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Abstract

We document shifts in the lead-lag properties of the US business cycle since the mid-1980s. Specifically, (i) the well-known inverted-leading-indicator-property of real interest rates has completely vanished; (ii) labour productivity switched from positively leading to negatively lagging output and labour inputs over the cycle; and (iii) the unemployment rate shifted from lagging productivity negatively to leading positively. Many contemporary business cycle models produce counterfactual cross-correlations revealing that popular frictions and shocks provide an incomplete account of business cycle comovement. Determining the underlying sources of these shifts in the lead-lag properties is therefore a promising direction for future research.

Key words: Business Cycles, Cross-Correlations, Lead-Lag, DSGE Models, Interest Rates, Productivity, Hours, Employment, Unemployment

JEL classification: E24, E32, E43

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1 Introduction

Stylized facts and regularities in the cyclical behaviour of macroeconomic aggregates continue to guide contemporary business cycle research. Models of the business cycle either seek to directly account for these stylized statistical properties or use them as evaluation criteria in determining the suitability of models aimed at studying a variety of topics such as the welfare costs of business cycles, the sources of business cycles, the role of economic policies, or asset prices. In this context, two popular types of comovements characterize aggregate fluctuations. Contemporaneous correlations with output indicating pro-, counter- or acyclicalities, and the largest absolute magnitude of cross-correlations with output (or another reference variable) indicating leads and lags. This latter type of business cycle comovement has been emphasized in the literature since [Blanchard and Watson \(1986\)](#) and [Kydland and Prescott \(1990\)](#). Changes in the economy’s structure, institutions, policies, and exogenous shocks can all impinge upon both types of comovements. While the recent business cycle literature has extensively studied *shifts* in contemporaneous correlations after the onset of the Great Moderation period in the mid-1980s, the shifts in the second type of comovement have either received less attention or have gone unexplored.¹

The main contributions of our paper are twofold. First, we document shifts in the cross-correlations (also referred to as phase shifts) among macroeconomic variables in the post-World War II US business cycle since the mid-1980s. We focus on the real interest rate—a key intertemporal price in decision-making—and labour market quantities, namely, labour productivity, labour inputs, and the unemployment rate. These shifts in the cross-correlations indicating leading or lagging properties are, by definition, larger in absolute magnitude than the contemporaneous correlations reflecting the presence of important empirically relevant mechanisms not captured by contemporaneous comovements alone. Second, we study a va-

¹Shifts in volatility and responses of macroeconomic variables to business cycle shocks have also been studied in the literature but these moments are not the focus of our paper.

riety of contemporary Dynamic Stochastic General Equilibrium (DSGE) models and show that they all produce counterfactual lead-lag patterns relative to US data. Even models that successfully explain the shifts in contemporaneous correlations display counterfactual lead-lag properties. We discuss important challenges for model development and evaluation for future research aimed at improving our understanding of comovement—a central feature of the US business cycle.

We use the [Hodrick and Prescott \(1980, 1997\)](#) (HP) filter as a baseline to obtain the cyclical component of the data. The advantage of using the HP filter is that it facilitates comparisons with the previous literature that has also used the same filter. We then consider the cyclical components based on three alternative filters, namely, [Baxter and King \(1999\)](#), [Christiano and Fitzgerald \(2003\)](#), and [Hamilton \(2018\)](#). The two time periods we consider are 1948-1984 (the pre-1985 period) and 1985-2016 (the post-1985 period). This sample split has been widely studied in the literature in the context of declining volatility and cyclicity of macroeconomic variables associated with the onset of the Great Moderation period.² We summarize the four major lead-lag shifts between the pre- and post-1985 periods as follows:

First, *real interest rates positively lag output*. Real interest rates display a ‘Positive Lagging Property’ (PLP). They strongly lag output by three quarters with positive signs. The well known inverted-leading-indicator property of real interest rates documented by [King and Watson \(1996\)](#) has completely vanished. We find a remarkable stability of the evidence for PLP. We show that the PLP of the real interest rate holds for ex-ante and ex-post real rates, for different prices deflators, and for filtered or unfiltered real interest rates. Importantly, we document that the shift from leading to lagging, and the sign switch, has also occurred in the nominal interest rate. Second, *labour productivity negatively lags output*. Labour productivity has shifted from leading the cycle with a positive sign to lagging with

²See, for example, [Hall \(2007\)](#), [Stirol \(2009\)](#), [Galí and Gambetti \(2009\)](#), [Barnichon \(2010\)](#), [Fernald and Wang \(2016\)](#), [Daly et al. \(2017\)](#), [Galí and van Rens \(2017\)](#), and [Garin, Pries and Sims \(2018\)](#).

a negative sign. Output per hour lags by four quarters and output per person lags by five quarters. Third, *labour inputs negatively lead labour productivity*. Total hours worked have shifted from lagging output per hour by three quarters with a positive sign to leading by two quarters with a negative sign. Employment has shifted from lagging output per person by three quarters with a positive sign to leading by four quarters with a negative sign. Fourth, *the unemployment rate positively leads labour productivity*. The unemployment rate shifted from negatively lagging output per hour by three quarters and output per person by two quarters to positively leading output per hour by two quarters, and output per person by four quarters.

We conduct extensive checks to establish that these properties are in fact robust post-1985 US business cycle stylized facts. They suggest business cycle comovement of the real interest rate along with labour productivity and labour market variables has experienced a substantial shift in the lead-lag properties. Interestingly, such a shift is not present in investment data. For example, the well known property that residential investment leads the US business cycle is also present in the post-1985 data.

In light of the new lead-lag stylized facts listed above, an immediate question is: how do the properties of simulated data from existing Dynamic Stochastic General Equilibrium (DSGE) models compare with their empirical counterparts? We provide a few selected examples. For real interest rate dynamics we consider simulated data from [Smets and Wouters \(2007\)](#), [Iacoviello \(2005\)](#), and [Basu and Bundick \(2017\)](#), respectively. Our rationale is that these models have frictions and shocks that are embedded in a many contemporary DSGE models, and therefore, provide a useful reference point. For labour productivity and labour input dynamics, we consider simulated data from the models in [Galí and van Rens \(2017\)](#) and [Garin, Pries and Sims \(2018\)](#), respectively. Our rationale is that since these models successfully explain the decline in the procyclicality of labour productivity after the mid-1980s, they provide a natural benchmark to determine their intrinsic lead-lag properties

relative to the stylized facts reported above. Finally, for the unemployment rate and labour productivity dynamics we consider simulated data from [Barnichon \(2010\)](#). Our rationale is that this model studies the change in the contemporaneous correlation of unemployment and labour productivity after the mid-1980s and, therefore, is well-suited to examine the cross-correlations between the same two variables.

While our rationales for selecting DSGE models are clear, it is important to note that none of these models were developed to match cross-correlations. Therefore, if it turns out that a particular model does match the lead-lag pattern, then it would be explaining something it was not designed to and that will reveal the strength of the proposed mechanism. On the other hand, if it turns out that a particular model does not match the lead-lag structure then that would provide important information for researchers toward developing new models to explain the stylized facts we have documented.

As we discuss in detail, our comparative analysis reveals that all the models we consider produce counterfactual lead-lag properties (both qualitatively and quantitatively) relative to their empirical counterparts in the post-1985 data. By extension, we hypothesize that this assessment applies to a wide class of contemporary DSGE models. This finding raises many important challenges and suggests promising areas for future research aimed at understanding business cycle comovement and improving DSGE models.

Our paper is related to three strands of literature on business cycles. First, recent business cycle literature has focused on the shifts in the unconditional contemporaneous correlations that indicate the pro-, counter-, or acyclical nature of certain macroeconomic variables (in particular, labour productivity, unemployment, labour inputs) and their volatility (see, for example, [Hall \(2007\)](#), [Stiroh \(2009\)](#), [Galí and Gambetti \(2009\)](#), [Barnichon \(2010\)](#), [Fernald and Wang \(2016\)](#), [Daly et al. \(2017\)](#), [Galí and van Rens \(2017\)](#), [Garin, Pries and Sims \(2018\)](#)). This literature, however, has not examined shifts in the lead-lags properties of these variables over the business cycle which is the objective of our paper.

Second, our paper is related to a large body of literature, starting at least since [Backus, Kehoe and Kydland \(1992\)](#), that has either motivated or evaluated models based on cross-correlations and lead-lag properties.³ The primary focus of this literature is to consider cross-correlations over the whole sample period of study.⁴ By contrast, we focus on the shifts in cross-correlations across the pre- and post-1985 sample split that coincides with the widely studied onset of the Great Moderation in the US economy.

Finally, our paper is related to current research on business cycles that is motivated by comovement properties of macroeconomic variables. The focus, however, has been on the first type of comovement, namely contemporaneous correlations, and not the lead-lag properties. Our findings suggest that for a complete explanation of US business cycle comovement both types should be simultaneously considered for motivating new models and their evaluation. We provide two examples to support our point. The first example is [Jordà, Schularick and Taylor \(2016\)](#) who emphasize the correlations between credit growth and output growth. Using their data, we calculated the cross-correlations between credit growth and output growth across the subsamples 1948-1984 and 1985-2013. As it turns out, there has been a shift in the lead-lag pattern in 13 of the 17 countries in their data.⁵ The second example is [Angeletos \(2017\)](#), who advances the research agenda on demand-driven business cycle models where higher-order uncertainty is the source of frictional coordination among agents. The motivating facts are based on comovements (contemporaneous correlations) and he notes that the contemporaneous correlation between output and labour productivity is approximately zero (see Figure 2 in [Angeletos \(2017\)](#) based on the 1960-2015 period). This

³The appendix provides a list of the contributions in literature that have studied business cycle cross-correlations.

⁴A few exceptions are [Backus, Kehoe and Kydland \(1994\)](#) who consider pre- and post-1972 data and [Dotsey, Lantz and Scholl \(2003\)](#) who consider sub-samples between 1955 and 1996. [Gavin and Kydland \(2000\)](#) consider pre- and post-1979 sub-samples.

⁵These results are reported in Tables 16 and 17 in the Appendix. If we consider cross-correlations using [Jordà, Schularick and Taylor \(2016\)](#) data set for HP filtered data, 12 of the 17 countries exhibit a lead-lag switch. These results are reported in Tables 18 and 19.

assessment, however, misses the picture revealed in the lead-lag shifts in labour productivity over the cycle since the onset of the Great Moderation period in the US economy. Specifically, while the contemporaneous correlation is close to zero even in the post-1985 period, labour productivity, measured as output per hour, lags output negatively by four quarters with a cross-correlation of -0.61 . By definition, the leads and lags denote the largest absolute cross-correlations, which are often substantially larger than the contemporaneous correlations, suggesting empirically relevant business cycle forces at work that are not reflected in contemporaneous correlations alone.

The rest of this paper is organized as follows. Section 2 presents the data and documents the shifts in the lead-lag properties of the real interest rate and the three labour market variables. It also provides a comparison with properties based on simulated data from DSGE models. Section 3 assesses the robustness of properties to alternative filtering methods. Section 4 provides a discussion. Section 5 concludes.

2 Shifts in Lead-Lag Properties

In this section we present the data and the shifts in the lead-lag properties of four macroeconomic series. We also provide a comparison of lead-lag properties when looking through the lens of recent DSGE models. The set of models includes those with a focus on the changes in contemporaneous correlations since the onset of the Great Moderation period in the mid-1980s.

2.1 Data

We use quarterly data obtained from the Federal Reserve Bank of St. Louis Economic Database (FRED).⁶ We employ two different measures of output in the paper, namely,

⁶A more detailed description of the data is provided in the Appendix.

real Gross Domestic Product (GDP) and nonfarm business sector real output, to allow a comparison with the model-based results in the literature. Our baseline measure of the real interest rate is the 3-month Treasury bill secondary market rate minus one period ahead ex-post inflation, where inflation is defined as the annualized log difference of the GDP deflator. We also consider alternative measures of the real interest rate which are described in Appendix A.5. The two measures of labour productivity are nonfarm business sector real output per hour and per person. Total hours and employment are the hours and employment of all persons in the nonfarm business sector, respectively. Finally, the unemployment rate is defined as the civilian unemployment rate.

We perform standard transformations of the variables prior to examining the cross-correlations. Specifically, we take the natural log of all variables (excluding the real interest rates and the unemployment rate). Throughout our analysis, the HP filter smoothing parameter for quarterly data is 1600. The baseline cyclical data is computed by detrending the entire sample prior to splitting into pre- and post-1985. In the robustness section we document that the results presented herein are not sensitive to detrending each sample independently. We present the main empirical findings on the shifts in cross-correlation and the lead-lag properties below.⁷

2.2 Real Interest Rates Positively Lag Output

We define the real interest rate as

$$\text{Real Interest Rate}_t = \begin{cases} 3\text{-Month T-Bill}_t - \pi_{t+1}^F & : \text{Ex-Ante} \\ 3\text{-Month T-Bill}_t - \pi_{t+1} & : \text{Ex-Post} \end{cases}$$

⁷Table 1 presents all the cross-correlations that we discuss in this section.

where π_{t+1}^F and π_{t+1} are the one-period-ahead forecast of the inflation rate and the one-period-ahead actual inflation rate, respectively. We use the GDP deflator to construct π_{t+1} . For π_{t+1}^F we consider a variety of methods. First, we use an in-sample 3 variable VAR consisting of inflation, unemployment, and the nominal interest rate to forecast inflation (as in [Stock and Watson \(1999\)](#)). By construction, the in-sample VAR contains future information via the estimated parameters, therefore we also consider recursive and rolling window VARs (with a window length of 40 quarters). Finally, we use consumer price index estimates from the Survey of Professional Forecasters as a measure of expected inflation.

Figure 1 shows the cross-correlations between HP filtered output, Y_t , and leads and lags of the HP filtered real interest rate, denoted as R_t .⁸ Specifically, $\text{Corr}(Y_t, R_{t+k})$: $k = \{-5, -4, \dots, 0, \dots, 4, 5\}$, where a negative k indicates correlations between past real interest rates and current output and a positive k indicates correlations between future real interest rates and current output. The largest correlation in absolute terms determines the lead-lag property of a given series relative to another. This cross-correlation is represented by the solid black dots.⁹

Panel (a) shows that in the pre-1985 period, the ex-post real interest rate was strongly negatively correlated with future output, and was countercyclical. This is the well-known Inverted Leading Indicator Property (ILP) of real interest rates documented by [King and Watson \(1996\)](#).¹⁰

Panel (b) shows that in the pre-1985 data the nominal interest rate also displayed a strong negative correlation with future output. In sharp contrast, the ILP for both the ex-post real interest rate and nominal interest rate has completely vanished in the post-1985 data. The

⁸The results are nearly identical if we do not filter the real interest rate. These are shown in [Table 6](#) and [Table 7](#).

⁹All leads and lags discussed in the paper are statistically significant against the null hypothesis $H_0 : \rho_{i,j} = 0$.

¹⁰Similar properties of interest rates dynamics are documented in [Fiorito and Kollintzas \(1994\)](#) ([Table 3](#)), [Chari, Christiano and Eichenbaum \(1995\)](#) ([Figure 3](#)), [Beaudry and Guay \(1996\)](#) ([Table 2](#)), and [Stock and Watson \(1999\)](#) ([Table 2](#)).

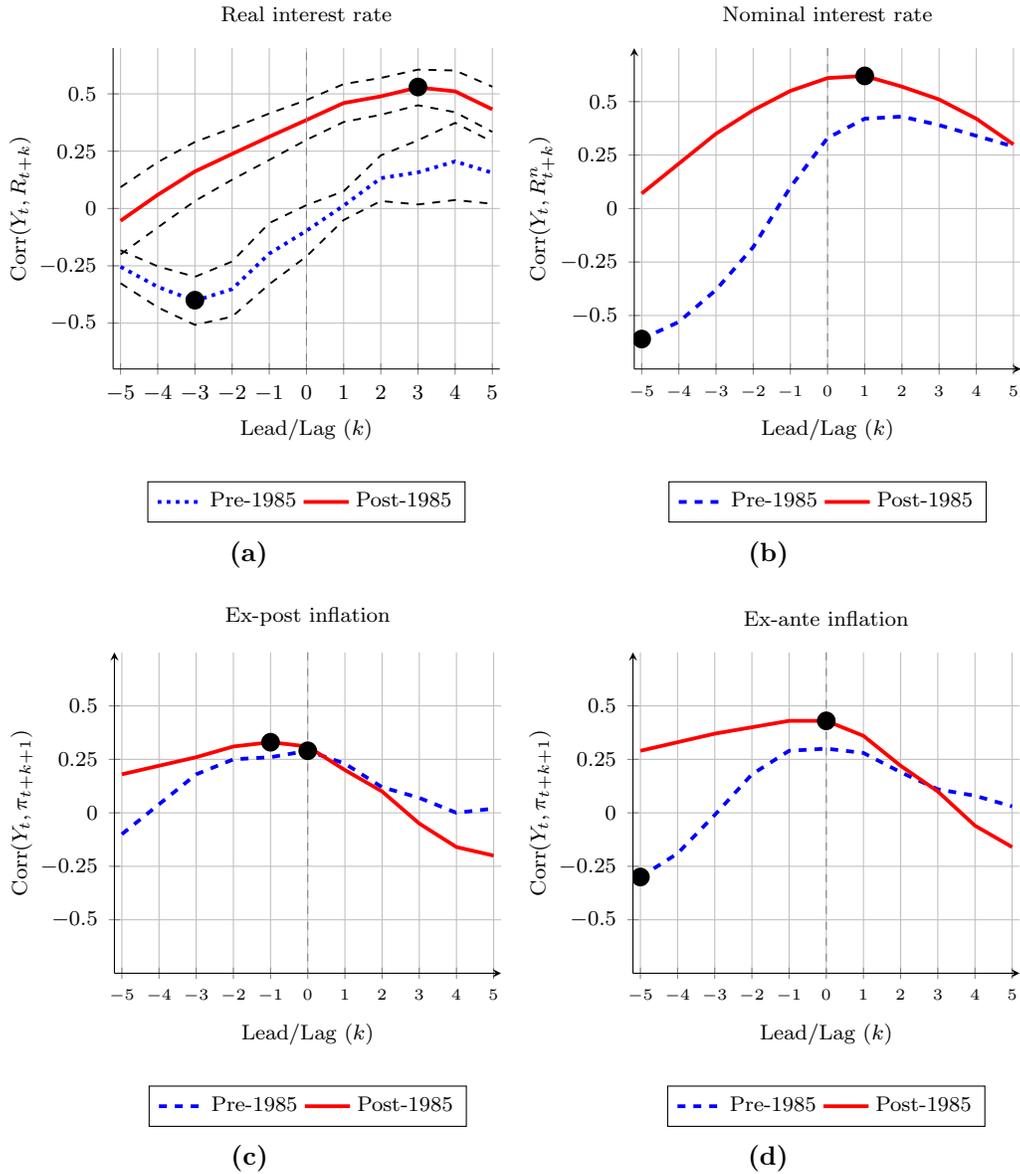


Figure 1: Cross-correlations between output, the real interest rate, the nominal interest rate, ex-post and ex-ante inflation

Note: Ex-post and ex-ante inflation measures are at time $t + 1$. Ex-post and ex-ante inflation are generated from the GDP deflator, the ex-ante measure is based on in-sample VAR forecasts. The black dashed bands represent one standard deviation confidence bands computed using GMM. For more information on computing standard errors, see Appendix A.2.

real interest rate lags output by three quarters with a positive sign and the nominal interest rate lags output by one quarter with a positive sign. The real interest rate in the post-1985 data is also strongly procyclical. We refer to this shift in business cycle dynamics of the real interest rate as the ‘Positive Lagging Property’ (PLP).

