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Monetary Policy and the Financial Cycle: International Evidence

Jaromír Baxa and Jan Žáček *

Abstract

We evaluate to what extent inflation-targeting central banks appear to have used their interest rate policies to respond to financial imbalances beyond the reaction via the conventional Taylor-rule variables. First, we use the multivariate structural time series model to extract financial cycles for Australia, Canada, Japan, New Zealand, Sweden, the United Kingdom, and the United States. We then estimate time-varying monetary policy reaction functions extended for the financial cycle. We interpret the responses to the financial cycle as attempts to lean against the wind of financial imbalances. The historical decompositions of interest rates reveal that most central banks raised interest rates in response to asset prices and credit booms in the past, including in the years preceding the global financial crisis. The interest rate response to financial cycles is more pronounced with ex-post than with pseudo real-time data. Finally, we document that the financial crisis of 2008 had less of an impact on credit and real housing prices in countries where the interest rate responses to financial cycles were accompanied by macroprudential measures.

Abstrakt

V této práci vyhodnocujeme, do jaké míry centrální banky uplatňující režim cílování inflace použily úrokové sazby v reakci na vývoj finančních nerovnováh, a to nad rámec odezvy skrze konvenční složky Taylorova pravidla. Nejprve používáme vícerozměrný strukturální model časových řad s cílem odhadnout finanční cykly pro Austrálii, Kanadu, Japonsko, Nový Zéland, Švédsko, Spojené království a Spojené státy americké. Následně odhadujeme reakční funkce s časově proměnlivými koeficienty, které jsou nad rámec standardních proměnných obohaceny o složku finančního cyklu. Reakci na vývoj finančního cyklu pak interpretujeme jako snahu centrálních bank o uplatňování „politiky jdoucí proti větru finančních nerovnováh“. Historická dekompozice úrokových sazeb naznačuje, že většina zkoumaných centrálních bank v minulosti zvýšila úrokové sazby v reakci na zvyšující se ceny aktiv a vzestupnou fázi úvěrového cyklu, a to včetně období předcházejícího globální finanční krizi v roce 2008. Odezva úrokových sazeb na vývoj finančního cyklu je zřetelnější na ex post datech než na datech v pseudoreálném čase. Nakonec dokumentujeme, že finanční krize z roku 2008 měla menší dopad na vývoj úvěrů a reálné ceny bydlení v zemích, kde byly reakce úrokových sazeb na finanční cykly doprovázeny makroobezřetnostními opatřeními.

JEL Codes: C32, E32, E40, E44, E52.
Keywords: Financial cycle, model-based filters, monetary policy, reaction functions.

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1. Introduction

Since the global financial crisis of 2007–2009, it has been widely understood that financial imbalances can lead to financial crises with long-lasting effects on the real economy. Moreover, and in contrast to the pre-crisis view of monetary policy, these imbalances can emerge even in an environment of low and stable inflation (Borio et al., 2019). Nevertheless, no consensus has emerged on the appropriate response of monetary policy to credit booms, asset price bubbles, and financial cycles in general.

The community of central bankers has converged to a perspective that macroprudential policy should be used to prevent financial imbalances and that monetary policy should focus on its usual goals. The main argument for such division of policies is that monetary policy actions have limited effects on financial risks, while macroprudential policy tools are regarded as more effective for such purposes. Additionally, according to this perspective, central banks should avoid the temptation to lean against the wind too often and should remain focused mainly on inflation and output stabilization to preserve their credibility. This position, referred to as the "modified Jackson Hole consensus" by Smets (2014), has been defended by many economists from various central banks (Svensson, 2014, 2017; Mishkin, 2017; Kok and Kockerols, 2019; Bernanke, 2020).

The alternative view suggests that monetary policymakers should use interest rate policy to address growing financial imbalances and thus lean against the wind systematically, because financial cycles cannot be tamed solely through macroprudential policy (Borio and Lowe, 2002; Cúrdia and Woodford, 2011). Others, such as Adrian and Shin (2010) and Brunnermeier and Sannikov (2013), stress that the tight connection between monetary policy and financial stability does not allow the two policies to be separated from each other. The financial sector's health affects liquidity flows in the economy, directly impacting aggregate demand and inflation. Also, recent contributions by Juselius et al. (2017) and Borio et al. (2019) suggest that monetary policy might have permanent effects on the real economy via its effects on the financial cycle, and they highlight the benefits of leaning against the wind.

