hy_t$) is not significantly associated with output growth. The latter finding might be explained by the inconclusive evidence of the existing literature on the link between output growth and output growth volatility discussed above.

The conditional variance results support the existence of the GARCH effects found in the series, as the coefficients $\alpha_1$ and $\beta_1$ are highly significant. Moreover, the coefficients $a$ and $b$ are highly significant indicating that the correlations between output growth and inflation are indeed time-varying. Both these results validate the choice of the DCC model. Finally, the model does not suffer from serial correlation in the squared (standardized) residuals, according to the misspecification tests reported in Panel C of Table 2.

Controlling for the effect of monetary policy, by including interest rates in model 2 of Table 2, we observe that interest rates increases are associated with lower inflation (as monetary policy theory suggests), while no significant evidence on interest rates on output is observed. The results of the remaining parameters are almost identical to those of model 1.

In Figure 2, we present the dynamic conditional correlations of output growth and inflation estimated in Table 2, along with their 90% confidence intervals. Panels (a) and (b) plot the dynamic correlations of models 1 and 2, respectively, from Table 2. In panel (a) of Figure 2, which corresponds to the results of model 1 in Table 2, it is evident that dynamic conditional correlations between output growth and inflation behaved rather heterogeneously overtime. In particular, correlations were negative apart from the early 1840s, and from the beginning till the mid of the 20th century wherein correlation were positive. Put differently, the overall price level was typically countercyclical in the last 215 years, apart from the early 1840s and between beginning and the mid of the 20th century were it became procyclical. Controlling for the potential influence of interest rates on output growth and inflation (panel (b) of Figure 2) does not affect the aforementioned dynamic correlation patterns. These results are in line with previous studies based on unconditional correlations (see, for instance Backus and Kehoe, 1992; Cooley and Ohanian, 1991) and on conditional correlations (see, e.g. Lee, 2006).

[Insert Figure 2 here]

### *4.1. Robustness analysis*

As a robustness check, we examined whether our series transformation could influence our main results. Thus, we have re-estimated the DCC model with detrended real GDP (i.e. output gap) and detrended prices based on the Hodrick-Prescott (HP) filtering technique (see, Figure 3), and our results remained qualitatively comparable. For instance, the dynamic conditional correlations based on HP-filtered data of output and prices, presented in Figure 4, are very similar to those of Figure 2.[4]

[Insert Figure 3 here]

[Insert Figure 4 here]

### *4.2. Historical decomposition of shocks*

A natural question that arises, is what could explain this time-varying correlations between output and prices? In order to answer that, we estimate a Bayesian SVAR model with sign restrictions, with the restrictions being imposed for a year, and carry out an historical decomposition analysis of the shocks of the model. The priors used for the model follow the standard Minnesota-priors as discussed in detail by Banbura et al. (2010). To identify the AS, AD and MP shoks, we impose the following sign restrictions: (i) A positive supply-side shock is associated with an increase in output and a fall in prices, with the interest rate left unrestricted; (ii) A positive demand-side shock is based on a restriction that increases output, prices and the interest rate; and (iii) a contractionary monetary shock would require output and prices to fall as the interest rate increases. In other words, if the aggregate of AD and MP shocks dominates the AS shock, prices would be procyclical, where as if the AS shock dominates the sum of the AD and MP shocks, prices would be countercyclical. Hence, we first aggregate the historical decomposition of output emanating from the AD and MP shocks, and then subtract the absolute value of those from the absolute value of the historical decomposition originating from the AS shock. Understandably, when this value is positive (negative), the impact of AS (AD and MP) shock would dominate the AD and MP (AS) shocks taken together, and the correlation between output and prices should be negative (positive). We plot this net historical decomposition of the shocks on output in panels (a) and (b) of Figure 5 for the cases of first-differenced and HP-filtered series, respectively. In general, for years when prices are found to be procyclical, especially during the early years of 1900 till the end of World War II (and to some extent during the early- to mid-1840s), the net historical decomposition plots in Figure 5 take negative values, i.e., the AD and MP shocks taken together dominate the AS shock. However, barring these years, the relationship between price and output is mostly countercyclical and our plotted series

[4] Detailed results of the DDC models based on HP-filtered series with or without monetary policy stance accounted for, are available from the authors upon request.