Panels (c) and (d) show the cross-correlation between output and one period ahead ex-post and ex-ante inflation. The cross-correlation properties of the ex-post inflation rate remain relatively unchanged while the cross-correlation for ex-ante inflation has become positively correlated with future output. These findings suggest that changes in the conduct of monetary policy is likely to be central in understanding the shifts in real interest rate dynamics.

We now provide further evidence that this switch from ILP to PLP is a robust stylized fact of the post-1985 real interest rate dynamics. The PLP of real interest rates also exists in the 1985I-2007IV sample, the Great Moderation period. This evidence (as shown in Table 8 in the Appendix) indicates that PLP is not driven by the zero-lower-bound on the federal funds rate reached in the aftermath of the Great Recession in the US. Furthermore, the findings are also robust to alternative measures of the real interest rate such as alternative price indexes for inflation (CPI, PCE, Core CPI), using the federal funds rate as the measure of the nominal interest rate, and estimates of the nominal interest rate in the absence of the zero-lower-bound from [Wu and Xia \(2016\)](#) (as shown in Table 6 and Table 7 in the appendix).

The evidence we document here is related to two previous studies. The first is by [Dotsey, Lantz and Scholl \(2003\)](#) who find that over the 1947-1996 period, the ex-ante real interest based on the GDP deflator measure of inflation is procyclical and lags output but displays the ILP property when the expected inflation measure is based on the CPI. They also find that ex-ante and ex-post real interest rates display different properties. Additionally, they find inconclusive lead-lag patterns in various sub-samples. While their preferred measure of the ex-ante real rate based on the GDP deflator displays PLP, their overall findings paint a

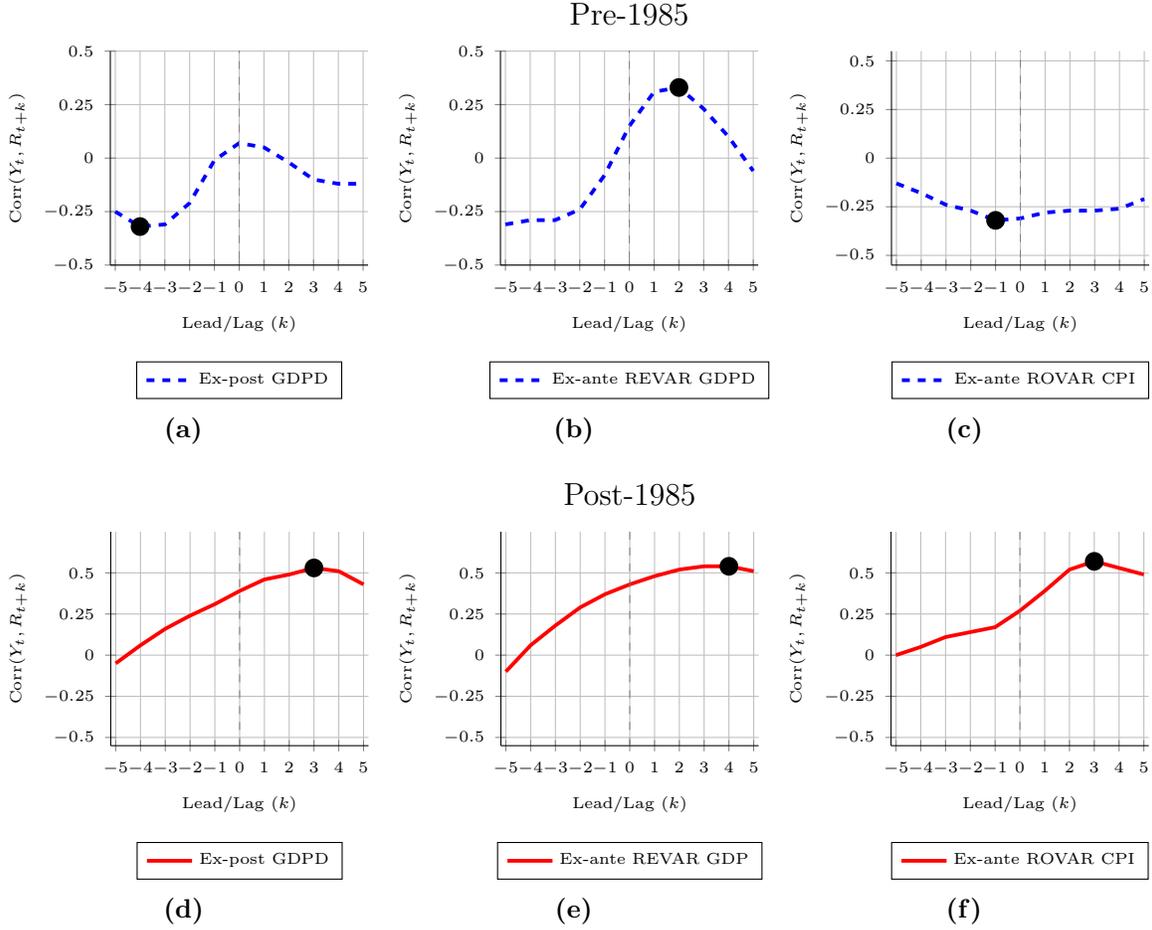


Figure 2: Ex-post and ex-ante real interest rates pre- and post-1985

Note: Ex-ante REVAR real interest rate is computed using estimates of expected inflation from the recursive VAR. Ex-ante ROVAR real interest rate is computed using estimates of expected inflation from the rolling VAR. The rolling window is set to 40 quarters. Pre-1985 cross-correlations are computed on data from 1956III:1984IV to avoid small sample VAR estimates.

mixed picture of the business cycle relationship between real interest rates and output. We concur with [Dotsey, Lantz and Scholl \(2003\)](#) in that the presence of ILP in the real interest rate data is largely related to the inflation instability during the 1970s. However, we find that in the post-85 data, that the relationship is remarkably robust to a variety of considerations. Both ex-ante and ex-post real interest rates display PLP, and real rates using both CPI and GDP based inflation measures display PLP. Figure 2 establishes that the various sources of

instability noted in [Dotsey, Lantz and Scholl \(2003\)](#) are not present in the post-1985 data. Thus, we conclude that the post-1985 data is consistent on the cyclical relationship between real interest rates and output, and represent a key stylized fact of business cycles.

The second study by [Mertens \(2010\)](#) investigates the relationship between real interest rates and output conditional on a variety of shocks. In particular, [Mertens \(2010\)](#) finds that the correlation between the real interest rate and output conditional on an identified technology shock is positive during the 1955-2006 period, and that ILP is driven by permanent shocks to inflation during the 1970s. He finds that real interest rates exhibit a leading indicator property conditional on the technology shock but with a positive sign.¹¹ This interpretation is, however, incorrect. The conditional correlation pattern documented in [Mertens \(2010\)](#) matches the post-1985 unconditional pattern as shown in [Figure 1](#) but it is a *lagging* rather than a leading relationship. The robust evidence that we have established shows that real interest rates exhibit PLP in the post-1985 data.

We now examine real interest rate-output dynamics through the lens of a variety of DSGE models and compare it with the evidence. In this context, our approach follows [King and Watson \(1996\)](#) who also presented a variety of models that were all unable to account for the ILP. This has been a long-standing puzzle in the literature. While this property was attributed to monetary shocks, [Boldrin, Christiano and Fisher \(2001\)](#) presented a technology shock driven two-sector real business cycle model with consumption habits and limited labour mobility that accounted for the ILP. Recently, [Pintus, Wen and Xing \(2017\)](#) present a model, building on [Kiyotaki and Moore \(1997\)](#), in which self-fulfilling belief shocks redistribute income away from lenders to borrowers during booms. Although their objective is to provide a theoretical rationale for the ILP, they do not provide a quantitative comparison of model-based cross-correlations with those in the data. However, the post-1985 evidence

¹¹[Mertens \(2010\)](#) states “Conditional on an identified technology shock, the real interest rate is procyclical and a positive leading indicator.”

we document poses a new challenge to the research aimed at explaining ILP since it no longer exists in the data. Business cycle dynamics of real interest rates are characterized by PLP.¹²

The right panel of Figure 3 shows the cross-correlation based on the simulated data from a standard Real Business Cycle (RBC) model.¹³ Interestingly, the procyclicality of real interest rates in the post-1985 data is, at least qualitatively, consistent with that based on this simulated data. While it is known that the model does not produce any lead-lag pattern between the real interest rate and output, the purpose of showing it here provides a useful perspective. The same challenge that the RBC model faced in matching ILP applies to matching PLP in the post-1985 data. Moreover, the mechanisms discussed in Boldrin, Christiano and Fisher (2001) and Pintus, Wen and Xing (2017) produce ILP, and therefore, by construction, cannot explain the PLP of real interest rates.

To investigate the real interest rate-output cross-correlations based on DSGE models developed more recently, we consider three models which have structural features—frictions and shocks—that are embedded in many contemporary DSGE models. These are Smets and Wouters (2007), Iacoviello (2005), and Basu and Bundick (2017).¹⁴ The bottom row in Figure 3 shows the cross-correlations based on data simulated from these models, respectively.

Panel (c) shows the cross-correlations based on the simulated data from the Smets and Wouters (2007) model estimated for 1966I:1984IV and 1985I:2007IV. It is perhaps not well recognized that the Smets and Wouters (2007) model did in fact generate ILP. The presence of

¹²Pintus, Wen and Xing (2018) study global financial linkages and the comovement of economic activity across countries. Their model, however, produces countercyclical real interest rate which runs counter to the the procyclical real rate in the the post-1985 data.

¹³We consider a frictionless version of the RBC model (See Cooley and Hansen (1995)).

¹⁴The replication code for Smets and Wouters (2007) is available from the *American Economic Review*'s website <https://www.aeaweb.org/articles?id=10.1257/aer.97.3.586>. The replication code for Iacoviello (2005) is available at Matteo Iacoviello's website <https://www2.bc.edu/matteo-iacoviello/research.htm>. The replication code for Basu and Bundick (2017) is available at Brent Bundick's website <http://www.brentbundick.com/research.html> and Johannes Pfeifer's github page https://github.com/JohannesPfeifer/DSGE_mod. For each simulation we generate 1000 simulations of 1280 observations, dropping the first 1000 observations to control for initial starting condition issues. We compute cross-correlations for each sample and take the median cross-correlation across the 1000 samples.

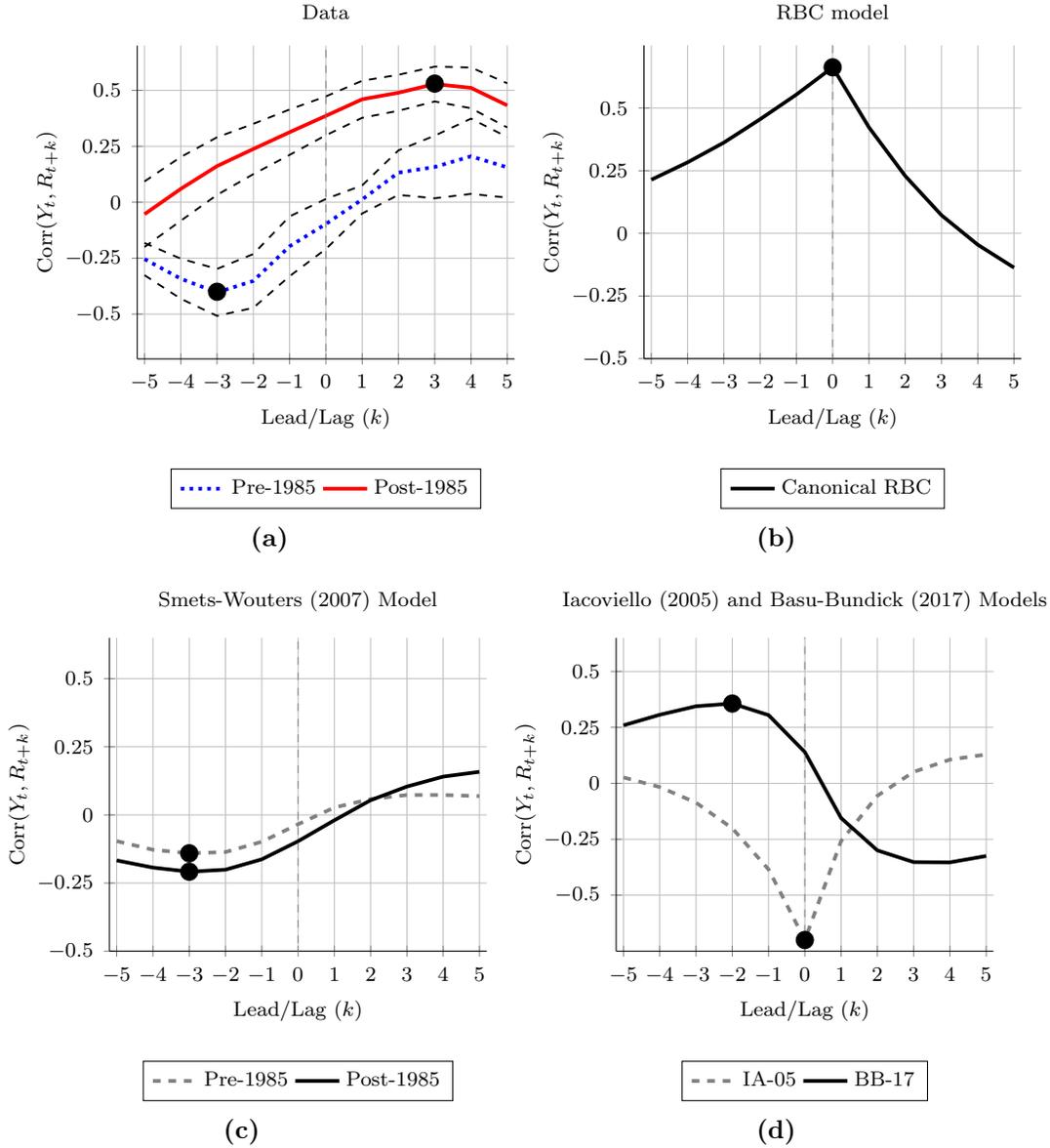


Figure 3: Cross-correlations between output and real interest rate

Note: k denotes the number of leads (negative values) or lags (positive values) between real interest rate and output, Y_t . The correlations at the black dashed line represent the contemporaneous correlations. Black solid circles denote the largest cross- or contemporaneous correlation that occurs at the k th lead/lag, $\max\{|\text{Corr}(Y_t, R_{t+k})|, k = -5, -4, \dots, 0, \dots, 4, 5\}$. Both actual and model-simulated output and real interest rates are HP filtered. For [Smets and Wouters \(2007\)](#) we estimate the pre-1985 model on data spanning from 1966I:1984IV and the post-1985 on data spanning from 1985I:2007IV. The black dashed bands represent one standard deviation confidence bands computed using GMM. For more information on computing standard errors, see [Appendix A.2](#).

consumption habits, a mechanism explored in [Boldrin, Christiano and Fisher \(2001\)](#), helped explain ILP. The [Smets and Wouters \(2007\)](#) model-based ILP is, however, counterfactual relative to the post-1985 evidence of PLP shown in panel (a).

Next, we examine the cross-correlations based on the simulated data from the [Iacoviello \(2005\)](#) model of housing that has two types of households—patient and impatient—and an endogenous borrowing constraint tied to the value of housing faced by the impatient agent. This model framework has been widely used in studying the role of monetary and fiscal policies in the presence of durable (housing) goods. As shown in panel (c), the real interest rate-output cross-correlations based on the simulated data do not match either the ILP in the pre-1985 data or the PLP in the post-1985 data.¹⁵ The largest correlation implied by the model is contemporaneous. The model also implies that the real interest rate is highly countercyclical which contradicts the post-1985 data. The final example is [Basu and Bundick \(2017\)](#) who study the role of countercyclical markups, sticky prices, and monetary policy in producing contractionary comovement among macroeconomic aggregates after an increased uncertainty about the future. We generate simulated data from their model and compute the real interest rate-output cross-correlations. In the present context, although their model generates a positive contemporaneous correlation between output and the real interest rate consistent with that observed in the post-1985 data, the lead-lag pattern turns out to be counterfactual. In their model, real interest rates lead output by one quarter and with a positive sign.

Based on the comparison between the cross-correlations in the post-1985 data and the models, we conclude that a broad class of contemporary DSGE models do not match the PLP—the defining property of real interest rates over the business cycle in the post-1985 data. Identifying new mechanisms to explain the positive lagging property of real interest rates is, therefore, an important research direction.

¹⁵The [Iacoviello \(2005\)](#) model does not have consumption habits.

Previously, [Boldrin, Christiano and Fisher \(2001\)](#) provided an explanation for the ILP of real interest rates in a model with intersectoral rigidities and consumption habits. Models with these features, however, cannot explain the PLP in the post-1985 period. Through a set of examples, we made the point that a broad class of contemporary DSGE models featuring a variety of mechanisms also do not produce PLP. This property of real interest rates is a serious challenge to developing a DSGE model-based explanation.

2.3 Labour Productivity Negatively Lags Output

Panels (a) and (b) in [Figure 4](#) show the cross-correlations between output and labour productivity, LP_t , where the latter variable is measured as output per hour and output per person, respectively. The cross-correlations in the figure represent $\text{Corr}(Y_t, LP_{t+k})$: $k = \{-5, -4, \dots, 0, \dots, 4, 5\}$.

While the decline in the procyclicality of labour productivity has been widely discussed in the literature, the post-1985 data show a prominent inverted lagging property of labour productivity over the cycle. Labour productivity shifted from leading the cycle in the pre-1985 period with a positive sign to lagging by at least a year with a negative sign. The absolute magnitude of these cross-correlations are substantially larger than the contemporaneous correlations, indicating the presence of a strong business cycle relationship not captured by comovement alone.

A natural question is: Do models that can either qualitatively or quantitatively explain the decline in the procyclicality of labour productivity also account for the lead-lag shift in the data that we have documented in panel (a) of [Figure 4](#)? To answer this question we consider two recent contributions to the literature, [Galí and van Rens \(2017\)](#) and [Garin, Pries and Sims \(2018\)](#). Both models have successfully explained the decline in the procyclicality of labour productivity.