Although the potential benefits of leaning against the wind are known, there are serious issues regarding its implementation. These relate mainly to the limited ability to detect growing financial imbalances in real time, but there is also conflicting evidence about the effects on asset prices and the costs associated with such policies due to weaker economic growth after monetary policy tightening. In particular, Svensson (2017) and Nier et al. (2020) argue that these costs may outweigh the potential benefits of leaning against the wind.

In light of these discussions, this paper explores how inflation-targeting central banks appear to have responded to financial imbalances in the past above and beyond the reactions to the traditional Taylor-type rule variables – inflation and the output gap. We employ the multivariate structural time series model introduced by Rünstler and Vlekke (2018) to identify financial cycles for Australia, Canada, Japan, New Zealand, Sweden, the United Kingdom, and the United States. We then estimate the augmented monetary policy reaction function with time-varying parameters, accounting for variables representing the financial cycle and its components. While the representatives of the central banks in our sample have shared many views on what is appropriate monetary policy since the 1990s, they have also had different experiences of past recessions and financial crises, and these have determined their responses to financial imbalances and approaches to financial regulation. We extend the studies on central banks' responses to asset prices (dating back to Rigobon and Sack, 2003) and to financial instability (see, for example, Baxa et al., 2013) by focusing explicitly on financial cycles. Therefore, we provide further insights into the benefits and limitations of leaning against the wind.

The time variation in the parameters of the policy reaction function allows us to assess whether the interest rate responses – if there were any at all – were only temporary and therefore in line with the pre-crisis consensus that monetary policymakers should consider financial variables only to the extent to which they possess information about future inflation. Other central banks might have aimed for systematic reactions to buildups of financial imbalances, intending to affect market beliefs about central banks' responses to future financial imbalances. This so-called "policy reaction function" channel of monetary policy was first hypothesized by Filardo et al. (2019) and tested for the United States. Using rolling regression, Filardo et al. (2019) identified a systematic countercyclical reaction to credit in the 1990s, but not to other variables. However, using the TVP-VAR model, Aastveit et al. (2017) concluded that the Fed assigned a positive weight to real house prices before the global financial crisis in 2007–2009, and similar results appear in Hafner and Lauwers (2017). Thus, the evidence supporting the hypothesis that the Fed aimed to affect market beliefs about its policy on financial imbalances remains inconclusive.

Besides estimating financial cycles using the multivariate structural time series model, we provide three main contributions to the literature. First, we deal explicitly with cyclical deviations of financial variables; we thus focus directly on financial cycles rather than on the temporary shocks usually associated with financial instability. Second, we provide cross-country evidence, consistently applying a single framework to a group of countries so that the results are directly comparable. Third, we conduct our analysis on both ex-post and pseudo real-time data on financial cycles to tackle the uncertainty about the stages of financial cycles in real time.

The main results of our analysis are the following. First of all, most of the central banks in our sample considered financial cycles in their reaction function; however, their interest rate responses were not systematic and appeared mainly when the imbalances were extensive. With the ex-post data, we document responses to financial cycles that can be interpreted as attempts to pursue leaning against the wind before the global financial crisis of 2008–2009 in all countries except Japan. Additionally, using pseudo real-time estimates of the financial cycles since 2000, we confirm the difficulty of identifying financial cycle phases in real time. Our analysis shows that the extent of financial imbalances was underestimated in real time before the 2008 financial crisis, especially in the United States. The Fed's interest rate response to the financial cycle therefore disappears when these pseudo real-time data are used. However, when the real-time data indicated the existence of financial cycle imbalances, such as in New Zealand, Sweden, and the United Kingdom, central banks used interest rate policy to suppress them. This finding is supported by historical evidence derived from the speeches of central bank representatives and from monetary policy reports. Finally, we show that real credit and housing prices were more affected by the 2008 financial crisis in countries where the interest rate responses to financial cycles were not accompanied by macroprudential measures.