pick that up based on the positive entries, thus, indicating that the AS shock dominates the aggregate of the AD and MP shocks.[5]

[Insert Figure 5 here]

## 5. Conclusion

The aim of this study was to examine the time-varying correlations between output and prices, while controlling for the impact of monetary policy stance, and output and inflation uncertainties over the period of 1800-2014. The results of the empirical analysis revealed that dynamic correlations of output and prices were typically negative, suggesting a countercyclical behaviour of prices, apart from the early 1840s, and from the beginning till the mid of the 20th century, wherein correlation were positive, indicating a procyclical behaviour of prices. A historical decomposition analysis based on a sign-restricted Bayesian SVAR, showed that the periods for which we observe countercyclical behavior, the aggregate supply shocks dominated the aggregate demand and monetary policy shocks, while it was the other way round for years when prices and output were found to be procyclical. Moreover, inflation uncertainty (monetary policy stance) was found to have a positive (negative) effect on inflation over the last 215 years.

While the historical decomposition is useful, it is based on a constant parameter sign-restricted SVAR. Thus a potential avenue for future research would be to re-examine the historical decomposition using a sign-restricted time-varying SVAR with stochastic volatility. This would also allow us to study the impact of various shocks over time and horizons on output, prices and interest rates.

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[5] We also conducted historical decomposition analyses with the shocks identified based on lower triangular restrictions of the short-run and long-run matrices separately, given the ordering of variables as output, prices and interest rates. However, these recursive identification approaches produced historical decompositions, which suggested that the AS shock dominated the aggregate of the AD and MP shocks for all periods, which in turn, does not match our dynamic correlations. Complete details of these results are available upon request from the authors.

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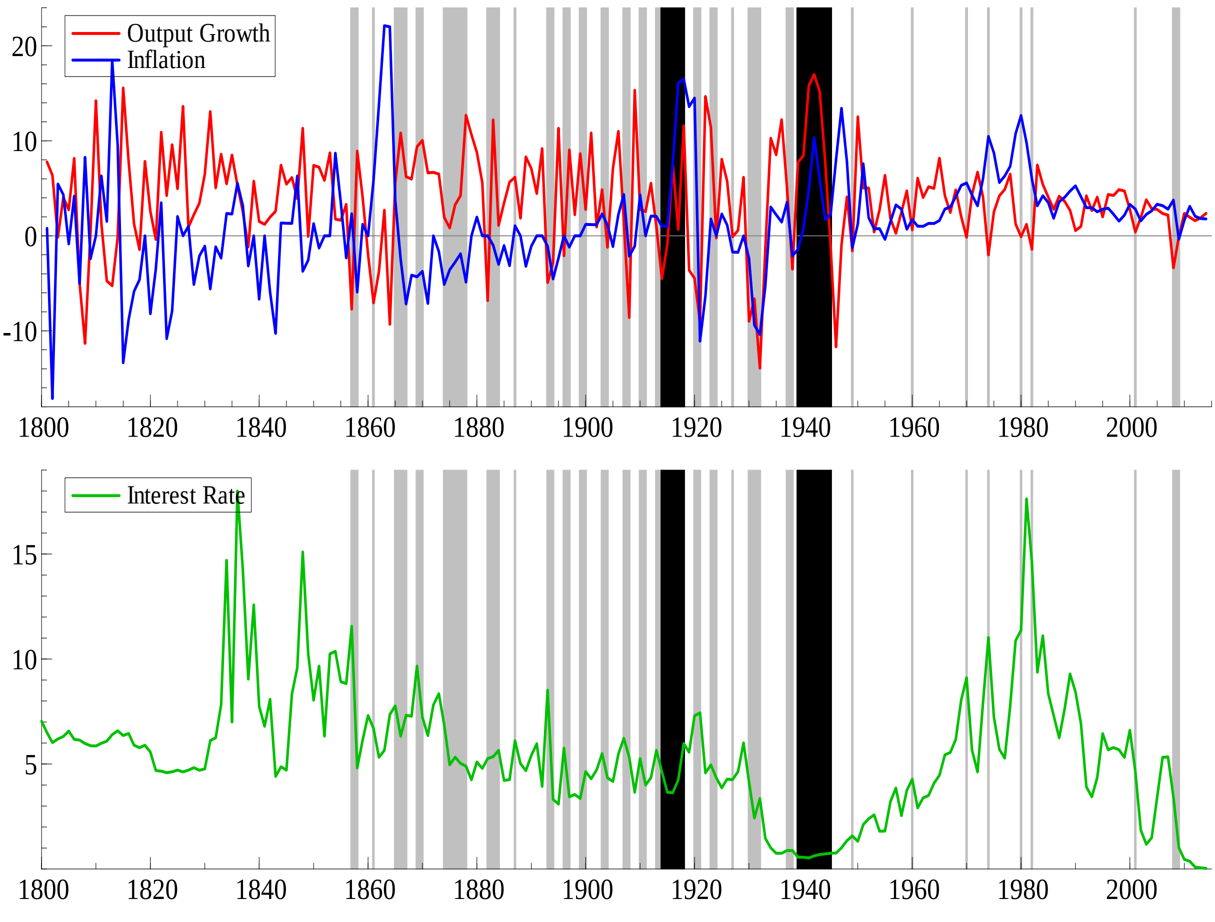
Table 1: Descriptive statistics