The main mechanism discussed in Galí and van Rens (2017) is the decline in turnover reflecting reduced hiring frictions since the mid-1980s as a force behind the vanishing procyclicality of labour productivity. Panel (c) shows the cross-correlations based on the simulated data where we set the separation rate $\delta = 0.35$ for the pre-1985 period and $\delta = 0.15$ for the post-1985 period, as in Galí and van Rens (2017).¹⁶

Consistent with the results in Galí and van Rens (2017), the diminished procyclicality of labour productivity is evident in panel (c). This exercise, however, also reveals that the model produces counterfactual cross-correlations for the two sub-samples. The model implies a contemporaneous correlation that is the largest in absolute value in both periods. We, therefore, conclude that the same mechanism—the decline in turnover—as developed in Galí and van Rens (2017), cannot account either qualitatively or quantitatively for (i) the switch from labour productivity leading output to lagging output and (ii) the switch in sign from positive to negative cross-correlation as shown in panel (a) of Figure 4.

The second example is Garin, Pries and Sims (2018) who develop a model in which they show that the importance of sectoral shocks relative to aggregate shocks can account for the decline in the procyclicality of labour productivity in the US economy. We use the simulated data from their model to compute cross-correlations between labour productivity and output.¹⁷ Panel (d) of Figure 4 shows the cross-correlations for the pre- and post-1985 period. While the model can clearly account for the decline in the procyclicality of labour productivity, it produces a counterfactual cross-correlation pattern between output and labour productivity. The cross-correlations based on the simulated data are very close to zero for the post-1985 calibration in Garin, Pries and Sims (2018).

There is little work in the literature that has addressed the lead-lag properties of labour productivity over the US business cycle. An early contribution by Burnside and Eichenbaum

¹⁶The replication code for Galí and van Rens (2017) is available from Thijs van Rens's website <http://www.thijsvanrens.com/VPLP/>.

¹⁷We thank Eric Sims and Julio Garin for providing us with the replication code for their paper.

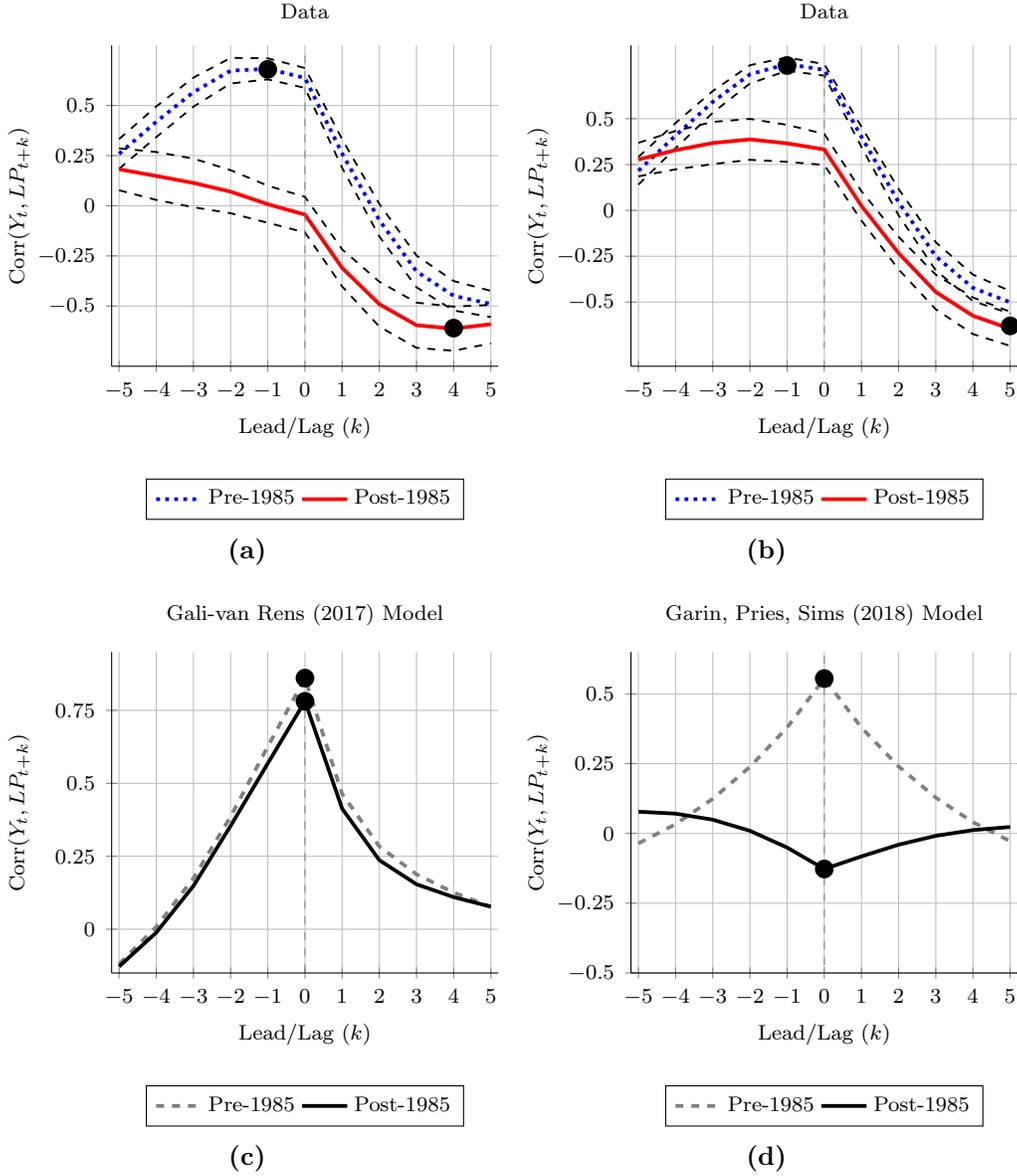


Figure 4: Cross-correlations between output and labour productivity

Note: k denotes the number of leads (negative values) or lags (positive values) between output and labour productivity. The correlations at the black dashed line represent the contemporaneous correlations. Black solid circles denote the largest cross- or contemporaneous correlation that occurs at the k th lead/lag, $\max |\{\text{Corr}(Y_t, LP_{t+k}), k = -5, -4, \dots, 0, \dots, 4, 5\}|$. Actual data and model data in [Garin et al. \(2018\)](#) and [Gali and van Rens \(2017\)](#) are HP filtered. The black dashed bands represent one standard deviation confidence bands computed using GMM. For more information on computing standard errors, see [Appendix A.2](#).

(1993) discussed the ability of the factor-loading model to generate dynamic correlations between labour productivity and output.¹⁸ The presence of factor hoarding behaviour, however, causes labour productivity to lead output, as noted in Burnside (1998). This means that changes in factor-hoarding are unlikely to explain the negatively lagging labour productivity over the business cycle in the post-1985 period.

In summary, existing models and mechanisms that have been used to explain the declining procyclicality of labour productivity do not account for its changing role in the lead-lag property over the business cycle. In light of the new evidence from the post-1985 period shown in panel (a) of Figure 4, explaining the shift in labour productivity from leading positively to lagging negatively is an important direction for future research. We discuss this point further in section ??.

To further understand the forces underlying the shift in the lead-lag properties of labour productivity, consider the following constant-returns-to-scale production function expressed in terms of labour productivity

$$\ln \left(\frac{Y}{H} \right) = \ln A + \ln \left(f \left(\frac{K}{L} \right) \right) = \ln A + \ln \left(\phi \left(\frac{W}{R} \right) \right)$$

where Y/H is labour productivity per hour, A is Total Factor Productivity (TFP), K/L is the capital services to labour ratio, and W/R is the real wage to real interest rate ratio. The second equality imposes the equilibrium condition in perfectly competitive factor markets. This decomposition allows us to examine if the shifts in labour productivity have occurred either through changes in forces driving TFP or those related to input markets reflected in factor prices, or both. We use Fernald (2014) data on utilization-adjusted TFP growth, convert it to a log level series, and then apply the HP filter to compute the cross-correlations.

¹⁸See Figure 3 in Burnside and Eichenbaum (1993) based on US data from 1955I - 1992IV. The discussion of cross-correlations is omitted in the published version (Burnside and Eichenbaum (1996)).

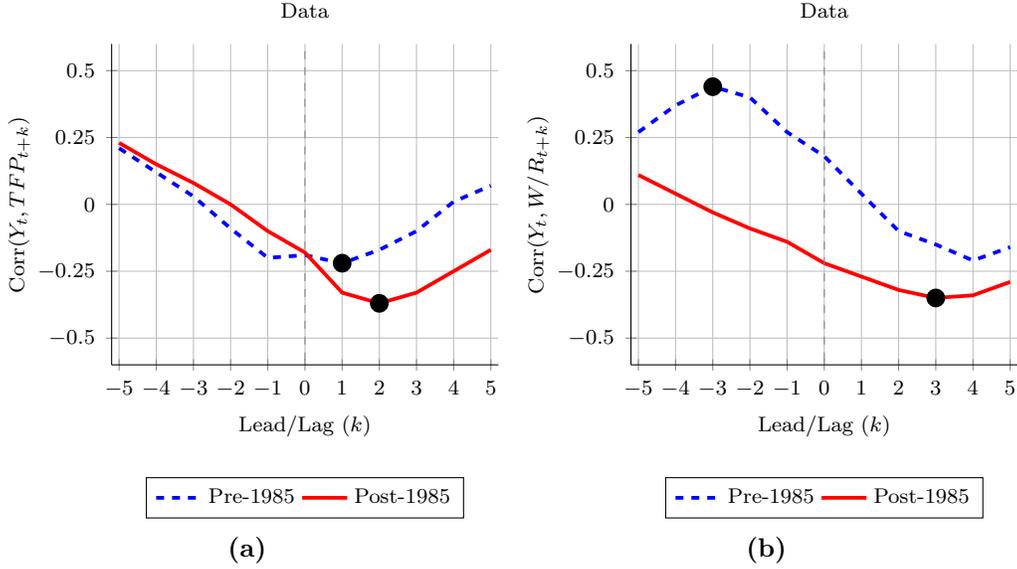


Figure 5: Cross-correlations of output with total factor productivity (Fernald (2014)) and wage-interest ratio

Note: k denotes the number of leads (negative values) or lags (positive values) of either TFP or W/R with respect to output. Black solid circles denote the largest cross- or contemporaneous correlation that occurs at the k th lead/lag, $\max\{|\text{Corr}(Y_t, TFP_{t+k}), k = -5, \dots, 0, \dots, 5|\}$ or $\max\{|\text{Corr}(Y_t, W/R_{t+k}), k = -5, \dots, 0, \dots, 5|\}$.

As shown in Panel (a) in Figure 5 TFP displayed a negative lagging property in the pre-1985 data relative to output over the business cycle, with $\text{Corr}(Y_t, TFP_{t+1}) = -0.22$. In the post-1985 data, this negative lagging property became more enhanced, with $\text{Corr}(Y_t, TFP_{t+2}) = -0.37$. So, although there is no shift in the lead-lag property, the stronger negative lagging property is consistent with the pattern observed for labour productivity. In both sub-samples, TFP has a negative contemporaneous correlation. Panel (b) shows that the factor price ratio displayed a strong positive leading property in the pre-1985 data with $\text{Corr}(Y_t, (W/R)_{t-3}) = 0.44$. This property shifted to a strongly lagging factor price ratio with a negative sign, $\text{Corr}(Y_t, (W/R)_{t+3}) = -0.35$. The factor price ratio also shifted from slightly procyclical to countercyclical. The shifts in the factor price comovement properties suggest that changes in factor market dynamics since the post-1985 period may have contributed to the negative

lagging property of labour productivity, with the TFP dynamics enhancing this pattern.

2.4 Labour Inputs Negatively Lead Labour Productivity

The dynamic relationship between total hours worked and productivity features prominently in a large body of business cycle research (see, for example, [Benhabib, Rogerson and Wright \(1991\)](#), [Christiano and Eichenbaum \(1992\)](#), [Galí \(1999\)](#) for early contributions). Panels (a) and (b) in [Figure 6](#) show two sets of cross-correlations. The first is between total hours worked, H_t , and output per hour. The second is between total employment, E_t , and output per worker. In the pre-1985 data, total hours worked lagged output per hour by three quarters and with a positive sign, $\text{Corr}(LP_t, H_{t+3}) = 0.62$. In the post-1985 data, however, this relationship has switched with total hours worked leading output per hour by two quarters. Employment also leads output per person by four quarters. Both of these cross-correlations have a negative sign, $\text{Corr}(LP_t, H_{t-2}) = -0.67$ and $\text{Corr}(LP_t, E_{t-4}) = -0.62$, respectively. The contemporaneous correlations between labour input and labour productivity measures have also switched signs from positive to negative. In particular, they have switched from $\text{Corr}(LP_t, H_t) = 0.21$ in the pre-1985 sample to -0.53 in the post-1985 sample for output per hour.¹⁹ Similarly, they switched from $\text{Corr}(LP_t, E_t) = 0.24$ to -0.27 for output per person.

The pre-1985 evidence of total hours worked lagging output per worker is consistent with the evidence reported in [Figure 6](#) of [Burnside and Eichenbaum \(1993\)](#). They show that the factor hoarding model does a good job of matching the cross-correlations. The switch in the lead-lag property, with total hours worked leading output per worker with a negative sign in the post-1985 data, however, suggests that the factor hoarding behaviour of firms cannot reconcile this evidence. We discuss this point further in [section ??](#). We now examine the cross-correlations between labour productivity and employment through

¹⁹This shift in contemporaneous correlation is similar to that reported in [Galí and van Rens \(2017\)](#), Table 1.

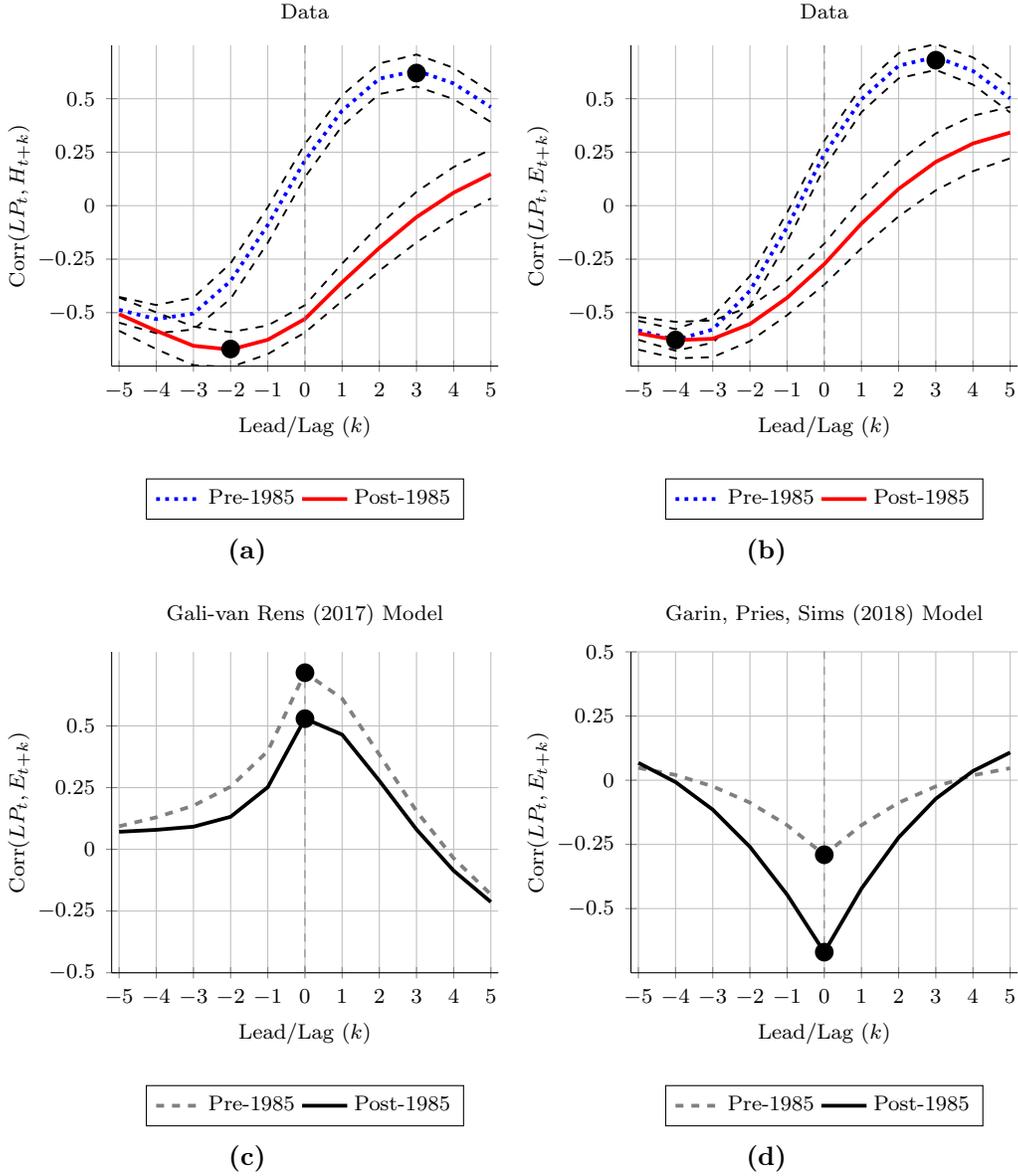


Figure 6: Cross-correlations between labour productivity and labour inputs

Note: k denotes the number of leads (negative values) or lags (positive values) between labour productivity and labour inputs. The correlations at the black dashed line represent the contemporaneous correlations. Black solid circles denote the largest cross- or contemporaneous correlation that occurs at the k th lead/lag, $\max\{|\text{Corr}(LP_t, \text{Labour Input}_{t+k})|, k = -5, \dots, 0, \dots, 5\}$. Actual data and simulated data from [Garin et al. \(2018\)](#) and [Galí and van Rens \(2017\)](#) are HP filtered. The black dashed bands represent one standard deviation confidence bands computed using GMM. For more information on computing standard errors, see [Appendix A.2](#).

the lens of the [Galí and van Rens \(2017\)](#) and [Garin, Pries and Sims \(2018\)](#) models. Panel (c) shows the cross-correlations based on the simulated data from [Galí and van Rens \(2017\)](#). The model qualitatively matches the decrease in contemporaneous correlations, but does not match the sign switch in the contemporaneous correlation and the lead-lag pattern is counterfactual. Panel (d) shows the cross-correlations based on the simulated data from [Garin, Pries and Sims \(2018\)](#). Unlike, [Galí and van Rens \(2017\)](#), their model does generate a negative contemporaneous correlation, but does not match the sign switch from positive to negative. From the perspective of our paper, it is important to note that the model produces a lead-lag pattern between labour productivity and employment which is counterfactual.

2.5 Unemployment Rate Positively Leads Labour Productivity

The relationship between labour productivity and the unemployment rate is a key component in models of search and matching (see, for example, [Mortensen and Pissarides \(1994\)](#), [Mertz \(1995\)](#), [Andolfatto \(1996\)](#), [Shimer \(2005\)](#), [Hall \(2005\)](#), among many other contributions). Recently, [Barnichon \(2010\)](#) noted that the contemporaneous correlation between cyclical unemployment and labour productivity over the post-WWII period switched sign in the mid-1980s: from significantly negative the correlation became significantly positive.