The structure of the paper is as follows. Section 2 discusses related literature and provides an overview of possible approaches to the estimation of the financial cycle and monetary policy reaction functions. Section 3 describes the data. Sections 4 and 5 present the estimations of financial cycles and reaction functions, respectively, while offering a description of the estimation strategies and the results. Section 6 provides robustness checks, and Section 7 concludes.

2. Related Literature

This section offers an overview of methods for estimating cycles of financial variables, supplemented by relevant empirical evidence and a discussion of the pros and cons of the stated approaches. It also reviews the literature that aims to incorporate finance-related variables into monetary policy reaction functions, from both a theoretical and empirical perspective. Last but not least, it deals with the estimation of monetary policy rules. A historical overview of central banks' experience with policies aimed at preventing asset price bubbles is provided in Appendix D.

2.1 The Identification of Financial Cycles and Estimation Methods

The literature identifies several methods for extracting or estimating financial cycles. Those methods can be classified into five general categories, ranging from simple turning point analysis, through univariate filters, to empirical models. Although these methods are different, they do share one common characteristic – the underlying time series used for the analysis. Given the relatively rich empirical evidence in this field, it can be stated that there is a consensus on which variables are relevant for the identification of financial cycles. Those variables are credit (or the credit-to-GDP ratio) and asset prices (usually grouped into stock and housing prices). As documented by Mian and Sufi (2010), Schularick and Taylor (2012), and many others, credit volumes and residential real estate prices tend to be the driving force in the buildup of financial instability and, subsequently, financial crises. Therefore, the above variables are frequently used as underlying indicators characterizing financial cycles.

The first method for identifying financial cycles, turning point analysis, is motivated by the pioneering work of Burns and Mitchell (1946), who introduced this type of analysis and used it to study business cycle properties. Inspired by Burns and Mitchell (1946), Claessens et al. (2010) apply turning point analysis to financial variables and study the characteristics and synchronization of cycles in credit, housing prices, and equity markets. Additionally, Claessens et al. (2012) employ a modified turning point methodology based on Harding and Pagan (2002) to identify cycles in selected financial variables and study their interactions with the business cycle. As argued by Canova (1998), the main advantage of such an approach resides in its robustness to the inclusion of new data, since, as opposed to other methodologies, the estimated trend is not affected. There are, however, several drawbacks as well. Most importantly, the detection of turning points faces the problem of using data in real time, with the problematic issues of edge effects and data revisions (Anas and Ferrara, 2004). Moreover, turning point analysis does not provide direct measures of the financial cycle.[1]

The second category of methods contains approaches based on various frequency domain univariate filters. The most influential research paper in this field, Borio and Lowe (2002), employs a rolling Hodrick-Prescott filter to estimate the gaps in credit, equity and real estate prices to infer the financial cycle based on the series' characteristics. Igan et al. (2011) use a univariate ideal bandpass filter based on Corbae and Ouliaris (2006) to extract cycles of credit, housing prices, and interest rates. The authors find that the housing price cycle leads credit in the long term, while interest rates lag behind other cycles in the short to long term. Drehmann et al. (2014) utilize the Christiano and Fitzgerald (2003) bandpass filter and find that the financial cycle can be well explained by joint cyclical movements of credit and real estate prices. In contrast, equity prices possess almost no explanatory power. Verona (2016) uses the same filter to study properties of the US financial cycle.

[1] Despite the said shortcomings, the results of studies employing turning point analysis can be used as a cross-check for cycles estimated by other methods, as they provide valid information on the length and amplitude of the phases of financial cycles.

Aikman et al. (2015) apply the univariate bandpass filter to real loan growth and identify a medium-term dimension of the credit cycle. Despite the relatively wide application of frequency domain filters, it is necessary to be cautious when using such methodologies. As documented by Murray (2003) and Schüler (2018), detrending based on univariate filters leads to spurious cycles. Moreover, frequency domain tools rely on the a priori definition of the band of cycle frequencies (32–120 quarters for financial cycles) used during the identification procedure. However, such selection of cut-off frequencies restricts the information set conveyed by the underlying time series.