| | Output Growth | Inflation | Interest Rate |
|---|---|---|---|
| Min | -13.929 | -17.136 | 0.03 |
| Mean | 3.6499 | 1.3732 | 5.4887 |
| Max | 16.992 | 22.116 | 18 |
| Std | 5.3093 | 5.4672 | 3.0519 |
| Skewness | -0.3132** | 0.5094*** | 0.9973*** |
| Kurtosis | 3.7476** | 5.5171*** | 5.4385*** |
| Jarque-Bera | 8.4825** | 65.752*** | 88.493*** |
| ADF[a] (constant) | -5.3643*** | -5.6453*** | -2.7345*** |
| ARCH(10) LM Test | 3.0393*** | 11.346*** | 17.095*** |
| | Unconditional Correlations | | |
| Output Growth | 1 | | |
| Inflation | -0.15166 | 1 | |
| Interest Rate | -0.074525 | 0.089559 | 1 |

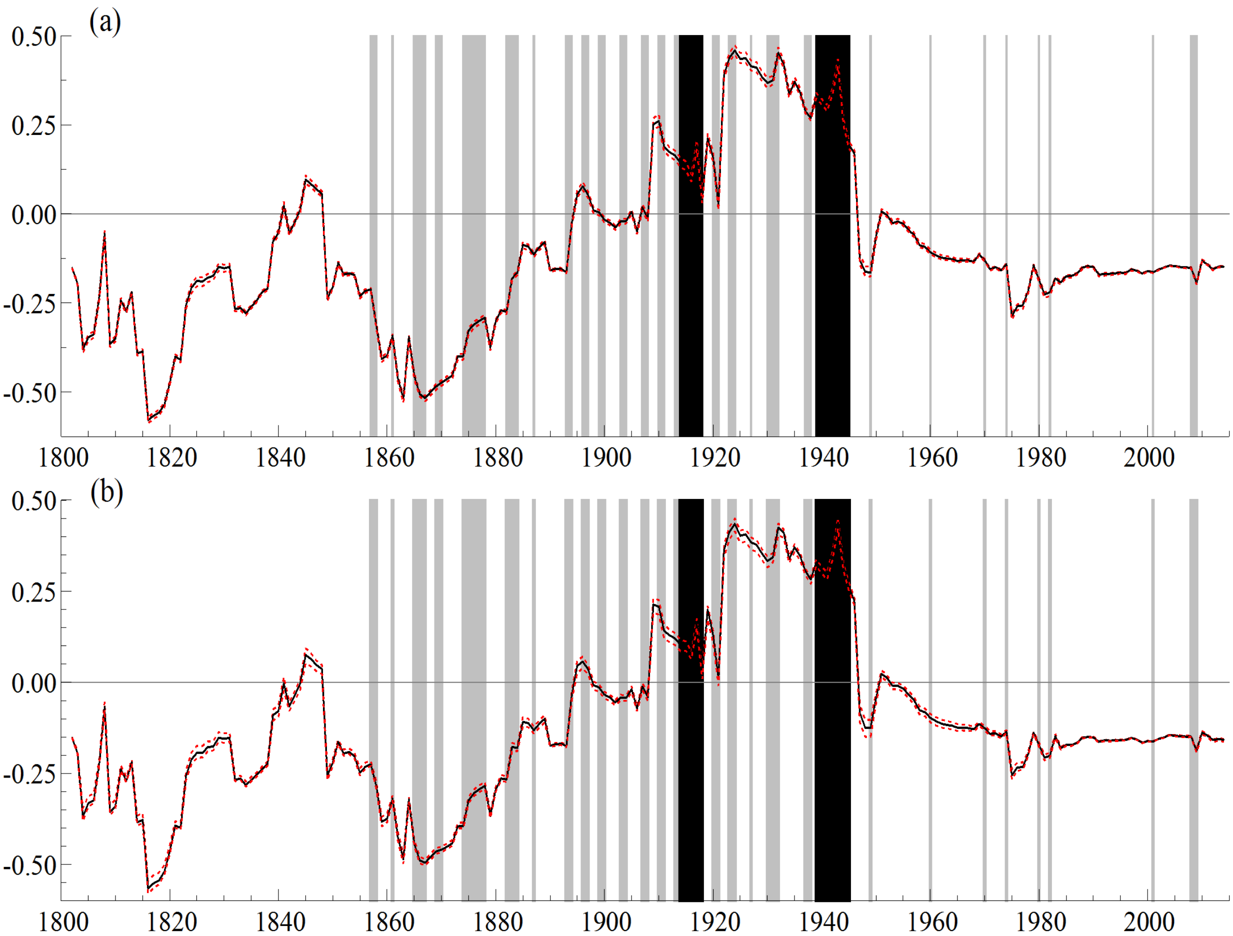
Note: [a] The 10%, 5% and 1% critical values are -1.62, -1.94 and -2.57, respectively. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