Panel (a) in [Figure 7](#) shows that in the pre-1985 data the largest cross-correlation between the unemployment rate, U_t and output per hour is $\text{Corr}(U_t, LP_{t-2}) = -0.64$, indicating that unemployment lagged output per hour by two quarters with a negative sign. Increases in productivity were associated with declines in unemployment two quarters ahead. This relationship switched in the post-1985 data to $\text{Corr}(U_t, LP_{t+2}) = 0.66$. Thus, increases in the unemployment rate are associated with an increase in productivity two quarters ahead.

[Barnichon \(2010\)](#) also notes in passing that the cross-correlogram between unemployment and productivity look ‘dramatically different’ (p. 1015). His focus, however, is on the shift in

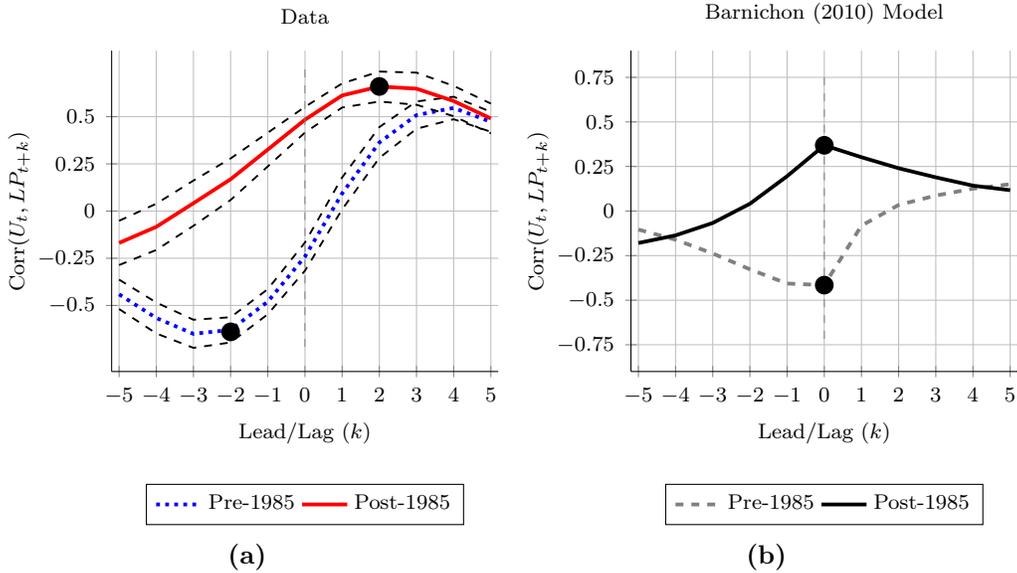


Figure 7: Cross-correlations between the unemployment rate and labour productivity

Note: k denotes the number of leads (negative values) or lags (positive values) between the unemployment rate and labour productivity. Black solid circles denote the largest cross- or contemporaneous correlation that occurs at the k th lead/lag, $\max\{|\text{Corr}(U_t, LP_{t+k})|, k = -5, \dots, 0, \dots, 5\}$. Both actual and model-simulated data are HP filtered. The black dashed bands represent one standard deviation confidence bands computed using GMM. For more information on computing standard errors, see Appendix A.2.

the contemporaneous correlation between unemployment and productivity and he, therefore, does not examine if the model produces the shift in cross-correlations which is the main focus of our paper. Interestingly, the absolute magnitude of the contemporaneous correlations in both pre-1984 and post-1984 periods that Barnichon (2010) considers are smaller than the cross-correlations. This observation reinforces our point that the focus in many recent papers has been on contemporaneous correlations, and the shifts in the lead-lag patterns (the largest absolute magnitude of cross-correlations) capturing important business cycle comovement relationships have either remained unnoticed or have received very little attention.

We simulate data from Barnichon (2010)'s model for pre-and post-1985 periods and compute the cross-correlations between unemployment and labour productivity.²⁰ Panel (b)

²⁰We thank Regis Barnichon for providing us with the replication codes.

in Figure 7 shows the model-based cross-correlations. We find that the model does not produce any lead-lag pattern for the post-1985 period.²¹ For the pre-1985 period, the model produces a lead of labour productivity over unemployment. Both of these properties are counterfactual relative to the stylized facts for the two sub-samples.

3 Robustness

In this section we present a variety of robustness checks to establish that the shifts in lead-lag properties are indeed robust stylized facts across the two sample periods in the US data.

3.1 Alternative filters

Our choice of using the HP filtered data as the baseline to present the lead-lag properties is advantageous for two reasons: first, the HP filter is arguably the most common method for obtaining the cyclical component from aggregate data, and second, it allows us to contrast the new stylized facts with those in the previous literature. All the lead-lag shifts that we have documented remain robust to [Baxter and King \(1999\)](#) (BK) and [Christiano and Fitzgerald \(2003\)](#) (CF) band-pass filters.²² These filters have been used in the literature as an alternative to the HP filter. Tables 3 and 4 in the Appendix present the results for the BK and CF filters, respectively. As is evident, the magnitude and signs of the cross-correlations are similar to the HP filter.

Recently, [Hamilton \(2018\)](#) has proposed an alternative to the HP filter.²³ This new

²¹In [Barnichon \(2010\)](#)'s model, employment is a state variable and does not respond on impact to shocks. We compute the contemporaneous correlation as $\text{Corr}(U_{t+1}, LP)$, and all leads and lags based on this vertical translation, consistent with the approach applied in the paper.

²²Previously, [Burnside \(1998\)](#), in his comment on [Canova \(1998\)](#), has noted that that business cycle stylized facts obtained from different filters do not necessarily have to agree. Specifically, [Burnside \(1998\)](#) (on page 514) states *I will argue that when the facts differ according to the filter, this simply means there are many facts to be explained.*

²³[Schüler \(2018\)](#) presents a detailed assessment of the [Hamilton \(2018\)](#) filter and discusses some of its shortcomings.

filtering method requires obtaining residuals from a regression of a variable h -periods ahead on its p most recent values as of date t . We refer to this regression-based procedure as the hp filter. To implement the hp filter, we use $h = 8$ and $p = 4$, which are [Hamilton \(2018\)](#)'s suggested parametric specification for detrending quarterly data.²⁴ The hp results are summarized in [Table 2](#). All the four headline stylized facts are consistent with the hp filter. There is, however, one measure of labour productivity, output per worker, which does not exhibit a shift in its lead over total employment or output. But the shift in the lead-lag properties of labour productivity measured as output per hour remains consistent across HP, BK, CF, and hp filters.

3.2 Broader business cycle phase of 8-50 quarters

Recently [Beaudry, Galizia and Portier \(2017a\)](#) have documented that many macroeconomic aggregates appear to exhibit a peak in their spectral densities at periodicities between 32 and 50 quarters. Their work suggests that broadening the definition of the business cycle to include up to 50 quarters to may be the more appropriate view of business cycles. With this background, it is of interest to determine if the lead-lag shifts that we document occur when we expand the conventional view of the business cycles (fluctuations occurring between 8 and 32 quarters) to include the lower frequencies. Using the BK and CF filter we confirm that all the lead-lag shifts that we have documented occur across this broader definition of the business cycle (See [Tables 10](#) and [11](#)).

²⁴Specially, for a series y_t , we run the regression $y_{t+h} = \beta_0 + \sum_{j=0}^p \beta_{j+1} y_{t-j} + v_{t+h}$ and construct the cyclical component as the residuals $\hat{v}_{t+h} = y_{t+h} - \left(\hat{\beta}_0 + \sum_{j=0}^p \hat{\beta}_{j+1} y_{t-j} \right)$.

3.3 Demographic adjusted hours

Are the lead-lag shifts in labour productivity related to demographic changes that have occurred over time? Using demographically adjusted hours from [Wolters \(2018\)](#) we recompute the cross-correlations containing output per hour.²⁵ These results are reported in [Table 15](#). As it turns out, the results reflect the same pattern as the baseline case. These finding suggests that the labour productivity shifts are not related to demographic changes.

3.4 Standardized variables

Sharp increases in volatility, as in the stock market data, across sub-samples may introduce a bias in unconditional correlation ([Forbes and Rigobon \(2002\)](#), [Stock and Watson \(2002\)](#)). While this is less of a concern in aggregate US macroeconomic data, we recompute the cross-correlations after standardizing the cyclical components to have variance equal to one in the entire sample, and then variance equal to one in each subsample. These results are reported in [Tables 12](#) and [13](#). The cross-correlations are nearly identical in both cases, suggesting that the changes in cross-correlations are not driven by changes in volatility after the Great Moderation.

3.5 Filtering on subsamples

The baseline cross-correlations presented in the paper are computed by first filtering the entire data, proceeded by splitting the data at 1984:4. Since the HP filter used in the paper is a two-sided filter, we investigate if the filter leads to any unintended spillovers between the cyclical data in each sample. [Table 14](#) highlights that the changes in lead-lag properties are robust to whether one filters on the entire sample or the pre- and post-1985 data independently.

²⁵We thank Maik Wolters for providing us with the adjusted hours data.

3.6 Alternative samples

The baseline samples used in the paper are 1948:I-1984:IV. As highlighted earlier, the changes in post-1985 data are robust to the exclusion of the Great Recession (ending the sample in 2007:IV). These results are reported in Table 8. In addition, we report results for an alternative onset of the Great Moderation (1983:I). All changes in the lead-lag properties discussed are robust to this alternative sample. These results are presented in Table 9.

3.7 Measurement error: an informative check

A well known fact is that residential investment ($INVR$) leads the cycle. We find that this fact is robust across pre-1985 and post-1985 data, and therefore, did not experience the type of shifts we have highlighted in the previous sections. In the post-1985 data, $INVR$ leads output by two quarters over the business cycle, the same as in the pre-1985 data. As shown in Figure 8, the largest cross-correlations are $\text{Corr}(Y_t, INVR_{t-2}) = 0.67$ and $\text{Corr}(Y_t, INVR_{t-2}) = 0.68$, respectively. This finding is also robust to using the BK, CF, and the hp filters. The evidence for the robust leading property of residential investment across the two periods is quite informative for at least two reasons. First, it suggests that the potential sources underlying the shifts in the lead-lag properties have likely occurred outside the investment sector. Second, it helps to allay any concern about measurement errors in aggregate data being the source of the shifts in the lead-lag properties.

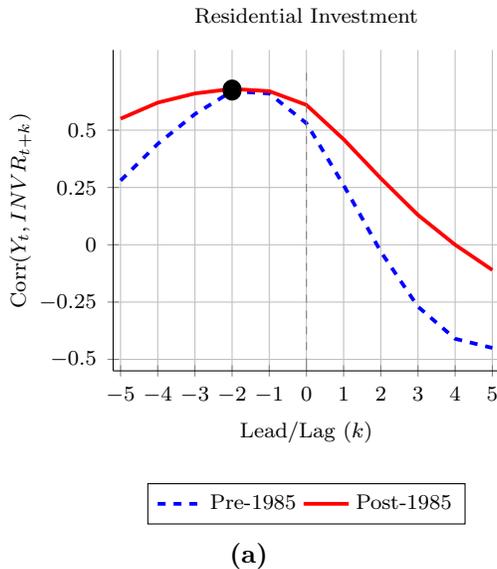


Figure 8: Cross-correlations between output and residential investment

Note: k denotes the number of leads (negative values) or lags (positive values) between output and residential investment. Black solid circles denote the largest cross- or contemporaneous correlation that occurs at the k th lead/lag, $\max |\{\text{Corr}(Y_t, \text{INVR}_{t+k}), k = -5, \dots, 0, \dots, 5\}|$.

4 Conclusion

In this paper, we document shifts in the lead-lag properties of the US business cycle since the onset of the Great Moderation period of the mid-1980s. We characterize four new stylized facts in terms of cross-correlations based on cyclical data. First, real interest rates positively lag output. Second, labour productivity negatively lags output. Third, labour inputs negatively lead labour productivity, and fourth, the unemployment rate positively leads labour productivity. The large absolute magnitude of these cross-correlations relative to contemporaneous correlations suggest important empirically relevant business cycle forces at work that are not reflected in contemporaneous correlations alone. We show that many contemporary DSGE models produce counterfactual lead-lag patterns, with incorrect signs. Our empirical findings suggest that explaining why the shifts in US business cycle comovement have occurred since the mid-1980s in both types comovement—contemporaneous correlations and

lead-lag properties—is a promising area for future research and for improving DSGE models.

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A Online Appendix

A.1 Cross-correlations across filters

Table 1 is the baseline cross-correlations reported in the paper. Cyclical components are obtained using a smoothing parameter of 1600. Table 2 are the cross-correlations when obtaining the cyclical components using Hamilton (2018)'s filter, using $h = 8$ and $p = 4$. Table 3 reports the cross-correlations obtained using Baxter and King (1999)'s filter examining the 6-32 quarter frequency. Table 4 reports the cross-correlations obtained using Christiano and Fitzgerald (2003) filter obtaining cyclical components between 6-32 quarter frequencies.

A.2 Standard errors of the cross-correlations

In the paper we compute standard errors for cross-correlations using the Delta method and generalized method of moments (see, for example (Cochrane 2005, pg. 207)),

$$\rho_{i,j}(\mu) = \frac{\mu_{yx} - \mu_x \mu_y}{(\mu_y - \mu_y^2)^{1/2} (\mu_{xx} - \mu_x^2)^{1/2}} \quad (1)$$

$$\text{var}(\hat{\rho}_{i,j}) = \frac{1}{T} \left\{ \frac{\partial \rho}{\partial \mu} \right\}' \sum_{j=-\infty}^{\infty} \text{cov}(\mathbf{x}_t, \mathbf{x}'_{t-j}) \left\{ \frac{\partial \rho}{\partial \mu} \right\} \quad (2)$$

where $\rho_{i,j}(\mu)$ is the standard correlation coefficient formula. Then the variance can be computed using (2) where $\mu = [\mu_y \ \mu_x \ \mu_{yy} \ \mu_{xx} \ \mu_{yx}]$ are the sample moments of the two variables of interest. Then $\partial \rho / \partial \mu$ is a 5×1 vector of derivatives (e.g. $\partial \rho / \partial \mu_{xy} = \frac{1}{\sigma_x \sigma_y}$). The variance covariance matrix is estimated using a Newey-West estimator with 10 lags.

A.3 Literature studying business cycle cross-correlations

Contributions in the case of real interest rates-output cross-correlations, for example, are [Fiorito and Kollintzas \(1994\)](#), [Chari, Christiano and Eichenbaum \(1995\)](#), [King and Watson \(1996\)](#), [Beaudry and Guay \(1996\)](#), [Boldrin, Christiano and Fisher \(2001\)](#), [Mertens \(2010\)](#), and [Dotsey et al. \(2003\)](#). For cross-correlations related to investment see [Hornstein and Praschnik \(1997\)](#), [Gomme, Kydland and Rupert \(2001\)](#), [Fisher \(2007\)](#), [Kydland, Rupert and Sustek \(2016\)](#), [Khan and Rouillard \(2017\)](#), [Khan and Rouillard \(2018\)](#), among others). For labour productivity-output and labour productivity-hours cross-correlations see [Burnside and Eichenbaum \(1993\)](#). In the case of net exports, terms of trade, and balance of payments cross-correlations see [Backus, Kehoe and Kydland \(1992\)](#), [Backus, Kehoe and Kydland \(1994\)](#), among others. [Christiano, Motto and Rostagno \(2014\)](#) for cross-correlations between output and investment, consumption, credit risk, and equity. [Azariadis, Kaas and Wen \(2016\)](#) examine cross-correlations in unsecured firm credit to motivate their model of self-fulfilling credit cycles. [Beaudry, Galizia and Portier \(2017b\)](#) discuss the positive correlation between their measure of capital over-accumulation prior to a recession and the subsequent severity of the recession over the period 1959-2015 in motivating their theoretical model. [Barsky and Sims \(2012\)](#) discuss the cross-correlations between consumer confidence and output.

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	2.02	1.02	.41	-.25	-.34	-.4	-.35	-.2	-.1	.01	.13	.15	.2	.14
Nominal interest rate	1.16	.59	.75	-.61	-.53	-.38	-.18	.1	.33	.42	.43	.39	.34	.29
Residential Inv	11.43	5.77	.88	.28	.44	.57	.67	.66	.53	.26	-.03	-.27	-.41	-.45
TFP	1.07	.54	.62	.21	.12	.03	-.09	-.2	-.19	-.22	-.17	-.1	.01	.07
W/R ratio	2.36	1.19	.48	.27	.37	.44	.4	.27	.18	.04	-.1	-.15	-.21	-.16
Ex-post inflation	2.01	1.02	.46	-.1	.04	.18	.25	.26	.29	.23	.12	.07	0	.02
Ex-ante inflation	1.35	.68	.65	-.3	-.19	-.01	.18	.29	.3	.28	.19	.11	.08	.03
1985Q1-2016Q4														
Real interest rate	1.06	.99	.62	-.05	.06	.16	.24	.31	.39	.46	.49	.53	.51	.43
Nominal interest rate	1.03	.96	.94	.07	.21	.35	.46	.55	.61	.62	.57	.51	.42	.3
Residential Inv	7.18	6.7	.93	.55	.62	.66	.68	.67	.61	.46	.29	.13	0	-.11
TFP	.84	.78	.69	.23	.15	.08	0	-.1	-.18	-.33	-.37	-.33	-.25	-.17
W/R ratio	1.74	1.62	.66	.11	.04	-.03	-.09	-.14	-.22	-.27	-.32	-.35	-.34	-.29
Ex-post inflation	.72	.67	.3	.18	.22	.26	.31	.33	.31	.2	.1	-.05	-.16	-.2
Ex-ante inflation	.59	.55	.54	.29	.33	.37	.4	.43	.43	.36	.22	.1	-.06	-.16
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	1.22	.47	.7	.26	.42	.56	.67	.68	.64	.26	-.07	-.32	-.44	-.48
Output per person	1.58	.61	.77	.21	.4	.59	.74	.79	.77	.4	.04	-.25	-.42	-.49
Total hours	2.05	.79	.88	-.35	-.21	.02	.33	.65	.89	.9	.77	.55	.3	.08
1985Q1-2016Q4														
Output per hour	.85	.58	.74	.18	.15	.11	.07	.01	-.04	-.31	-.49	-.59	-.61	-.58
Output per person	.88	.6	.74	.27	.32	.36	.39	.36	.33	.02	-.23	-.44	-.57	-.63
Total hours	1.72	1.18	.94	.04	.22	.4	.59	.75	.87	.91	.86	.75	.59	.42
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	2.05	1.68	.88	-.47	-.52	-.5	-.35	-.09	.21	.44	.59	.62	.56	.45
1985Q1-2016Q4														
Total hours	1.72	2.03	.94	-.5	-.58	-.65	-.67	-.63	-.53	-.36	-.2	-.05	.06	.15
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	1.72	1.09	.89	-.57	-.62	-.58	-.4	-.1	.24	.5	.65	.68	.62	.49
1985Q1-2016Q4														
Total employment	1.44	1.64	.96	-.59	-.62	-.62	-.55	-.43	-.27	-.08	.08	.2	.29	.34
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	1.22	1.34	.7	-.43	-.56	-.64	-.62	-.48	-.24	.09	.36	.5	.54	.46
Output per person	1.58	1.74	.77	-.41	-.57	-.7	-.73	-.62	-.39	-.03	.29	.5	.58	.54
1985Q1-2016Q4														
Output per hour	.85	1.25	.74	-.17	-.08	.04	.17	.33	.48	.61	.66	.65	.58	.48
Output per person	.88	1.29	.74	-.37	-.35	-.28	-.2	-.05	.14	.34	.49	.58	.61	.59