The third pool of methods relies on model-based filters. As opposed to frequency domain univariate filters, model-based filters do not depend on the a priori definition of a band of cycle frequencies, because they can be estimated. Therefore, full information is utilized when extracting the cycles of underlying variables. For example, Bonis and Silvestrini (2014) use a univariate structural trend-cycle model to identify the Italian financial cycle based on the credit-to-GDP ratio. Another application of a univariate trend-cycle model is Galati et al. (2016), who find that housing prices and total credit can sufficiently represent financial cycles. Chen et al. (2012) employ a multivariate unobserved components model with phase shifts to analyze the linkages between the cyclical properties of several financial variables and output. One of the latest applications of multivariate unobserved components models for the estimation of trends and cycles is Rünstler and Vlekke (2018). The authors decompose gross domestic product, credit volumes, and housing prices for the United States and the five largest European economies using a modified multivariate unobserved components model by adding another layer of persistence to the cycles of financial variables. As documented by the listed studies, multi-dimensional filters are flexible tools that can be used for various economic phenomena. Moreover, the modification of the structural unobserved components model presented by Rünstler and Vlekke (2018) makes their use for financial variables even more appropriate. However, one needs to be careful when selecting observables in the analysis, since these models are quite sensitive to over-parametrization.[2]

The fourth approach to extracting financial cycles consists in the direct estimation of spectra of the underlying time series. One of the first applications of this approach is provided by Schüler et al. (2015), who construct a particular multivariate spectral measure for estimation purposes. Other examples of this approach include Strohsal et al. (2019a) and Strohsal et al. (2019b). The first of these papers considers the cross-country interaction of financial cycles between the United States and the United Kingdom and finds that the relation between cycles has intensified in recent years and that there is a Granger causality from the US to the UK financial cycle. The second study estimates isolated financial cycles and confirms that the financial cycle is considerably longer and more extensive in amplitude than the business cycle.

Finally, the last category contains empirical models based on a theoretical background. The pioneering work in this field is Juselius et al. (2017), who construct a VAR model in error correction form with two cointegrating relationships that pin down the long-run evolution of the credit-to-GDP ratio, real asset prices, and the nominal lending rate. Juselius and Drehmann (2020) present a similar model. Although the methodology implemented in these research papers seems promising, Giannoni (2017) raises several concerns. Most importantly, he questions the assumption of cointegrating relationships, which by definition exclude permanent changes to leverage or debt-service levels, because any deviation from their long-run relationships must revert them to their "normal" level.

[2] The number of parameters grows rapidly when additional observed variables are added.

2.2 What Role Should Financial Variables Play in Monetary Policy Rules?

The relationship between monetary policy and financial stability started to be investigated more thoroughly after the financial crisis of 2008. One of the streams of this literature focuses on augmented monetary policy rules. It aims to assess whether and under which conditions it is optimal for monetary policy to respond to financial developments above and beyond their impact on expected inflation and the output gap. Even though the literature is growing, studies do not arrive at the same view, and the evidence is still mixed. Here we offer a brief discussion of theoretical studies employing dynamic stochastic general equilibrium (DSGE) models.

The pre-crisis perspective was formed by theoretical contributions such as Bernanke and Gertler (1999) and Bernanke and Gertler (2001), who argue that the benefits of attempts to stabilize asset prices are small and that monetary policy should focus on underlying inflationary pressures. With a New Keynesian DSGE model with financial frictions, a financial accelerator, and exogenous asset price bubbles, Bernanke and Gertler show that the inflation-targeting approach (supposedly accompanied by sound regulatory policies) provides sufficient stabilization for financial developments, since it instructs central banks to increase interest rates during asset price booms and to reduce them during asset price busts. They consider the potential for leaning against the wind to be rather small, since it is *nearly impossible* to distinguish asset price booms driven by fundamental factors from speculative bubbles. Moreover, their model implies that once the public expects interest rates to increase in response to rising asset prices beyond the standard response to inflationary pressures, the fundamental component of asset prices declines, leading to lower output and an effectively destabilizing effect of leaning against the wind. Similar results are obtained by Faia and Monacelli (2007) and others.

The view on leaning against the wind was also determined by skepticism about the power of interest rate policy to prevent the emergence of asset price bubbles. Perhaps most famously, Greenspan (2004) highlighted that monetary tightening was often followed by an increase rather than a decrease in asset prices.