Figure 1: Output growth, inflation and interest rates



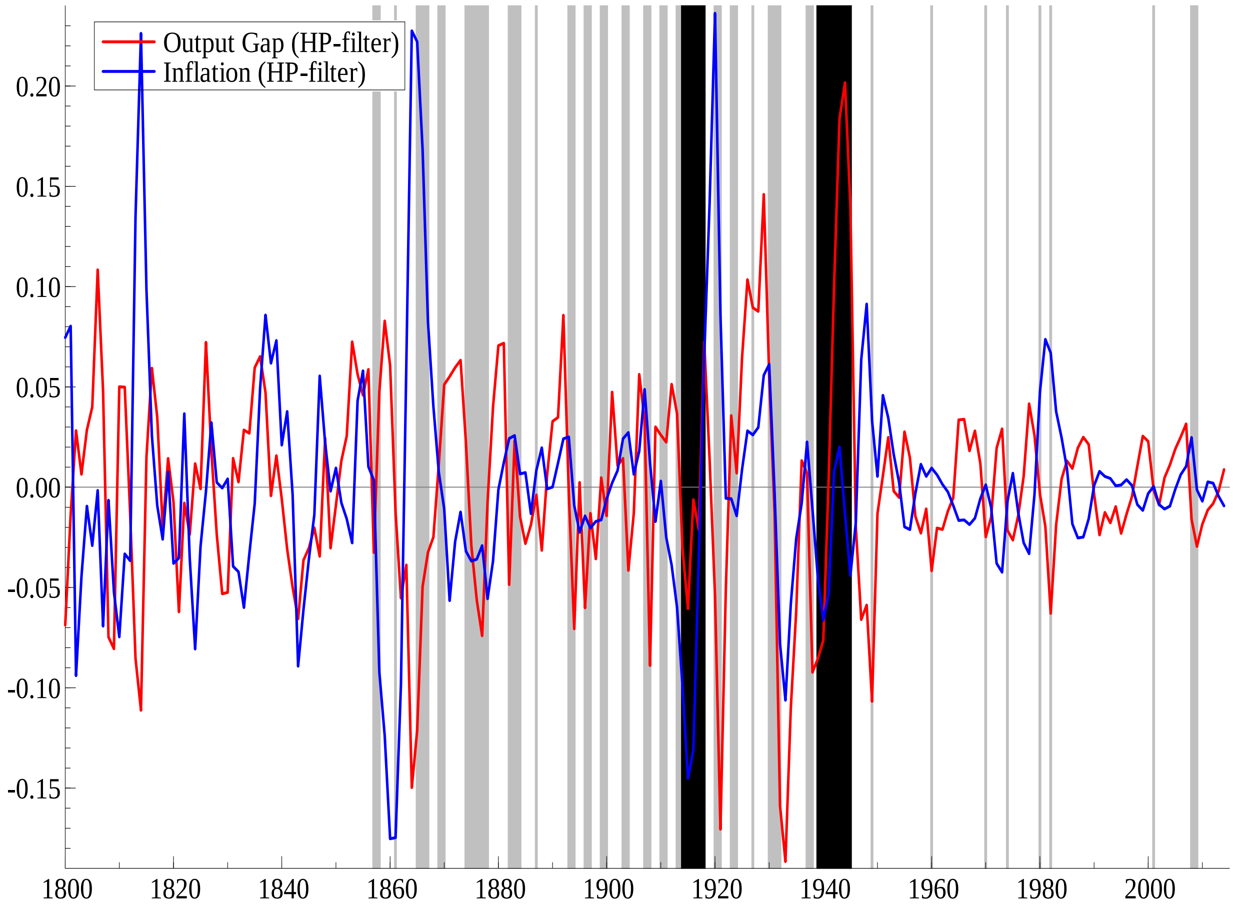

Note: Shaded grey areas denote US recessions as defined by the National Bureau of Economic Research (NBER) and shaded black areas denote world wars.

Figure 2: Dynamic conditional correlations between output and price (First-differenced data)