TABLE 1: Cross-correlations and volatilities using Hodrick-Prescott filter

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	2.5	.65	.63	-.26	-.33	-.35	-.31	-.23	-.17	-.11	-.06	-.02	.03	.02
Nominal interest rate	2.16	.56	.88	-.58	-.49	-.39	-.23	0	.2	.3	.34	.38	.38	.35
Residential Inv	20.75	5.38	.89	.39	.5	.55	.57	.54	.43	.18	-.03	-.21	-.36	-.42
TFP	1.95	.51	.83	.3	.21	.13	.02	-.09	-.14	-.16	-.12	-.08	.01	.07
W/R ratio	3.63	.94	.73	.27	.36	.4	.38	.33	.27	.18	.09	.01	-.07	-.08
Ex-post inflation	2.01	.52	.46	-.19	-.08	-.03	0	.04	.08	.07	.07	.1	.11	.17
Ex-ante inflation	1.35	.35	.65	-.25	-.19	-.08	0	.04	.08	.06	.02	.04	.08	.12
1985Q1-2016Q4														
Real interest rate	1.82	.68	.86	.03	.11	.21	.32	.41	.5	.56	.59	.6	.58	.54
Nominal interest rate	1.86	.69	.95	.16	.29	.41	.51	.58	.63	.62	.58	.53	.46	.38
Residential Inv	16.95	6.33	.94	.7	.73	.74	.73	.71	.67	.57	.48	.38	.29	.2
TFP	2.04	.76	.9	.3	.27	.23	.19	.15	.13	.08	.08	.11	.15	.18
W/R ratio	3.54	1.32	.88	.17	.14	.09	.03	-.01	-.07	-.09	-.11	-.1	-.06	-.02
Ex-post inflation	.72	.27	.3	.07	.15	.18	.22	.23	.2	.16	.1	.04	-.01	-.03
Ex-ante inflation	.59	.22	.54	.05	.15	.22	.28	.31	.32	.26	.21	.14	.08	.03
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	2.43	.5	.88	.56	.66	.72	.72	.69	.62	.38	.13	-.06	-.19	-.27
Output per person	3.24	.66	.9	.51	.64	.73	.76	.76	.72	.48	.23	.02	-.15	-.27
Total hours	3.92	.8	.85	-.15	.03	.23	.45	.7	.88	.81	.72	.6	.41	.23
1985Q1-2016Q4														
Output per hour	2.07	.58	.91	.16	.14	.11	.05	-.01	-.03	-.13	-.19	-.2	-.19	-.17
Output per person	1.94	.54	.89	.3	.33	.34	.3	.26	.23	.06	-.06	-.15	-.22	-.27
Total hours	3.92	1.09	.93	.35	.48	.6	.71	.8	.87	.85	.79	.7	.58	.46
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	3.92	1.61	.85	-.48	-.46	-.4	-.23	0	.22	.37	.48	.54	.53	.49
1985Q1-2016Q4														
Total hours	3.92	1.89	.93	-.43	-.5	-.55	-.58	-.56	-.5	-.42	-.35	-.27	-.2	-.13
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	3.51	1.08	.84	-.6	-.56	-.46	-.28	-.04	.21	.35	.45	.5	.46	.39
1985Q1-2016Q4														
Total employment	3.29	1.7	.94	-.5	-.52	-.5	-.45	-.36	-.25	-.14	-.05	.01	.07	.11
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	2.43	1.54	.88	-.6	-.65	-.69	-.67	-.58	-.45	-.22	0	.15	.25	.29
Output per person	3.24	2.06	.9	-.59	-.67	-.72	-.72	-.65	-.52	-.29	-.07	.11	.25	.32
1985Q1-2016Q4														
Output per hour	2.07	1.66	.91	-.06	-.02	.04	.1	.16	.22	.26	.27	.24	.19	.1
Output per person	1.94	1.55	.89	-.23	-.22	-.17	-.13	-.05	.04	.14	.22	.27	.29	.26

TABLE 2: Cross-correlations and volatilities using the *hp* filter (Hamilton (2018))

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	1.33	.73	.84	-.39	-.44	-.4	-.28	-.1	.07	.19	.19	.1	-.01	-.08
Nominal interest rate	1.06	.58	.92	-.73	-.64	-.44	-.16	.14	.39	.53	.55	.49	.37	.27
Residential Inv	11.02	6.07	.92	.33	.49	.64	.72	.69	.52	.27	0	-.24	-.39	-.45
TFP	.97	.53	.88	.34	.24	.09	-.07	-.2	-.28	-.26	-.18	-.07	.02	.08
W/R ratio	1.68	.92	.88	.34	.42	.43	.36	.23	.07	-.06	-.09	-.06	-.01	.02
Ex-post inflation	2.01	1.11	.46	-.16	-.07	.03	.11	.17	.2	.17	.2	.2	.28	.24
Ex-ante inflation	1.35	.74	.65	-.31	-.21	-.05	.1	.22	.26	.23	.16	.15	.16	.25
1985Q1-2016Q4														
Real interest rate	.89	.85	.93	-.09	.05	.16	.24	.32	.41	.5	.57	.61	.58	.5
Nominal interest rate	.99	.95	.95	.04	.21	.35	.47	.56	.62	.62	.58	.5	.39	.27
Residential Inv	6.78	6.47	.96	.53	.61	.68	.72	.7	.62	.48	.31	.15	.02	-.08
TFP	.81	.77	.91	.3	.23	.15	.04	-.08	-.21	-.31	-.35	-.32	-.24	-.11
W/R ratio	1.54	1.47	.92	.22	.13	.04	-.04	-.12	-.21	-.3	-.37	-.41	-.4	-.35
Ex-post inflation	.72	.69	.3	.2	.25	.31	.36	.38	.35	.25	.1	-.06	-.19	-.26
Ex-ante inflation	.59	.56	.54	.26	.34	.4	.45	.48	.47	.39	.27	.11	-.06	-.2
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	1.13	.47	.89	.26	.44	.63	.76	.77	.61	.32	-.02	-.32	-.5	-.54
Output per person	1.47	.61	.9	.21	.42	.65	.83	.88	.75	.46	.1	-.24	-.47	-.55
Total hours	1.94	.8	.89	-.38	-.24	.01	.34	.66	.89	.92	.8	.57	.31	.08
1985Q1-2016Q4														
Output per hour	.79	.56	.91	.2	.18	.18	.16	.08	-.07	-.27	-.46	-.6	-.64	-.58
Output per person	.82	.58	.9	.28	.35	.44	.49	.47	.34	.1	-.19	-.45	-.62	-.67
Total hours	1.67	1.18	.95	0	.17	.37	.58	.75	.88	.92	.87	.74	.57	.37
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	1.94	1.72	.89	-.51	-.58	-.53	-.37	-.11	.18	.45	.61	.65	.6	.49
1985Q1-2016Q4														
Total hours	1.67	2.11	.95	-.49	-.6	-.68	-.71	-.65	-.53	-.36	-.18	-.02	.1	.18
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	1.63	1.11	.9	-.61	-.67	-.62	-.42	-.13	.21	.5	.67	.71	.65	.52
1985Q1-2016Q4														
Total employment	1.38	1.68	.96	-.61	-.66	-.65	-.58	-.44	-.25	-.05	.13	.26	.34	.37
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	1.13	1.34	.89	-.46	-.6	-.68	-.67	-.53	-.28	.04	.33	.52	.57	.49
Output per person	1.47	1.74	.9	-.44	-.61	-.75	-.79	-.68	-.43	-.08	.25	.5	.6	.56
1985Q1-2016Q4														
Output per hour	.79	1.21	.91	-.19	-.11	.01	.16	.34	.5	.63	.69	.67	.59	.48
Output per person	.82	1.26	.9	-.39	-.38	-.34	-.24	-.07	.13	.34	.52	.63	.66	.63

TABLE 3: Cross-correlations and volatilities using [Baxter and King \(1999\)](#) filter

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	1.61	.85	.84	-.3	-.42	-.48	-.44	-.31	-.13	.05	.17	.23	.21	.16
Nominal interest rate	1.05	.56	.91	-.71	-.61	-.41	-.14	.15	.4	.55	.59	.53	.43	.33
Residential Inv	11.79	6.26	.92	.33	.5	.66	.74	.71	.54	.26	-.06	-.33	-.5	-.56
TFP	.98	.52	.86	.33	.22	.07	-.08	-.2	-.27	-.27	-.23	-.16	-.07	.02
W/R ratio	2	1.06	.87	.35	.48	.54	.5	.38	.2	0	-.15	-.25	-.27	-.24
Ex-post inflation	2.01	1.07	.46	-.13	.02	.16	.27	.31	.3	.23	.15	.08	.05	.04
Ex-ante inflation	1.35	.72	.65	-.3	-.17	.01	.19	.32	.37	.32	.24	.16	.1	.08
1985Q1-2016Q4														
Real interest rate	.84	.85	.91	-.18	-.05	.06	.15	.24	.32	.4	.46	.48	.44	.35
Nominal interest rate	.92	.93	.94	-.07	.08	.23	.35	.44	.49	.49	.45	.36	.24	.12
Residential Inv	5.4	5.46	.93	.32	.48	.63	.75	.79	.75	.62	.44	.26	.11	-.02
TFP	.76	.77	.89	.33	.24	.12	-.01	-.16	-.3	-.43	-.5	-.5	-.43	-.32
W/R ratio	1.59	1.61	.93	.29	.22	.15	.08	0	-.08	-.15	-.21	-.26	-.27	-.24
Ex-post inflation	.72	.73	.3	.15	.18	.21	.25	.25	.21	.12	-.01	-.15	-.25	-.3
Ex-ante inflation	.59	.6	.54	.22	.27	.31	.35	.36	.33	.22	.11	-.04	-.19	-.3
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	1.14	.45	.89	.26	.46	.67	.8	.8	.63	.33	-.02	-.33	-.52	-.57
Output per person	1.5	.59	.9	.2	.44	.68	.87	.91	.78	.48	.11	-.24	-.48	-.57
Total hours	2.02	.8	.91	-.44	-.27	.01	.35	.68	.9	.94	.82	.57	.28	.03
1985Q1-2016Q4														
Output per hour	.75	.56	.9	.4	.39	.39	.36	.26	.09	-.15	-.38	-.56	-.65	-.63
Output per person	.83	.62	.9	.44	.53	.62	.68	.65	.5	.24	-.08	-.38	-.6	-.69
Total hours	1.47	1.1	.94	-.22	-.01	.23	.48	.7	.86	.91	.85	.71	.52	.3
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	2.02	1.77	.91	-.54	-.6	-.55	-.37	-.09	.22	.49	.67	.71	.64	.5
1985Q1-2016Q4														
Total hours	1.47	1.96	.94	-.51	-.61	-.67	-.67	-.59	-.43	-.22	0	.19	.33	.43
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	1.66	1.11	.91	-.63	-.68	-.61	-.39	-.07	.28	.58	.76	.8	.71	.55
1985Q1-2016Q4														
Total employment	1.17	1.42	.94	-.68	-.7	-.66	-.55	-.37	-.14	.1	.32	.49	.58	.61
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	1.14	1.28	.89	-.48	-.63	-.71	-.68	-.51	-.23	.1	.4	.59	.64	.56
Output per person	1.5	1.68	.9	-.45	-.64	-.78	-.81	-.68	-.41	-.05	.3	.55	.66	.63
1985Q1-2016Q4														
Output per hour	.75	1.3	.9	-.39	-.3	-.16	.01	.22	.42	.58	.65	.65	.58	.48
Output per person	.83	1.44	.9	-.57	-.57	-.53	-.41	-.23	.01	.25	.46	.6	.66	.66

TABLE 4: Cross-correlations and volatilities using [Christiano and Fitzgerald \(2003\)](#) filter