Numerous attempts to revise the pre-crisis perspective on leaning against the wind appeared after the global financial crisis. Cúrdia and Woodford (2010) built a New Keynesian DSGE model with time-varying credit spreads and with shocks to credit frictions. They show that the optimal monetary policy is shock-dependent, so monetary policy should respond to movements in credit spreads but not necessarily to the volume of credit. Similarly, Gelain et al. (2013) demonstrate that an interest rate response to house prices or credit growth can stabilize certain economic variables while amplifying the volatility of others.

Furthermore, Gambacorta and Signoretti (2014) test the monetary policy rule augmented with asset prices in a closed economy DSGE model with firm balance-sheet and bank-lending channels. The results suggest that leaning against the wind policies are desirable. However, Žáček (2020) modifies the model of Gambacorta and Signoretti (2014) by introducing an occasionally binding credit constraint. Simulations then show that direct reactions to movements in asset prices via the augmented Taylor rule might not be welfare-improving for both types of agents included in the model, as Gambacorta and Signoretti (2014) state. Then, Cúrdia and Woodford (2016) investigate the consequences of a central-bank reaction function adjusted for changes in current and expected future credit spreads. They conclude that such a rule provides a reasonable approximation for the optimal policy.[3] On top of that, the benefits of using interest rate policy in preventing financial crises are

[3] A similar result appears in Ma and Zhang (2016), who incorporate the financial cycle into a conventional Taylor rule and find that the augmented rule could better stabilize both the financial and the real side of an economy

also stressed by Borio et al. (2019), who believe that responding systematically to the financial cycle does not imply abandoning price-stability-oriented frameworks but the adoption of more flexibility in policymaking.

Nevertheless, the limits of leaning against the wind remain widely acknowledged, by Blanchard and Summers (2018) among others, due to the difficulty in distinguishing *good* credit and asset price booms from *bad* ones. In this regard, Svensson (2017) provides a cost-benefit analysis of leaning against the wind. He shows that under reasonable assumptions, the costs in the form of lower economic growth and higher unemployment both before and during a crisis do not outweigh the potential benefits in terms of lower probability and smaller magnitude of financial crises. These results are driven by the relatively low policy-rate effects on the probability and magnitude of crises identified in the previous literature. Already a draft of Svensson (2017) sparked a lively debate among Svensson and others – Adrian and Liang (2018), BIS (2016) – Box IV.B, and Filardo and Rungcharoenkitkul (2016), who defended the desirability of leaning against the wind. Many remarks and concerns were reflected in the version published by Svensson, but the debate continues. For example, Kashyap and Sim (2018) use a small New Keynesian DSGE model to consider the risk of a financial crisis that depends on "excess credit." The authors find that leaning against the wind may be attractive, although this conclusion depends on the severity of financial crises and the sensitivity of the crisis probability to excess credit. More recently, Adrian et al. (2019) and Adrian et al. (2020) demonstrate that the optimal monetary policy rule taking into account financial conditions brings sizable welfare gains and argue that the outcomes of Svensson's cost-benefit analysis of leaning against the wind hold only in simplified models.[4]

2.3 Has Monetary Policy Already Responded to Movements in Financial Variables?

Inspired by studies employing structural models, such as Bernanke and Gertler (2000), researchers began to empirically investigate monetary policy reactions to financial developments and vulnerabilities. These empirical studies aim to provide evidence on whether monetary authorities have responded to financial variables in the past and to assess the usefulness of such policies. This research field gained even more attention after the global financial crisis of 2008, since the roots of the crisis could be traced back to the US financial sector. Like the theoretical work discussed in the previous subsection, the empirical evidence does not provide a unanimous view. Moreover, the literature usually focuses on isolated financial variables or financial instability measures rather than their cyclical components characterizing financial cycles. Therefore, there is still room for further investigation to add some arguments to what is already a lively debate.