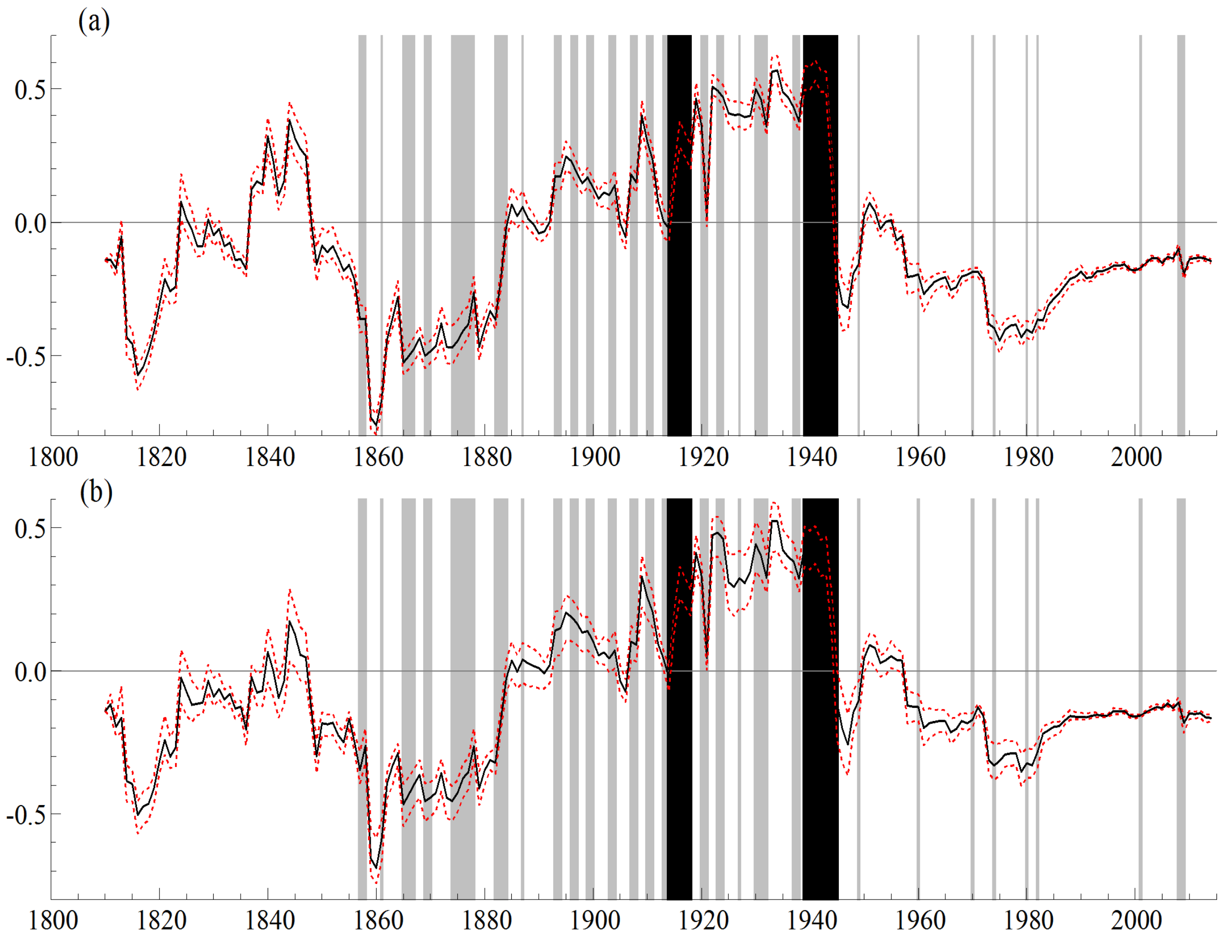

Note: Dotted lines are the 90% confidence intervals. Shading denotes US recessions as defined by NBER and shaded black areas denote world wars.

Figure 3: Output and prices (HP-filtered data)