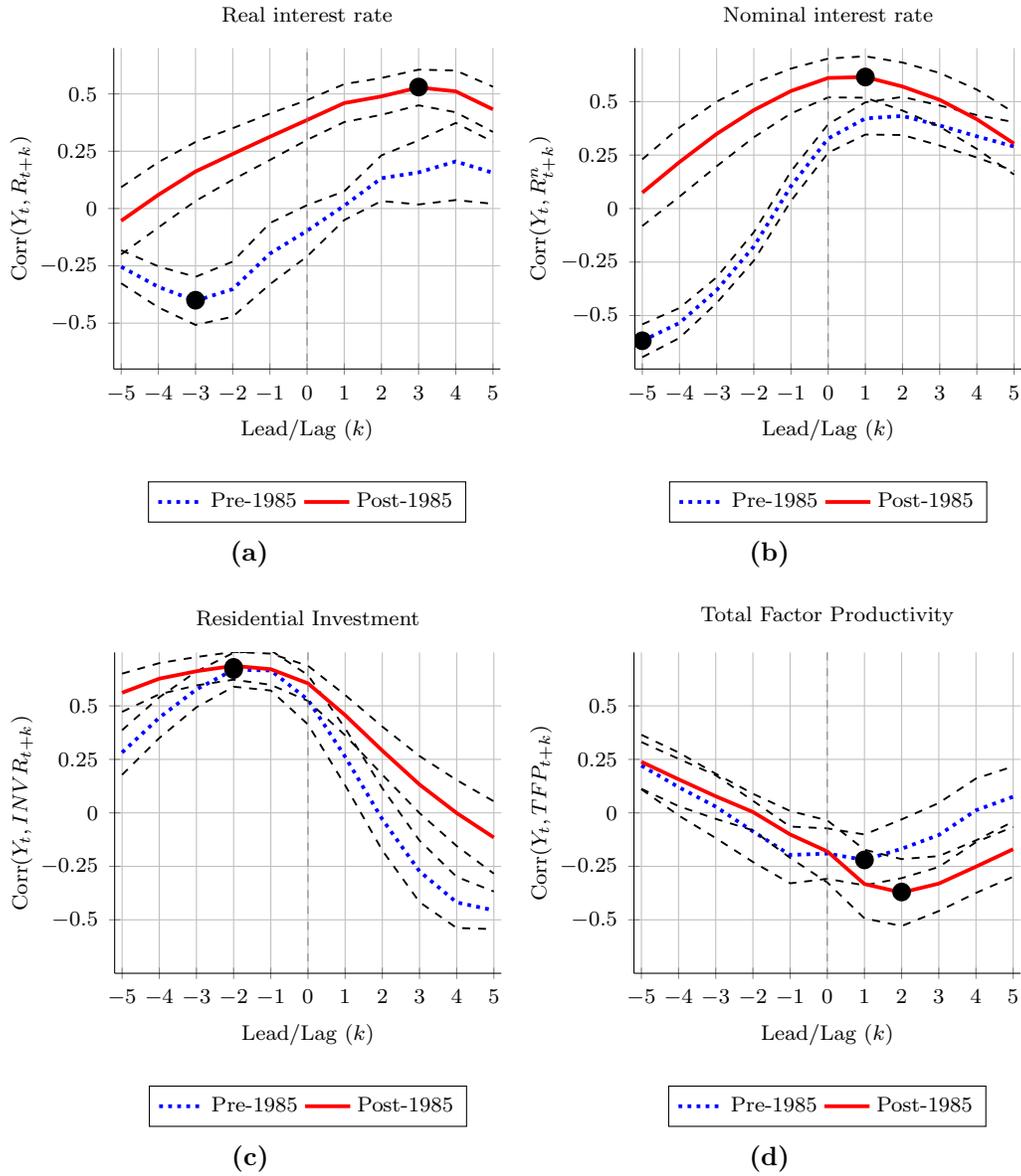


Figure 9: Cross-correlations with 1 standard deviation confidence bands

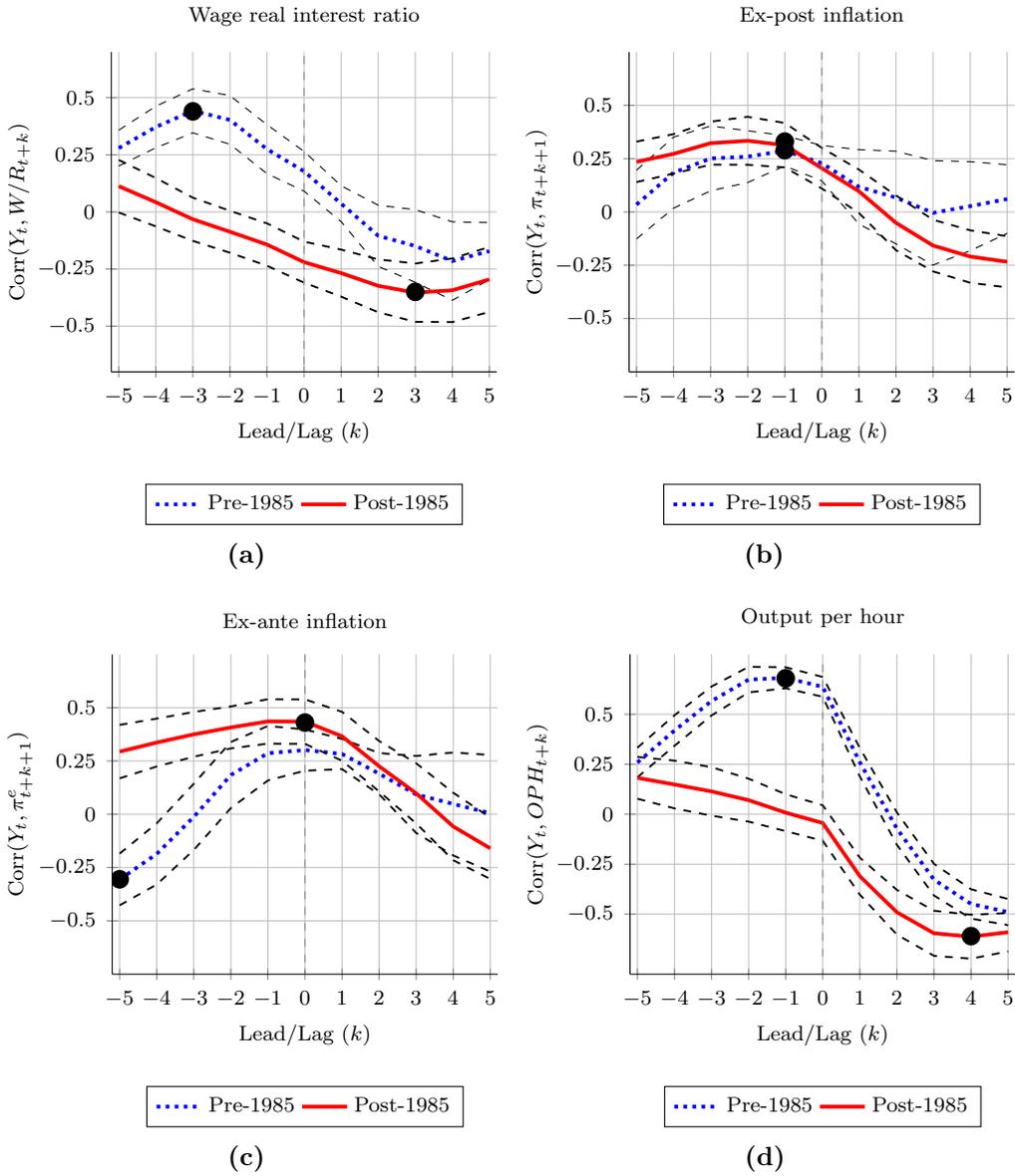


Figure 10: Cross-correlations with 1 standard deviation confidence bands

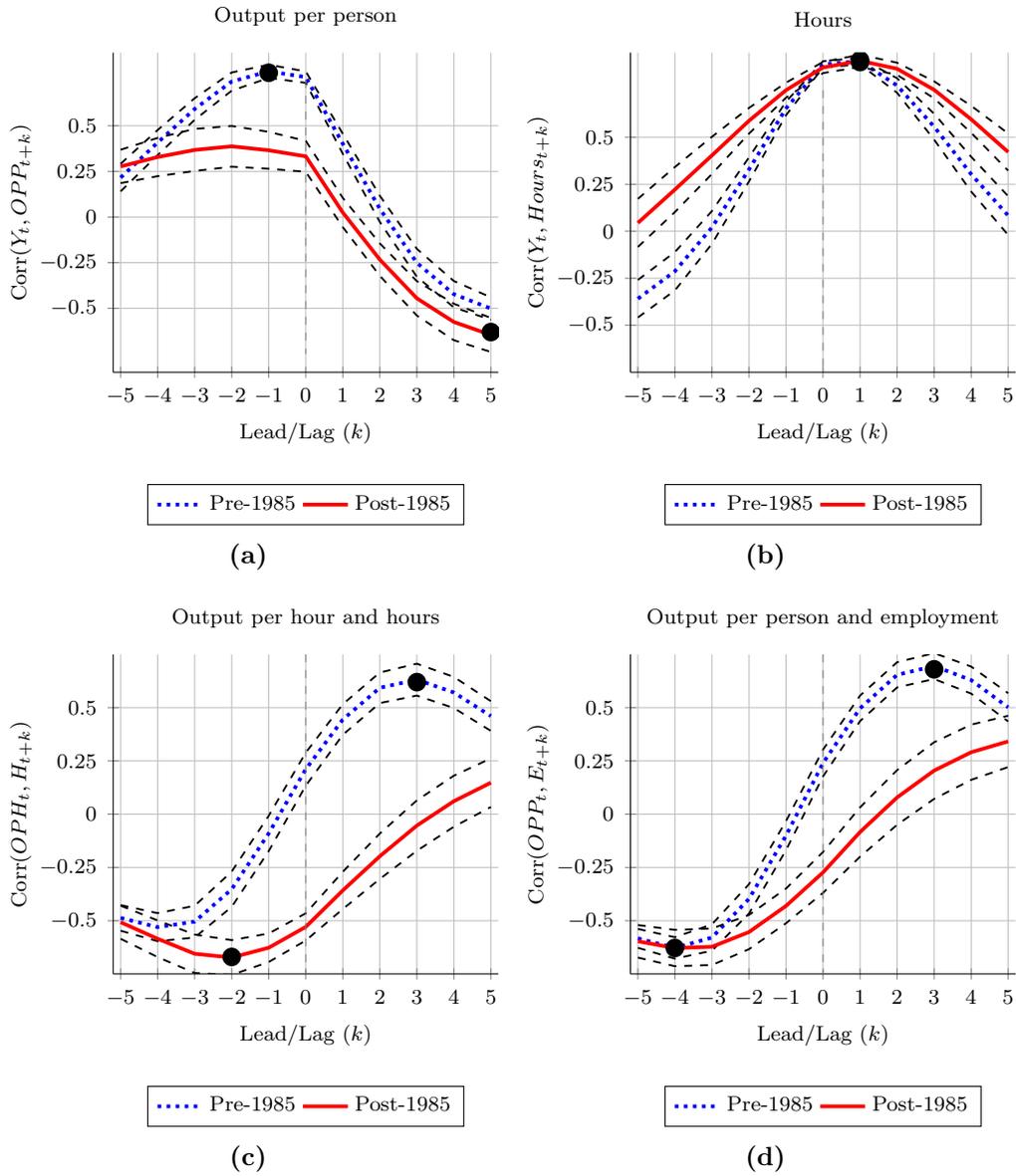


Figure 11: Cross-correlations with 1 standard deviation confidence bands

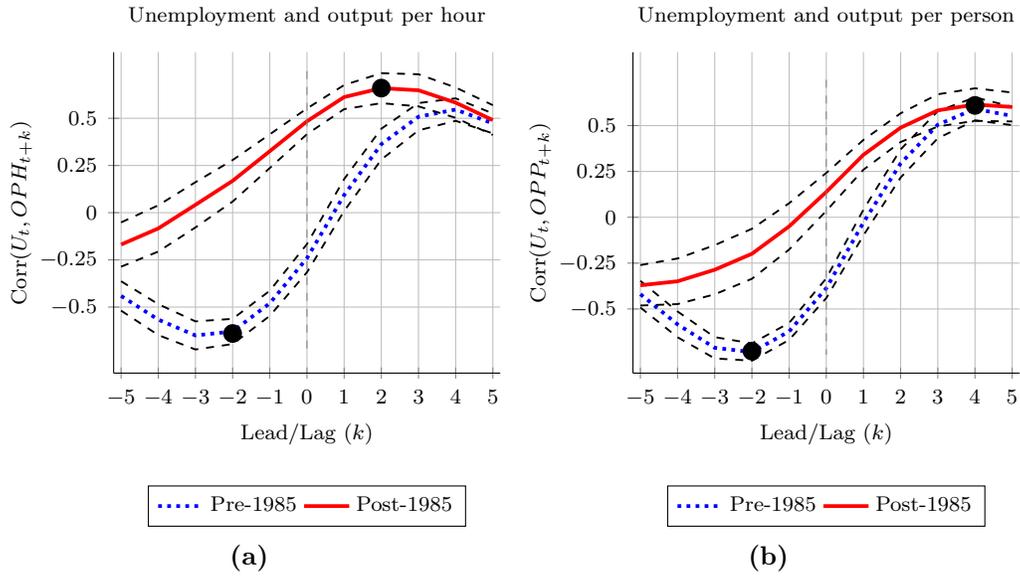


Figure 12: Cross-correlations with 1 standard deviation confidence bands

A.4 Data and Definitions

The data series used in the paper are described below:

Variable	Data source	Sample	Notes
Real GDP	FRED	1947:I-2017:I	FRED code (GDPC1)
Nonfarm output	FRED	1947:I-2017:I	FRED code (OUTNFB)
GDP Deflator	FRED	1947:I-2017:I	FRED code (GDPDEF)
Federal funds rate	FRED	1954I:2017I	FRED code (FEDFUNDS)
3-month treasury bill	FRED	1947I:2017I	FRED code (TB3MS)
Total hours worked	FRED	1947:I-2017:I	FRED code (HOANBS)
Total employment	FRED	1947:I-2017:I	FRED code (PRS85006013)
Unemployment rate	FRED	1948:I-2017:I	FRED code (UNRATE)
Output per person	FRED	1947:I-2017:I	FRED code (PRS85006163)
Output per hour	FRED	1947:I-2017:I	FRED code (OPHNFB)
Residential investment	FRED	1947:I-2017:I	FRED code (A011RA3Q086SBEA)
Shadow federal funds rate	Wu and Xia (2016)	1960:I-2015:III	No zero lower bound
Consumer price index	FRED	1947:I-2017:I	FRED code (CPIAUCSL)
Core CPI	FRED	1957:I-2017:I	FRED code (CPILFESL)
PCE Deflator	FRED	1947:I-2017:I	FRED code (DPCERD3Q086SBEA)
Total factor productivity	Fernald (2014)	1947:I-2017:I	Level 1947:I=1
Forecasted inflation	SPF	1981:III-2017:I	One quarter ahead forecast
Demographic adj. hours	Wolters (2018)	1948I:2017I	Demographics purged
Real compensation	FRED	1947:I-2017:I	FRED code (COMPRNFB)

TABLE 5: Data sources

In compiling the data sources, any variables in monthly format are converted to quarterly by averaging. In the paper we defined additional variables via the following formulas:

$$\pi_t = (\ln(\text{Price}_t) - \ln(\text{Price}_{t-1})) * 400$$

$$r_t = R_t - \pi_{t+1}$$

$$\frac{W}{R} = \frac{\text{Real compensation}}{1 + \text{Real interest rate}}$$

Where π_t is the inflation rate, r_t is the real interest rate, R_t is the nominal interest rate, and W is the real compensation per hour, respectively. We log transform all of the variables prior to filtering, excluding interest rates and the unemployment rate. We use a smoothing parameter of $\lambda = 1600$ for the Hodrick-Prescott filter. Applying the Hamilton filter, we use $h = 8$ and $p = 4$, Hamilton's suggested parametric specification for detrending quarterly data.

We compute the cross-correlations as follows. Cross-covariance is defined as,

$$\text{Cov}\{x_1(t), x_2(t+k)\} = R_{12}(k)$$

and cross-correlation is computed as,

$$\rho_{ij}(k) = \text{Corr}\{x_i(t), x_j(t+k)\} = \frac{R_{ij}(k)}{\sqrt{R_{ii}(k)R_{jj}(k)}}$$

where $R_{ii}(k)$ and $R_{jj}(k)$ are the variances of the corresponding series.

A.5 Alternative definitions of real interest rate

The baseline real interest rate defined in the paper is the 3-month treasury bill rate minus ex-post inflation defined as the annualized log difference in the GDP deflator in $t + 1$. Below we consider a variety of ex-ante and ex-post measures for the real interest rate from alternative price indexes (also we consider whether the real interest rate series is stationary or non-stationary). Table 6 reports cross-correlations for real interest rate using alternative definitions for the pre-1985 period. Table 7 reports the real interest rate cross-correlations for the same definitions in the post-1985 period.

Note: Ex-post measures of real interest rate are calculated using actual inflation at $t + 1$. ISVAR computes expected inflation using an in-sample VAR. REVAR computes expected inflation using a recursive VAR forecast (using all information up to time t to forecast inflation at time $t + 1$). ROVAR computes expected inflation using a rolling VAR forecast where the window is 40 quarters. Finally, in brackets (U) or (F) indicates whether the real interest rate series was passed through the Hodrick-Prescott filter with a smoothing parameter of 1600 (U for unfiltered and F for filtered). We begin the pre-1985 subsamples in 1956Q3 for all measures in this table to ensure the VAR has enough observations to generate reliable forecasts. We also consider the estimated nominal interest series from [Wu and Xia \(2016\)](#), which estimates the nominal interest rate in the absence of the zero lower bound (this is only relevant for the post-1985 sample). Finally, we consider expected inflation from the Survey of Profession Forecasters obtained through the Federal Reserve Bank of Philadelphia. Our measure of expected inflation is the median response for expected CPI growth in $t + 1$ (CPI3 in the data). Since this data is only available from 1981:III onwards, we consider this measure for the post-1985 subsample only.

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
1956Q3-1984Q4														
Ex-post (U)														
GDP Deflator	2.45	1.31	.84	-.23	-.27	-.27	-.21	-.1	-.06	-.07	-.11	-.16	-.16	-.14
CPI Deflator	2.69	1.44	.85	-.18	-.25	-.28	-.33	-.33	-.33	-.32	-.34	-.33	-.26	-.21
PCE Deflator	2.5	1.34	.86	-.23	-.26	-.27	-.26	-.2	-.17	-.16	-.17	-.21	-.16	-.11
Core CPI	2.3	1.23	.79	-.18	-.18	-.14	-.21	-.2	-.15	-.15	-.2	-.21	-.24	-.25
Ex-post (F)														
GDP Deflator	1.38	.74	.3	-.25	-.32	-.31	-.21	-.01	.07	.05	-.02	-.1	-.12	-.12
CPI Deflator	1.59	.85	.47	-.12	-.22	-.27	-.34	-.34	-.33	-.32	-.35	-.33	-.24	-.18
PCE Deflator	1.45	.78	.43	-.23	-.29	-.29	-.27	-.17	-.13	-.11	-.14	-.21	-.13	-.08
Core CPI	1.47	.79	.34	-.13	-.13	-.06	-.16	-.13	-.06	-.05	-.13	-.16	-.21	-.25
Ex-ante ISVAR (U)														
GDP Deflator	1.99	1.07	.93	-.27	-.24	-.22	-.19	-.08	.04	.07	.07	0	-.07	-.09
CPI Deflator	1.9	1.02	.92	-.18	-.24	-.29	-.32	-.33	-.27	-.23	-.21	-.23	-.23	-.19
PCE Deflator	1.98	1.06	.94	-.27	-.25	-.24	-.22	-.13	-.05	-.01	0	-.05	-.11	-.09
Core CPI	1.91	1.02	.91	-.23	-.24	-.21	-.15	-.14	-.09	-.08	-.12	-.16	-.19	-.2
Ex-ante ISVAR (F)														
GDP Deflator	1	.54	.43	-.37	-.32	-.28	-.23	0	.24	.3	.29	.16	.01	-.06
CPI Deflator	1.01	.54	.47	-.15	-.25	-.33	-.37	-.39	-.27	-.19	-.16	-.2	-.21	-.17
PCE Deflator	1.05	.56	.5	-.33	-.31	-.29	-.25	-.1	.06	.12	.14	.04	-.08	-.09
Core CPI	1.11	.59	.54	-.19	-.2	-.13	-.05	-.05	.03	.04	-.02	-.09	-.15	-.18
Ex-ante REVAR (U)														
GDP Deflator	1.8	.96	.91	-.22	-.21	-.22	-.19	-.1	.03	.12	.13	.07	0	-.08
CPI Deflator	1.97	1.06	.83	-.1	-.14	-.2	-.23	-.27	-.26	-.23	-.2	-.22	-.23	-.23
PCE Deflator	1.89	1.01	.92	-.23	-.22	-.24	-.23	-.16	-.08	-.02	.02	-.01	-.07	-.08
Core CPI	2.41	1.29	.8	-.12	-.15	-.18	-.13	-.2	-.22	-.24	-.27	-.33	-.33	-.33
Ex-ante REVAR (F)														
GDP Deflator	1.01	.54	.45	-.31	-.29	-.29	-.24	-.08	.15	.31	.33	.23	.1	-.06
CPI Deflator	1.14	.61	.35	-.11	-.15	-.22	-.26	-.31	-.27	-.2	-.15	-.17	-.19	-.21
PCE Deflator	1.01	.54	.49	-.34	-.31	-.34	-.31	-.18	-.03	.09	.16	.11	-.02	-.06
Core CPI	1.61	.86	.42	-.01	-.04	-.07	.02	-.08	-.12	-.13	-.17	-.26	-.26	-.29
Ex-ante ROVAR (U)														
GDP Deflator	2.02	1.08	.92	-.2	-.22	-.24	-.24	-.18	-.1	-.05	-.04	-.09	-.13	-.14
CPI Deflator	2.64	1.41	.86	-.13	-.18	-.24	-.27	-.32	-.31	-.28	-.27	-.27	-.26	-.21
PCE Deflator	2.26	1.21	.9	-.17	-.16	-.21	-.22	-.19	-.16	-.12	-.1	-.13	-.17	-.14
Core CPI	2.47	1.32	.81	-.19	-.22	-.26	-.23	-.29	-.34	-.33	-.33	-.34	-.3	-.25
Ex-ante ROVAR (F)														
GDP Deflator	1.07	.57	.49	-.26	-.28	-.32	-.32	-.19	-.04	.06	.07	-.01	-.12	-.16
CPI Deflator	1.66	.89	.56	-.1	-.16	-.24	-.29	-.34	-.32	-.28	-.26	-.26	-.26	-.21
PCE Deflator	1.27	.68	.5	-.18	-.17	-.24	-.27	-.21	-.14	-.08	-.04	-.1	-.2	-.17
Core CPI	1.73	.93	.53	-.09	-.12	-.17	-.12	-.21	-.28	-.27	-.28	-.3	-.26	-.22
Nominal rates														
3M Tbill (U)	3.12	1.67	1	-.35	-.3	-.22	-.11	.03	.15	.21	.23	.22	.21	.21
3M Tbill (F)	1.31	.7	.75	-.7	-.61	-.44	-.22	.1	.35	.46	.48	.44	.4	.35
Fed funds (U)	3.84	2.06	.99	-.38	-.33	-.25	-.15	.02	.16	.25	.28	.28	.27	.27
Fed funds (F)	1.81	.97	.79	-.68	-.61	-.47	-.27	.06	.34	.49	.53	.51	.47	.43

TABLE 6: Cross-correlations using alternative measures of real interest rate, pre-1985.