One of the first empirical studies in this field, Rigobon and Sack (2003), measures the response of monetary policy to the stock market, with a finding of a significant policy response of the Federal Open Market Committee (FOMC) to developments in the S&P 500 index. Based on estimates for

than its conventional counterpart. Also, Primiceri (2017) looks at a modified Taylor rule from the perspective of excess reserves and countercyclical reserve requirements. Experiments reveal that both the rule accounting for movements in excess reserves and the countercyclical reserve requirement rule mitigate the macroeconomic and financial volatility stemming from liquidity shocks. Finally, Žáček (2019) tests the performance of a monetary policy rule enriched by financial variables in a small open economy. While the rule delivers the best performance for specific domestic shocks, its usefulness significantly deteriorates in the case of shocks originating abroad. Therefore, any strict rule-like behavior is not optimal.

[4] We believe that Svensson (2017) should be interpreted in the context of the author's Riksbank board experience, during which he opposed the interest rate hikes of 2010–2011, when the policy rate was increased from 0.25% to 2%. By and large, this movement resembled the ECB's policy at that time, although it was motivated by a rising household debt-to-income ratio and not by other inflationary pressures. See Appendix D for a more thorough discussion.

the United States, the United Kingdom, and Japan, Chadha et al. (2004) conclude that reacting to asset prices may be an important aspect of monetary policy design. The first study estimating the response of central banks (those of Australia, Germany, Japan, and the United States) to a broader measure of financial imbalances, Borio and Lowe (2004), finds ambiguous evidence for all the countries under investigation except the United States, where an asymmetric response to financial imbalances is confirmed. On the contrary, Fuhrer and Tootell (2008) find little evidence supporting the claim that the FOMC responds to stock values.

After 2008, attention turned to the United States. For example, Belke and Klose (2010) investigate the factors behind the Fed's interest rate decisions during the financial crisis. The authors find a significant difference between the "pre-crisis" and "crisis" monetary policy rules of the Fed given by the difference in its responses to asset price inflation. Roskelley (2016) shows that the Taylor rule augmented by bond yields improves the in-sample and out-of-sample fit of the model, suggesting that bond yields play a certain role in the FOMC's decision making. Hafner and Lauwers (2017) investigate whether the Fed reacted to asset prices, equity, and real estate over 1979–2011. Their findings suggest that while the role of house prices is subdued in this regard, stock prices prove to be a vital component of the conduct of the Fed's monetary policy. However, no systematic reactions to stock price movements are found. Aastveit et al. (2017) provide somewhat heterogeneous evidence on the role of asset prices for US monetary policy. They find a significant reaction of the Fed to house prices in their baseline. However, once they extend their sample or omit stochastic volatility, the results flip and a significant reaction appears for stock prices but not for house prices. In contrast, Filardo et al. (2019) do not confirm the countercyclical reaction of the Fed to house or stock prices over the 2000–2010 period. Oet and Lyytinen (2017) extract statements from the minutes of FOMC meetings related to financial stability. Using this information, the authors try to explain the deviations of realized policy rates from the rates implied by the Taylor rule. They find that the "discussion-based" Taylor rule outperforms the standard rule, both in normal times and in zero lower bound conditions.

There are also research papers focusing on regions other than the United States. For example, Siklos and Bohl (2009) construct a forward-looking and forecast-based Taylor rule enriched by asset prices for France, Germany, Italy, and the euro area as a whole and investigate the compatibility of the rules across the countries within the currency area. Although the augmented rules deliver better estimates, different assets are relevant in different countries. Therefore, one general rule for the whole euro area does not seem to be an optimal strategy. Fouejieu (2017) analyses monetary policy in 26 emerging countries and finds targeting countries to be more sensitive to financial risks. Additionally, the results suggest that the control of inflation should remain strictly separated from the financial stability objective. On the contrary, the findings of Çevik et al. (2019) reveal that Taylor rule-based monetary policies in major emerging economies serve to achieve both price and financial stability.