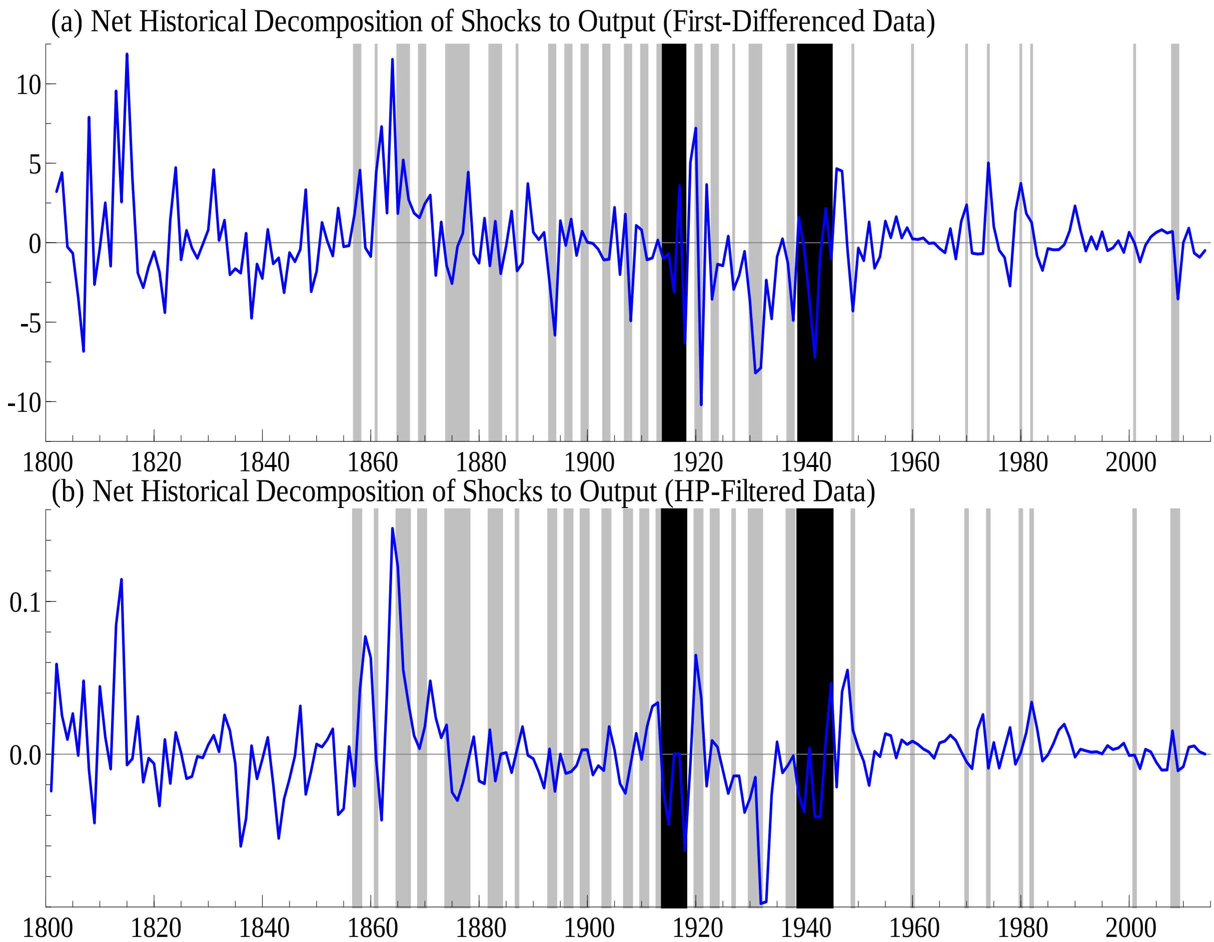

Note: Shaded grey areas denote US recessions as defined by the NBER and shaded black areas denote world wars.

Figure 4: Dynamic conditional correlations between output and price (HP-filtered data)




Note: Dotted lines are the 90% confidence intervals. Shading denotes US recessions as defined by NBER and shaded black areas denote world wars.

Figure 5: Historical decomposition of aggregate supply, aggregate demand and monetary policy shocks to output




Note: Shading denotes US recessions as defined by NBER and shaded black areas denote world wars.

Table 2: Estimation results of DCC-GARCH model, Period: 1800 – 2014

| | Model 1 | | Model 2 | |
|---|---|---|---|---|
| Panel A: Conditional mean | | | | |
| | $y_t$ | $\pi_t$ | $y_t$ | $\pi_t$ |
| $Cons$ | 2.9093*** | 0.1906 | 2.813*** | -0.1053 |
| | (0.5696) | (0.2265) | (0.8245) | (0.2268) |
| $y_{t-1}$ | 0.1316* | 0.1291*** | 0.1261* | 0.0966*** |
| | (0.0706) | (0.0347) | (0.0689) | (0.0277) |
| $\pi_{t-1}$ | -0.1314** | 0.7079*** | -0.1360** | 0.6793*** |
| | (0.0614) | (0.0457) | (0.0607) | (0.0329) |
| $hy_t$ | 0.0157 | | 0.0164 | |
| | (0.0177) | | (0.0199) | |
| $h\pi_t$ | | 0.0190** | | 0.0225** |
| | | (0.0088) | | (0.0093) |
| $i_t$ | | | 0.0105 | -0.1132** |
| | | | (0.0824) | (0.0504) |