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
1985Q1-2016Q4														
Ex-post (U)														
GDP Deflator	2.32	2.16	.93	.04	.12	.19	.24	.29	.34	.38	.39	.4	.38	.34
CPI Deflator	2.6	2.43	.62	.06	.07	.09	.12	.17	.28	.33	.33	.33	.33	.27
PCE Deflator	2.42	2.26	.82	.06	.09	.12	.17	.23	.34	.39	.4	.38	.36	.29
Core CPI	1.89	1.76	.93	.16	.24	.31	.36	.39	.41	.39	.35	.31	.27	.23
Ex-post (F)														
GDP Deflator	1.06	.99	.62	-.05	.06	.16	.24	.31	.39	.46	.49	.53	.51	.43
CPI Deflator	1.89	1.76	.21	-.02	-.02	-.01	-.01	.06	.19	.27	.27	.27	.29	.23
PCE Deflator	1.49	1.39	.4	-.02	0	.03	.07	.15	.31	.4	.41	.39	.38	.28
Core CPI	.92	.86	.71	.13	.26	.35	.42	.45	.47	.44	.37	.32	.27	.21
Ex-ante ISVAR (U)														
GDP Deflator	2.07	1.93	.95	.03	.11	.19	.26	.31	.36	.38	.4	.39	.38	.35
CPI Deflator	2	1.87	.78	.03	.08	.1	.16	.18	.24	.33	.39	.41	.4	.38
PCE Deflator	2.04	1.9	.9	.06	.12	.16	.21	.25	.31	.38	.43	.43	.4	.36
Core CPI	1.76	1.64	.94	.08	.18	.26	.33	.38	.41	.42	.39	.35	.31	.27
Ex-ante ISVAR (F)														
GDP Deflator	.83	.77	.75	-.11	.03	.17	.28	.37	.45	.51	.55	.56	.56	.49
CPI Deflator	1.18	1.1	.33	-.08	-.02	-.02	.04	.05	.13	.28	.37	.42	.41	.39
PCE Deflator	1.04	.97	.62	-.04	.04	.08	.13	.18	.27	.42	.51	.54	.49	.42
Core CPI	.79	.74	.81	0	.16	.28	.39	.47	.51	.53	.48	.41	.35	.28
Ex-ante REVAR (U)														
GDP Deflator	1.99	1.86	.96	.03	.11	.19	.26	.3	.35	.37	.38	.39	.38	.36
CPI Deflator	1.99	1.86	.81	0	.06	.1	.13	.15	.21	.3	.38	.4	.39	.39
PCE Deflator	2.04	1.9	.9	.05	.1	.15	.18	.22	.28	.36	.42	.43	.4	.38
Core CPI	1.73	1.61	.95	.06	.16	.24	.32	.36	.4	.41	.39	.35	.31	.28
Ex-ante REVAR (F)														
GDP Deflator	.8	.75	.8	-.1	.06	.18	.29	.37	.43	.48	.52	.54	.54	.51
CPI Deflator	1.23	1.15	.48	-.09	-.04	-.01	0	.02	.08	.23	.35	.39	.39	.39
PCE Deflator	1.08	1.01	.63	-.04	.02	.07	.09	.13	.22	.37	.48	.51	.47	.44
Core CPI	.78	.73	.86	-.04	.13	.26	.37	.44	.48	.51	.48	.41	.35	.29
Ex-ante ROVAR (U)														
GDP Deflator	2.21	2.06	.96	.06	.14	.21	.27	.31	.37	.4	.42	.43	.4	.37
CPI Deflator	2.39	2.23	.82	0	.05	.11	.14	.17	.27	.39	.52	.57	.53	.49
PCE Deflator	2.29	2.14	.89	.05	.13	.2	.25	.29	.37	.46	.54	.54	.5	.44
Core CPI	1.79	1.67	.95	.11	.2	.28	.34	.37	.41	.42	.41	.37	.32	.26
Ex-ante ROVAR (F)														
GDP Deflator	.92	.86	.8	-.02	.1	.21	.29	.36	.45	.51	.56	.58	.54	.47
CPI Deflator	1.55	1.45	.57	-.11	-.06	-.02	-.01	.01	.13	.3	.49	.57	.52	.46
PCE Deflator	1.28	1.19	.64	-.06	.04	.11	.15	.19	.32	.47	.61	.62	.55	.47
Core CPI	.92	.86	.86	.06	.21	.31	.38	.43	.48	.5	.49	.42	.35	.26
Wu & Xia (2016)														
Unfiltered	2.97	2.77	.95	.02	.09	.16	.22	.27	.33	.38	.41	.44	.43	.4
Filtered	1.21	1.13	.7	-.11	0	.11	.21	.3	.4	.5	.56	.6	.57	.5
SPF														
Unfiltered	1.9	1.77	.96	.15	.24	.31	.36	.41	.43	.44	.42	.38	.34	.29
Filtered	.84	.78	.85	.12	.26	.37	.45	.51	.54	.56	.53	.48	.4	.32
Nominal rates														
3M Tbill (U)	2.59	2.42	.98	.12	.2	.27	.34	.4	.43	.43	.41	.38	.33	.28
3M Tbill (F)	1.03	.96	.94	.07	.21	.35	.46	.55	.61	.62	.57	.51	.42	.3
Fed funds (U)	2.85	2.66	.98	.1	.19	.28	.35	.41	.45	.46	.44	.4	.35	.3
Fed funds (F)	1.13	1.05	.94	.03	.19	.34	.46	.56	.63	.65	.61	.54	.44	.33

TABLE 7: Cross-correlations using alternative measures of real interest rate, post-1985.

A.6 Alternative sample periods

In the paper we consider two subsamples, the pre-1985 and post-1985 periods. Below we report two alternative subsamples to assess how sensitive the shifts are to alternative subsamples. Table 8 reports post-1985 cross-correlations and volatilities when excluding the Great Recession. This table highlights that the Positive Lagging Property reported in the paper is not driven by the nominal interest rate binding at the zero lower bound. Table 9 reports cross-correlations and volatilities when we consider the post-1983 time period as the onset of the Great Moderation.

A.7 Extending the definition of the business cycle to 8-50 quarters

Tables 10 and 11 report cross-correlations when we examine the 8-50 frequency range using the [Christiano and Fitzgerald \(2003\)](#) and [Baxter and King \(1999\)](#) filters.

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1985Q1-2007Q4														
Real interest rate	1.16	1.12	.71	-.1	-.02	.1	.25	.4	.47	.54	.57	.56	.54	.47
Nominal interest rate	1.18	1.13	.95	-.02	.11	.26	.41	.54	.64	.68	.66	.62	.54	.43
Residential inv	6.62	6.37	.94	.61	.65	.68	.69	.65	.55	.38	.21	.06	-.07	-.18
TFP	.82	.79	.67	.18	.09	.03	.02	-.05	-.09	-.2	-.21	-.22	-.19	-.17
W/R ratio	1.86	1.79	.77	.12	.06	0	-.08	-.15	-.22	-.29	-.35	-.35	-.35	-.3
Ex-post inflation	.67	.64	.3	.15	.24	.27	.27	.26	.31	.26	.19	.12	.01	-.06
Ex-ante inflation	.59	.57	.57	.23	.26	.35	.41	.43	.43	.44	.34	.27	.16	.04
Cross-correlations with non-farm output														
1985Q1-2007Q4														
Output per hour	.82	.59	.73	.13	.06	-.01	-.03	-.04	-.03	-.22	-.34	-.43	-.44	-.44
Output per person	.81	.59	.73	.26	.27	.26	.29	.3	.32	.07	-.12	-.29	-.38	-.43
Total hours	1.63	1.18	.98	.17	.34	.49	.64	.76	.86	.85	.79	.7	.59	.46
Cross-correlations with output per hour														
1985Q1-2007Q4														
Total hours	1.63	1.98	.98	-.4	-.45	-.51	-.55	-.56	-.53	-.41	-.29	-.15	-.02	.09
Cross-correlations with output per person														
1985Q1-2007Q4														
Total employment	1.36	1.68	.99	-.42	-.44	-.45	-.43	-.37	-.27	-.13	-.01	.11	.21	.28
Cross-correlations with unemployment														
1985Q1-2007Q4														
Output per hour	.82	1.38	.73	-.15	-.04	.12	.26	.38	.47	.55	.53	.5	.45	.39
Output per person	.81	1.36	.73	-.34	-.29	-.19	-.08	.04	.16	.31	.37	.4	.41	.4

TABLE 8: Cross-correlations and volatilities using Hodrick-Prescott filter, excluding the Great Recession

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1982Q4														
Real interest rate	2.06	1.04	.42	-.23	-.32	-.41	-.37	-.22	-.11	0	.13	.16	.21	.16
Nominal interest rate	1.16	.59	.76	-.59	-.52	-.4	-.24	.04	.29	.38	.39	.35	.31	.29
Residential Inv	11.6	5.87	.9	.22	.37	.51	.62	.64	.53	.26	-.02	-.25	-.39	-.42
TFP	1.05	.53	.6	.26	.16	.05	-.08	-.21	-.23	-.29	-.26	-.22	-.1	-.03
W/R ratio	2.4	1.21	.48	.26	.36	.45	.43	.31	.2	.05	-.11	-.16	-.24	-.2
Ex-post inflation	2.06	1.04	.46	-.1	.03	.18	.24	.25	.28	.21	.09	.04	-.03	.01
Ex-ante inflation	1.37	.69	.65	-.31	-.2	-.03	.17	.27	.29	.26	.16	.07	.04	.01
1983Q1-2016Q4														
Real interest rate	1.07	.93	.57	-.04	.06	.15	.22	.3	.37	.44	.41	.45	.4	.32
Nominal interest rate	1.04	.9	.91	.05	.18	.31	.44	.54	.64	.61	.52	.44	.32	.2
Residential Inv	7.2	6.24	.88	.5	.57	.61	.65	.64	.58	.38	.19	.04	-.07	-.15
TFP	.87	.75	.72	-.14	.07	.01	-.03	-.08	-.09	-.18	-.18	-.16	-.13	-.1
W/R ratio	1.73	1.5	.65	.07	.01	-.05	-.1	-.16	-.23	-.26	-.26	-.29	-.24	-.19
Ex-post inflation	.74	.64	.31	.12	.17	.23	.29	.34	.36	.21	.13	-.05	-.12	-.18
Ex-ante inflation	.61	.53	.55	.19	.25	.3	.37	.43	.48	.36	.21	.1	-.06	-.12
Cross-correlations with non-farm output														
1948Q1-1982Q4														
Output per hour	1.24	.48	.71	.23	.37	.52	.64	.67	.65	.26	-.06	-.31	-.42	-.45
Output per person	1.59	.61	.78	.19	.36	.55	.71	.78	.78	.41	.06	-.23	-.39	-.45
Total hours	2.04	.78	.89	-.36	-.23	0	.3	.63	.88	.88	.73	.51	.26	.06
1983Q1-2016Q4														
Output per hour	.84	.54	.72	.17	.15	.13	.1	.04	0	-.31	-.49	-.58	-.58	-.54
Output per person	.9	.58	.73	.26	.32	.37	.39	.38	.36	.01	-.26	-.44	-.55	-.6
Total hours	1.76	1.14	.92	0	.16	.34	.53	.71	.88	.88	.81	.68	.51	.35
Cross-correlations with output per hour														
1948Q1-1982Q4														
Total hours	2.04	1.64	.89	-.46	-.51	-.49	-.35	-.09	.22	.43	.55	.57	.51	.42
1983Q1-2016Q4														
Total hours	1.76	2.09	.92	-.48	-.57	-.64	-.67	-.62	-.48	-.31	-.16	-.02	.07	.15
Cross-correlations with output per person														
1948Q1-1982Q4														
Total employment	1.69	1.06	.9	-.54	-.6	-.56	-.38	-.09	.26	.49	.62	.64	.55	.43
1983Q1-2016Q4														
Total employment	1.49	1.65	.94	-.58	-.63	-.63	-.57	-.44	-.24	-.05	.1	.21	.28	.32
Cross-correlations with unemployment														
1948Q1-1982Q4														
Output per hour	1.24	1.38	.71	-.39	-.5	-.59	-.58	-.46	-.25	.09	.36	.49	.52	.44
Output per person	1.59	1.77	.78	-.36	-.51	-.65	-.69	-.61	-.4	-.03	.28	.48	.55	.5
1983Q1-2016Q4														
Output per hour	.84	1.17	.72	-.16	-.09	.01	.12	.27	.42	.6	.65	.63	.56	.46
Output per person	.9	1.26	.73	-.33	-.33	-.29	-.23	-.1	.09	.34	.5	.58	.6	.57

TABLE 9: Cross-correlations and volatilities using Hodrick-Prescott filter, alternative onset of Great Moderation 1983Q1

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	1.26	.67	.9	-.45	-.45	-.39	-.28	-.13	.03	.15	.19	.16	.08	.01
Nominal interest rate	1.11	.59	.94	-.77	-.64	-.43	-.15	.13	.38	.53	.59	.56	.47	.36
Residential Inv	11.46	6.09	.94	.42	.58	.71	.75	.69	.52	.28	.02	-.21	-.39	-.49
TFP	1	.53	.91	.36	.25	.09	-.07	-.21	-.3	-.3	-.25	-.14	-.02	.09
W/R ratio	1.64	.87	.92	.38	.43	.43	.38	.27	.12	0	-.08	-.1	-.08	-.06
Ex-post inflation	2.01	1.07	.46	-.16	-.07	.02	.11	.17	.2	.17	.2	.21	.29	.25
Ex-ante inflation	1.35	.72	.65	-.28	-.19	-.05	.08	.2	.25	.23	.18	.17	.18	.25
1985Q1-2016Q4														
Real interest rate	.93	.85	.95	-.14	0	.14	.26	.37	.47	.54	.59	.6	.57	.51
Nominal interest rate	1.05	.96	.95	.03	.21	.37	.51	.6	.65	.64	.59	.5	.39	.27
Residential Inv	7.05	6.43	.97	.58	.66	.71	.72	.69	.61	.48	.34	.19	.04	-.09
TFP	.85	.78	.93	.37	.27	.15	.01	-.13	-.25	-.33	-.36	-.33	-.25	-.13
W/R ratio	1.59	1.45	.94	.26	.18	.08	-.03	-.14	-.26	-.34	-.41	-.44	-.43	-.37
Ex-post inflation	.72	.66	.3	.23	.29	.35	.39	.38	.33	.23	.1	-.05	-.17	-.26
Ex-ante inflation	.59	.54	.54	.26	.36	.44	.49	.51	.48	.38	.26	.11	-.05	-.19
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	1.14	.46	.91	.4	.6	.75	.83	.77	.59	.31	-.01	-.29	-.49	-.57
Output per person	1.51	.61	.92	.33	.57	.77	.89	.89	.74	.46	.13	-.19	-.44	-.57
Total hours	2.04	.82	.91	-.39	-.19	.08	.39	.68	.89	.94	.86	.66	.41	.15
1985Q1-2016Q4														
Output per hour	.79	.53	.94	.31	.29	.24	.16	.03	-.14	-.32	-.48	-.61	-.66	-.63
Output per person	.83	.56	.93	.39	.48	.53	.54	.46	.3	.07	-.19	-.43	-.61	-.71
Total hours	1.78	1.19	.95	-.03	.17	.39	.6	.78	.9	.93	.89	.77	.59	.39
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	2.04	1.79	.91	-.57	-.62	-.56	-.39	-.14	.16	.43	.63	.72	.7	.61
1985Q1-2016Q4														
Total hours	1.78	2.25	.95	-.56	-.68	-.74	-.74	-.68	-.56	-.39	-.21	-.04	.12	.23
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	1.72	1.14	.91	-.67	-.71	-.63	-.43	-.14	.19	.48	.68	.77	.75	.64
1985Q1-2016Q4														
Total employment	1.47	1.77	.96	-.68	-.72	-.7	-.6	-.45	-.26	-.06	.13	.28	.38	.43
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	1.14	1.3	.91	-.61	-.73	-.77	-.7	-.52	-.25	.05	.33	.52	.6	.57
Output per person	1.51	1.72	.92	-.58	-.75	-.84	-.82	-.67	-.41	-.09	.23	.48	.62	.64
1985Q1-2016Q4														
Output per hour	.79	1.14	.94	-.25	-.13	.02	.2	.38	.54	.66	.73	.72	.66	.54
Output per person	.83	1.2	.93	-.47	-.44	-.37	-.24	-.06	.14	.35	.53	.66	.71	.7

TABLE 10: Cross-correlations and volatilities using [Baxter and King \(1999\)](#) filter, 8-50 quarters

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	1.61	.69	.89	-.4	-.51	-.57	-.54	-.45	-.31	-.17	-.05	.02	.04	.03
Nominal interest rate	1.23	.53	.95	-.76	-.67	-.51	-.29	-.07	.13	.27	.34	.36	.34	.3
Residential Inv	12.58	5.38	.94	.36	.5	.62	.68	.64	.5	.29	.05	-.16	-.31	-.39
TFP	1.04	.45	.91	.21	.14	.05	-.04	-.11	-.13	-.12	-.08	-.01	.07	.15
W/R ratio	2.1	.9	.92	.4	.52	.6	.59	.52	.4	.26	.14	.05	.01	.01
Ex-post inflation	2.01	.86	.46	-.11	.02	.15	.24	.28	.27	.22	.17	.12	.08	.07
Ex-ante inflation	1.35	.58	.65	-.28	-.18	-.03	.13	.24	.29	.27	.2	.12	.07	.05
1985Q1-2016Q4														
Real interest rate	1.17	.82	.96	.03	.17	.3	.41	.51	.59	.64	.67	.67	.64	.58
Nominal interest rate	1.33	.93	.97	.12	.27	.41	.52	.61	.67	.69	.67	.62	.54	.45
Residential Inv	11.02	7.71	.98	.7	.71	.69	.66	.58	.48	.34	.19	.02	-.13	-.27
TFP	.8	.56	.93	.1	.03	-.06	-.15	-.24	-.31	-.36	-.37	-.35	-.28	-.19
W/R ratio	1.81	1.27	.96	-.06	-.13	-.2	-.27	-.32	-.37	-.4	-.41	-.41	-.38	-.33
Ex-post inflation	.72	.5	.3	.16	.2	.25	.27	.28	.25	.2	.11	.02	-.07	-.14
Ex-ante inflation	.59	.41	.54	.22	.3	.35	.38	.39	.37	.31	.23	.13	.02	-.08
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	1.32	.45	.92	.48	.63	.76	.83	.79	.64	.39	.1	-.17	-.36	-.44
Output per person	1.82	.61	.93	.45	.62	.78	.87	.86	.74	.51	.22	-.06	-.28	-.4
Total hours	2.36	.8	.94	-.21	-.04	.2	.48	.73	.9	.96	.89	.72	.51	.3
1985Q1-2016Q4														
Output per hour	.92	.47	.95	.13	.06	-.01	-.09	-.19	-.32	-.45	-.58	-.67	-.71	-.68
Output per person	.96	.49	.94	.34	.34	.34	.31	.23	.09	-.09	-.28	-.46	-.59	-.66
Total hours	2.4	1.24	.97	.26	.43	.59	.74	.85	.93	.95	.92	.84	.72	.57
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	2.36	1.79	.94	-.53	-.54	-.45	-.27	-.02	.24	.48	.64	.72	.71	.63
1985Q1-2016Q4														
Total hours	2.4	2.61	.97	-.62	-.72	-.78	-.78	-.73	-.64	-.52	-.38	-.24	-.1	.03
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	2.03	1.12	.94	-.63	-.63	-.54	-.35	-.09	.18	.43	.6	.68	.68	.61
1985Q1-2016Q4														
Total employment	2.08	2.18	.98	-.65	-.69	-.68	-.61	-.51	-.37	-.22	-.06	.07	.19	.28
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	1.32	1.27	.92	-.64	-.72	-.74	-.67	-.51	-.26	.02	.28	.47	.56	.55
Output per person	1.82	1.75	.93	-.61	-.72	-.78	-.75	-.61	-.38	-.1	.18	.41	.54	.57
1985Q1-2016Q4														
Output per hour	.92	.96	.95	-.08	.06	.2	.34	.49	.62	.72	.78	.79	.74	.65
Output per person	.96	1.01	.94	-.37	-.3	-.2	-.07	.08	.25	.41	.55	.64	.69	.68

TABLE 11: Cross-correlations and volatilities using [Christiano and Fitzgerald \(2003\)](#) filter, 8-50 quarters

A.8 Robustness to standardized volatility

[Forbes and Rigobon \(2002\)](#) highlighted that correlation coefficients may be biased if significant changes in volatility occur over time. Since we are examining subsamples consisting of pre- and post Great Moderation which coincides with declining macroeconomic volatility, we provide a robustness check to ensure that the shifts we highlight are not driven by this potential bias.