Besides empirical studies focusing on single financial variables, several empirical research papers evaluate monetary policy responses using broader measures of financial imbalances, such as financial stress or financial sector vulnerability. For example, Cecchetti and Li (2008) construct and estimate an optimal monetary policy rule augmented by a measure of banking stress. Bulíř and Čihák (2008) deal with monetary policy responses to financial sector vulnerabilities captured by seven alternative measures (ranging from crisis occurrence probability to credit default swap spreads). Baxa et al. (2013) examine whether and how central banks in the United States, the United Kingdom, Australia, Canada, and Sweden responded to financial stress episodes. The authors find that stock market stress and bank stress could play an essential role in monetary policy decisions. Their results also support the view on central banks' asymmetric responses when they change policy rates, mainly in the face of high financial stress. Kremer (2016) and Floro and Roye (2017) test how monetary policy responds to changes in systemic financial stress and financial sector-specific stress, respectively. The first study concludes that the indicator of systemic financial stress has a significant influence on policy interest rates. The latter research brings evidence of aggressive monetary policy loosening in response to stock market and banking stress, but only in episodes of high volatility on financial markets.

2.4 Approaches to Modeling and Estimating Monetary Policy Reaction Functions

Early studies investigating Taylor rules relied on single-equation models estimated via time-invariant techniques. For example, Clarida et al. (1998) and Clarida et al. (2000) estimate the interest rate rule for three European countries and the United States using the generalized method of moments (GMM) with correction for MA(12) autocorrelation. Gelain et al. (2014) estimate a single-equation model while employing the non-linear least squares procedure. Rühl (2015) analyze the interest rate setting of the ECB using several GMM estimation procedures. Hafner and Lauwers (2017) construct the Fed's reaction function augmented with asset prices and employ instrumental variables along with the GMM to estimate the model. Although the listed methods have been used extensively, they do not allow changes in monetary policy regimes to be tracked over time. Given that the estimated coefficients are not allowed to vary, they indicate the average sensitivity of central banks to the evolution of variables included in policy rules. Therefore, alternative approaches to assessing structural changes need to be implemented.

There are generally two ways to model such changes. The first is to apply regime-switching models. Such approaches distinguish between periods of different monetary policy stances based on the application of Markov-switching coefficients (Assenmacher-Wesche, 2006; Debortoli and Nunes, 2014), the implementation of thresholds in single-equation Taylor rule models (Floro and Roye, 2017; Ahmad, 2019), or the application of more complex Markov-switching VAR models with inherited policy functions (Valente, 2003; Sims and Zha, 2006; Drakos and Kouretas, 2015). The second option for modeling and assessing structural changes in monetary policy over time is to implement state-space models with time-varying coefficients (Trecroci and Vassalli, 2010; Baxa et al., 2013; Creel and Hubert, 2015). Unlike in the case of regime-switching models, the resulting changes in the monetary policy regime (or stance) are rather smooth and are not driven by sharp regime changes. On top of this, Baxa et al. (2014) show that time-varying parameter (TVP) models work well not only when modeling slow transitions but even when the shifts are rather fast. As argued by Kim and Nelson (2006), TVP models also allow for more flexibility and for treatment of the endogeneity that is generally present in the estimation of forward-looking monetary policy rules. Additionally, as explained by Baxa et al. (2013), TVP models are suitable for evaluating the effects of factors influencing monetary policy conduct for a limited length of time.

Another class of state-space models with time-varying coefficients is formed of various VAR models. Cogley and Sargent (2005) and Benati and Surico (2008) use vector autoregression models with drifting parameters and stochastic volatility to compare the Fed's monetary policy reactions in different periods of the post-World War II era and before the financial crisis of 2008, respectively. Belongia and Ireland (2016) and Lakdawala (2016) estimate a TVP-VAR model to study the Fed's monetary policy reactions. Finally, Best (2017) uses a form of discounted least squares estimation to assess monetary policy reaction coefficients within a VAR model.

3. Data

Our data sample covers seven economies – Australia, Canada, Japan, New Zealand, Sweden, the United Kingdom, and the United States. It captures the period 1970q1–2019q2 for the estimation of financial cycles and 1986q1–2019q2 for the estimation of reaction functions, both on a quarterly basis.[5]

To estimate the financial cycle, we choose three underlying financial variables – credit, housing prices, and share prices. These variables are transformed into real quantities by dividing them by the GDP deflator. The selection of variables is motivated by ECB (2014) and Juselius and Drehmann (2020), who report that those financial variables provide a reasonable and sufficient decomposition of the financial cycle.[6] The last input into the financial cycle analysis is gross domestic product measured using the expenditure approach.