| Panel B: Conditional variance: $H_t = \Gamma'\Gamma + A'\epsilon_{t-1}\epsilon'_{t-1}A + B'H_{t-1}B$ | | | | |
| $\gamma$ | 0.3430 | 0.1274 | 0.3226 | 0.1136 |
| | (0.2961) | (0.0797) | (0.2938) | (0.07) |
| $\alpha_1$ | 0.1301*** | 0.4384*** | 0.1276*** | 0.4365*** |
| | (0.0463) | (0.0915) | (0.0436) | (0.0990) |
| $\beta_1$ | 0.8590*** | 0.4552*** | 0.8618*** | 0.4488*** |
| | (0.0446) | (0.0285) | (0.0444) | (0.0302) |
| $a$ | 0.0920** | | 0.0869** | |
| | (0.0358) | | (0.0389) | |
| $b$ | 0.8655*** | | 0.8671*** | |
| | (0.0518) | | (0.0570) | |
| Panel C: Misspecification tests | | | | |
| $Q(10)$ | 3.5056 | 15.7859 | 3.5057 | 15.8142 |
| | [0.9669] | [0.1935] | [0.9669] | [0.1924] |
| $Q^2(10)$ | 12.9700 | 5.7453 | 12.9714 | 5.7458 |
| | [0.2254] | [0.8362] | [0.2243] | [0.8360] |

Note: $y_t$, $p_t$, and $i_t$ denote real GDP growth, inflation, and the interest rate, respectively, at time $t$. $hy_t$ and $h\pi_t$ denote the conditional variance of reaal GDP growth and the conditional variance of inflation, respectively. $Q(10)$ and $Q^2(10)$ are the Ljung-Box $Q$-Statistics on the standardized and squared standardized residuals, respectively, up to 10 lags. Standard Errors in parenthesis and $p$-values in square brackets. ***, ** and * denote statistical significance at the 1%, 5% and the 10% level, respectively.