To address these concerns, we follow a procedure highlighted in [Stock and Watson \(2002\)](#). First, we standardize the volatility of all variables such that they have a variance equal to 1 $\rightarrow X_t = \frac{x_t}{\sigma_x^2}$. In [Table 12](#) we standardize the volatility of the entire sample and recompute the cross-correlations.

In [Table 13](#) we again standardize the volatility, but in this instance we standardize each subsample (1948I:1984IV and 1985I:2016IV) to have unit variance. If the shifts in cross-correlations were the result of volatility changes these patterns would differ from those discussed in the results of the paper. These results suggest that the changes in cross-correlations are not the result of changes in volatility.

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	1.21	.99	.41	-.25	-.34	-.4	-.35	-.2	-.1	.01	.13	.15	.2	.14
Nominal interest rate	1.06	.86	.75	-.61	-.53	-.38	-.18	.1	.33	.42	.43	.39	.34	.29
Residential Inv	1.18	.96	.88	.28	.44	.57	.67	.66	.53	.26	-.03	-.27	-.41	-.45
TFP	1.1	.9	.62	.21	.12	.03	-.09	-.2	-.19	-.22	-.17	-.1	.01	.07
W/R ratio	1.11	.9	.48	.27	.37	.44	.4	.27	.18	.04	-.1	-.15	-.21	-.16
Ex-post inflation	1.28	1.04	.46	-.1	.04	.18	.25	.26	.29	.23	.12	.07	0	.02
Ex-ante inflation	1.27	1.03	.65	-.3	-.19	-.01	.18	.29	.3	.28	.19	.11	.08	.03
1985Q1-2016Q4														
Real interest rate	.64	.96	.62	-.05	.06	.16	.24	.31	.39	.46	.49	.53	.51	.43
Nominal interest rate	.95	1.43	.94	.07	.21	.35	.46	.55	.61	.62	.57	.51	.42	.3
Residential Inv	.74	1.11	.93	.55	.62	.66	.68	.67	.61	.46	.29	.13	0	-.11
TFP	.86	1.29	.69	.23	.15	.08	0	-.1	-.18	-.33	-.37	-.33	-.25	-.17
W/R ratio	.82	1.23	.66	.11	.04	-.03	-.09	-.14	-.22	-.27	-.32	-.35	-.34	-.29
Ex-post inflation	.46	.69	.3	.18	.22	.26	.31	.33	.31	.2	.1	-.05	-.16	-.2
Ex-ante inflation	.56	.84	.54	.29	.33	.37	.4	.43	.43	.36	.22	.1	-.06	-.16
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	1.15	.94	.7	.26	.42	.56	.67	.68	.64	.26	-.07	-.32	-.44	-.48
Output per person	1.21	.99	.77	.21	.4	.59	.74	.79	.77	.4	.04	-.25	-.42	-.49
Total hours	1.09	.9	.88	-.35	-.21	.02	.33	.65	.89	.9	.77	.55	.3	.08
1985Q1-2016Q4														
Output per hour	.79	1.15	.74	.18	.15	.11	.07	.01	-.04	-.31	-.49	-.59	-.61	-.58
Output per person	.67	.98	.74	.27	.32	.36	.39	.36	.33	.02	-.23	-.44	-.57	-.63
Total hours	.91	1.33	.94	.04	.22	.4	.59	.75	.87	.91	.86	.75	.59	.42
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	1.09	.95	.88	-.47	-.52	-.5	-.35	-.09	.21	.44	.59	.62	.56	.45
1985Q1-2016Q4														
Total hours	.91	1.15	.94	-.5	-.58	-.65	-.67	-.63	-.53	-.36	-.2	-.05	.06	.15
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	1.09	.9	.89	-.57	-.62	-.58	-.4	-.1	.24	.5	.65	.68	.62	.49
1985Q1-2016Q4														
Total employment	.91	1.35	.96	-.59	-.62	-.62	-.55	-.43	-.27	-.08	.08	.2	.29	.34
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	1.15	1.02	.7	-.43	-.56	-.64	-.62	-.48	-.24	.09	.36	.5	.54	.46
Output per person	1.21	1.07	.77	-.41	-.57	-.7	-.73	-.62	-.39	-.03	.29	.5	.58	.54
1985Q1-2016Q4														
Output per hour	.79	.94	.74	-.17	-.08	.04	.17	.33	.48	.61	.66	.65	.58	.48
Output per person	.67	.79	.74	-.37	-.35	-.28	-.2	-.05	.14	.34	.49	.58	.61	.59

TABLE 12: Cross-correlations and volatilities using Hodrick-Prescott filter, standardizing entire sample

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	1	1	.41	-.25	-.34	-.4	-.35	-.2	-.1	.01	.13	.15	.2	.14
Nominal interest rate	1	1	.75	-.61	-.53	-.38	-.18	.1	.33	.42	.43	.39	.34	.29
Residential Inv	1	1	.52	.28	.44	.57	.67	.66	.53	.26	-.03	-.27	-.41	-.45
TFP	1	1	.62	.21	.12	.03	-.09	-.2	-.19	-.22	-.17	-.1	.01	.07
W/R ratio	1	1	.48	.27	.37	.44	.4	.27	.18	.04	-.1	-.15	-.21	-.16
Ex-post inflation	1	1	.46	-.1	.04	.18	.25	.26	.29	.23	.12	.07	0	.02
Ex-ante inflation	1	1	.65	-.3	-.19	-.01	.18	.29	.3	.28	.19	.11	.08	.03
1985Q1-2016Q4														
Real interest rate	1	1	.62	-.05	.06	.16	.24	.31	.39	.46	.49	.53	.51	.43
Nominal interest rate	1	1	.94	.07	.21	.35	.46	.55	.61	.62	.57	.51	.42	.3
Residential Inv	1	1	.93	.55	.62	.66	.68	.67	.61	.46	.29	.13	0	-.11
TFP	1	1	.7	.23	.15	.08	0	-.1	-.18	-.33	-.37	-.33	-.25	-.17
W/R ratio	1	1	.66	.11	.04	-.03	-.09	-.14	-.22	-.27	-.32	-.35	-.34	-.29
Ex-post inflation	1	1	.32	.18	.22	.26	.31	.33	.31	.2	.1	-.05	-.16	-.2
Ex-ante inflation	1	1	.56	.29	.33	.37	.4	.43	.43	.36	.22	.1	-.06	-.16
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	1	1	.7	.26	.42	.56	.67	.68	.64	.26	-.07	-.32	-.44	-.48
Output per person	1	1	.77	.21	.4	.59	.74	.79	.77	.4	.04	-.25	-.42	-.49
Total hours	1	1	.88	-.35	-.21	.02	.33	.65	.89	.9	.77	.55	.3	.08
1985Q1-2016Q4														
Output per hour	1	1	.74	.18	.15	.11	.07	.01	-.04	-.31	-.49	-.59	-.61	-.58
Output per person	1	1	.75	.27	.32	.36	.39	.36	.33	.02	-.23	-.44	-.57	-.63
Total hours	1	1	.95	.04	.22	.4	.59	.75	.87	.91	.86	.75	.59	.42
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	1	1	.88	-.47	-.52	-.5	-.35	-.09	.21	.44	.59	.62	.56	.45
1985Q1-2016Q4														
Total hours	1	1	.95	-.5	-.58	-.65	-.67	-.63	-.53	-.36	-.2	-.05	.06	.15
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	1	1	.89	-.57	-.62	-.58	-.4	-.1	.24	.5	.65	.68	.62	.49
1985Q1-2016Q4														
Total employment	1	1	.96	-.59	-.62	-.62	-.55	-.43	-.27	-.08	.08	.2	.29	.34
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	1	1	.7	-.43	-.56	-.64	-.62	-.48	-.24	.09	.36	.5	.54	.46
Output per person	1	1	.77	-.41	-.57	-.7	-.73	-.62	-.39	-.03	.29	.5	.58	.54
1985Q1-2016Q4														
Output per hour	1	1	.74	-.17	-.08	.04	.17	.33	.48	.61	.66	.65	.58	.48
Output per person	1	1	.75	-.37	-.35	-.28	-.2	-.05	.14	.34	.49	.58	.61	.59

TABLE 13: Cross-correlations and volatilities using Hodrick-Prescott filter, standardizing each subsample

A.9 Filtering on subsamples

Table 14 reports cross-correlations when applying the Hodrick-Prescott filter to each subsample. The baseline case in the paper apply the HP-filter to the entire sample prior to examining cross-correlations in each subsample.

A.10 Demographic adjusted productivity

Table 15 reports cross-correlations when using demographic adjusted hours in computing output per hour.

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with real GDP														
1948Q1-1984Q4														
Real interest rate	2	1.02	.39	-.2	-.3	-.36	-.32	-.17	-.08	.03	.17	.2	.24	.18
Nominal interest rate	1.17	.59	.75	-.61	-.54	-.39	-.19	.1	.32	.42	.44	.41	.36	.32
Residential Inv	11.43	5.81	.89	.27	.45	.59	.68	.68	.55	.27	-.03	-.28	-.43	-.47
TFP	1.03	.52	.61	.27	.17	.06	-.07	-.19	-.19	-.23	-.19	-.14	-.04	.02
W/R ratio	2.3	1.17	.45	.22	.32	.4	.37	.25	.16	.01	-.15	-.21	-.27	-.22
Ex-post inflation	2.01	1.02	.46	-.12	.02	.17	.23	.24	.27	.21	.09	.04	-.03	.02
Ex-ante inflation	1.35	.69	.65	-.32	-.21	-.03	.17	.27	.28	.26	.17	.1	.07	.04
1985Q1-2016Q4														
Real interest rate	1.06	1	.58	-.05	.07	.17	.25	.32	.4	.48	.52	.56	.56	.49
Nominal interest rate	1.01	.95	.92	.09	.24	.38	.51	.6	.67	.68	.64	.57	.48	.37
Residential Inv	7.12	6.7	.9	.56	.62	.66	.68	.66	.6	.44	.26	.09	-.06	-.18
TFP	.84	.79	.69	.23	.15	.07	-.01	-.11	-.19	-.34	-.39	-.34	-.27	-.18
W/R ratio	1.73	1.63	.63	.11	.04	-.04	-.09	-.15	-.23	-.29	-.36	-.41	-.41	-.37
Ex-post inflation	.72	.68	.3	.22	.26	.31	.36	.39	.38	.27	.15	0	-.12	-.19
Ex-ante inflation	.59	.56	.54	.31	.36	.41	.45	.49	.49	.44	.3	.16	0	-.11
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	1.22	.47	.7	.23	.4	.55	.66	.68	.64	.25	-.08	-.34	-.46	-.5
Output per person	1.57	.61	.77	.18	.38	.57	.73	.8	.77	.4	.04	-.26	-.43	-.5
Total hours	2.04	.79	.88	-.4	-.25	-.01	.3	.64	.89	.89	.75	.52	.26	.03
1985Q1-2016Q4														
Output per hour	.84	.58	.72	.17	.14	.1	.06	-.01	-.06	-.34	-.53	-.64	-.66	-.62
Output per person	.86	.59	.72	.27	.32	.35	.37	.35	.32	0	-.27	-.48	-.61	-.67
Total hours	1.72	1.18	.93	.04	.22	.4	.58	.75	.87	.91	.87	.76	.6	.43
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	2.04	1.67	.88	-.49	-.54	-.52	-.36	-.1	.21	.44	.58	.61	.54	.43
1985Q1-2016Q4														
Total hours	1.72	2.05	.93	-.52	-.61	-.68	-.7	-.64	-.54	-.36	-.2	-.05	.07	.15
Cross-correlations with output per person														
1948Q1-1984Q4														
Total employment	1.7	1.08	.89	-.58	-.63	-.59	-.4	-.1	.25	.51	.65	.68	.59	.45
1985Q1-2016Q4														
Total employment	1.44	1.67	.94	-.6	-.64	-.64	-.57	-.44	-.28	-.09	.08	.21	.3	.34
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	1.22	1.34	.7	-.4	-.54	-.63	-.62	-.49	-.25	.09	.36	.51	.55	.48
Output per person	1.57	1.72	.77	-.37	-.54	-.69	-.73	-.63	-.4	-.04	.29	.5	.58	.54
1985Q1-2016Q4														
Output per hour	.84	1.23	.72	-.17	-.08	.04	.17	.33	.49	.63	.68	.67	.6	.5
Output per person	.86	1.26	.72	-.37	-.35	-.29	-.2	-.05	.15	.36	.51	.6	.63	.6

TABLE 14: Cross-correlations and volatilities using Hodrick-Prescott filter, filtering pre- and post subsamples

	SD(%)	Rel Vol	ϕ_1	x(-5)	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)	x(+5)
Cross-correlations with non-farm output														
1948Q1-1984Q4														
Output per hour	.91	.35	.64	.15	.3	.46	.59	.59	.53	.18	-.13	-.36	-.44	-.41
1985Q1-2016Q4														
Output per hour	.71	.49	.75	.25	.19	.14	.08	.02	-.06	-.31	-.5	-.59	-.58	-.53
Cross-correlations with output per hour														
1948Q1-1984Q4														
Total hours	2.05	2.24	.88	-.38	-.47	-.49	-.38	-.14	.13	.37	.51	.52	.44	.32
1985Q1-2016Q4														
Total hours	1.72	2.42	.94	-.51	-.59	-.65	-.67	-.61	-.51	-.34	-.18	-.03	.1	.2
Cross-correlations with unemployment														
1948Q1-1984Q4														
Output per hour	.91	1	.64	-.27	-.4	-.52	-.54	-.4	-.17	.14	.39	.48	.47	.34
1985Q1-2016Q4														
Output per hour	.71	1.04	.75	-.23	-.12	.01	.14	.31	.47	.6	.66	.64	.57	.49

TABLE 15: Cross-correlations and volatilities using demographic adjusted hours in definition of output per hour

A.11 Jordá, Schularick, and Taylor (2016)

The following tables report cross-correlations by country using [Jordà et al. \(2016\)](#)'s dataset. We report cross-correlations for both growth rates and HP filtered data. We use real GDP per capita as our measure of output. We define credit as the total real loans per capita, which we compute by dividing total loans by the consumer price index and country population. Prior to filtering, we take the logs of both variables. We use a smoothing parameter of $\lambda = 6.25$ in detrending, as suggested by [Ravn and Uhlig \(2002\)](#). We examine two time periods, 1948-1984 and 1984-2013.

A.11.1 Cross-correlations for growth rates

	x(-2)	x(-1)	x	x(+1)	x(+2)
Australia	-.14	.14	.5	.21	-.31
Belgium	.17	.47	.23	.21	-.03
Canada	.03	.12	.56	.07	.02
Denmark	0	.26	.58	.27	.1
Finland	.1	-.03	.53	.38	-.18
France	.26	.52	.35	-.07	.06
Germany	.36	.37	.79	.5	.15
Italy	.17	.41	.43	.32	.24
Japan	.34	.52	.45	.25	.21
Netherlands	-.27	.31	.55	.28	.05
Norway	-.06	.37	.17	-.2	-.23
Portugal	.06	.43	.6	.35	.18
Spain	.31	.44	.65	.44	.3
Sweden	.04	.28	.44	-.02	-.11
Switzerland	.25	.4	.47	-.17	-.28
UK	-.44	.09	.48	-.03	-.45
USA	-.2	.23	.68	-.1	-.21

TABLE 16: Cross-correlations between growth rate of real gdp per capita and leads/lags of real credit per capita. Data from 1948-1984.

	x(-2)	x(-1)	x	x(+1)	x(+2)
Australia	-.48	-.41	.31	.4	.32
Belgium	-.25	.29	.61	.3	.15
Canada	-.42	-.07	.19	.04	-.01
Denmark	-.26	.15	.48	.51	.29
Finland	-.14	.18	.45	.53	.45
France	-.26	-.02	.46	.45	.09
Germany	.24	.19	.02	.04	-.07
Italy	-.09	.19	.59	.36	.37
Japan	.44	.34	.36	.4	.32
Netherlands	.47	.54	.47	.39	.15
Norway	-.37	-.11	.35	.51	.36
Portugal	-.14	.08	.3	.33	.25
Spain	.04	.41	.66	.6	.45
Sweden	-.27	-.03	.38	.46	.37
Switzerland	.14	.37	.47	.39	.06
UK	-.04	.29	.59	.81	.65
USA	.08	.32	.65	.42	.13

TABLE 17: Cross-correlations between growth rate of real gdp per capita and leads/lags of real credit per capita. Data from 1985-2013.

A.11.2 Cross-correlations for HP filtered data

	x(-2)	x(-1)	x	x(+1)	x(+2)
Australia	-.29	.14	.57	.21	-.44
Belgium	.16	.5	.28	.09	-.28
Canada	-.07	.12	.53	.04	-.15
Denmark	-.31	.13	.6	.23	-.13
Finland	-.03	.12	.6	.38	-.26
France	.18	.47	.12	-.52	-.44
Germany	-.19	-.08	.63	.24	-.3
Italy	-.31	.2	.41	.28	.1
Japan	-.1	.33	.38	.06	-.04
Netherlands	-.39	.32	.68	.29	-.19
Norway	-.02	.52	.35	-.07	-.18
Portugal	-.33	.23	.51	.26	.04
Spain	-.03	.25	.52	.13	-.17
Sweden	-.16	.36	.42	-.23	-.43
Switzerland	.28	.48	.44	-.21	-.47
UK	-.6	.07	.59	.13	-.37
USA	-.25	.34	.8	0	-.35

TABLE 18: Cross-correlations between HP filtered real gdp per capita and leads/lags of HP filtered real credit per capita. Data from 1948-1984.

	x(-2)	x(-1)	x	x(+1)	x(+2)
Australia	-.66	-.52	.34	.63	.32
Belgium	-.28	.34	.74	.4	.04
Canada	-.36	.18	.47	.25	-.04
Denmark	-.37	.08	.54	.64	.33
Finland	-.29	.13	.49	.56	.36
France	-.36	.04	.66	.66	.13
Germany	.24	.21	-.01	-.07	-.16
Italy	-.44	-.04	.43	.12	.07
Japan	-.02	-.24	-.33	-.03	.09
Netherlands	.44	.51	.3	.09	-.17
Norway	-.45	-.09	.54	.82	.5
Portugal	-.19	.15	.52	.56	.39
Spain	-.02	.52	.77	.51	.11
Sweden	-.33	-.02	.46	.53	.31
Switzerland	.15	.48	.55	.31	-.23
UK	-.6	-.12	.48	.85	.52
USA	.03	.42	.78	.47	-.05

TABLE 19: Cross-correlations between HP filtered real gdp per capita and leads/lags of HP filtered real credit per capita. Data from 1985-2013.

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