We employ two sets of variables in the estimation of reaction functions (monetary policy rules). The first set is used to estimate the baseline rules, while the second set is employed for robustness checks. The dependent variable is the 3-month interbank interest rate, which is closely related to the official policy rate. However, as conventional interest rates were not the only source of monetary policy implementation in the last decade, we replace the short-term interest rates of Japan, Sweden, the United Kingdom, and the United States with *shadow interest rates*. Inflation is measured as the year-on-year change in the consumer price index. We employ the Hamilton (2018) regression filter to obtain estimates of output gaps.[7]

We also use several other variables in the robustness analyses – the inflation target, the real effective exchange rate, commodity prices, the effective federal funds rate, the CAD/USD exchange rate pair, and the Greenbook datasets on inflation and the output gap.[8] Last but not least, long-term interest rates on government bonds maturing in 10 years, nominal effective exchange rates, and selected main stock market indices[9] are used to construct a simplified financial stress index (FSI), which is used in one of the robustness checks of our results.

More details about the data can be found in Appendix F.

4. The Financial Cycle

This section describes the estimation of the financial cycle from its constituent cyclical components, as represented by real credit, housing prices, and stock prices.[10] We apply parametric trend-cycle decomposition based on a multivariate structural time series model inspired by Rünstler and Vlekke

[5] Given that financial cycles are longer than the usual business cycle, the longest possible period should be covered to obtain reliable estimates. Since we are limited by the availability of data on interest rates, the data sample is shorter in the case of the estimation of reaction functions.
[6] The selection also resembles previous studies, such as Claessens et al. (2010).
[7] Although we also estimate output gaps as part of the estimation of the financial cycle, we resort to a standard output gap extraction method used in the literature.
[8] One of the robustness exercises in Section 6 presents a real-time perspective on the Fed's monetary policymaking. To offer such a view, we use data vintages from the Greenbooks of the Federal Reserve Board of Governors.
[9] The data for leading stock market indices are retrieved from the platforms Yahoo Finance and investing.com.
[10] Although there is a growing persuasion that the financial cycle should be characterized mainly by credit and housing prices (Schularick and Taylor, 2012; Borio, 2014), we decided to include share prices as well, mainly due to the influential literature discussing whether central banks should respond to movements in share prices published since the late 1990s, in particular Bernanke and Gertler (2000) and Rigobon and Sack (2003). However,

(2018).[11] Unlike methods based on frequency domain tools, this modeling approach allows for different characteristics of the cyclical components of financial variables and also for interaction between them. The technique is based on the estimation of the cyclical components of the underlying financial time series. Once we obtain the estimates of the individual cyclical components, we apply principal component analysis to extract the common pattern.

4.1 Methodology

The multivariate structural time series model (STSM) is given by

$$\boldsymbol{y}_t = \boldsymbol{\tau}_t + \tilde{\boldsymbol{c}}_t + \boldsymbol{\varepsilon}_t \tag{1}$$

where $\boldsymbol{y}_t$ is an $N \times 1$ vector of observed variables, $\boldsymbol{\tau}_t$ is an $N \times 1$ vector of stochastic trend components, $\tilde{\boldsymbol{c}}_t$ is an $N \times 1$ vector of cyclical components, and $\boldsymbol{\varepsilon}_t$ is an $N \times 1$ vector of irregular components, such that $\boldsymbol{\varepsilon}_t \sim NID(\boldsymbol{0}, \boldsymbol{\Sigma}_\varepsilon)$, where $\boldsymbol{\Sigma}_\varepsilon$ is an $N \times N$ non-negative definite covariance matrix. The stochastic component, $\boldsymbol{\tau}_t$, of the model specified in Equation (1) is modeled as a multivariate local linear trend model with time-varying drift, $\boldsymbol{\beta}_t$, following a random walk. The stochastic component is given by

$$\boldsymbol{\tau}_t = \boldsymbol{\beta}_{t-1} + \boldsymbol{\tau}_{t-1} + \boldsymbol{\xi}_t, \tag{2}$$

$$\boldsymbol{\beta}_t = \boldsymbol{\beta}_{t-1} + \boldsymbol{\zeta}_t \tag{3}$$

with $\boldsymbol{\beta}_t$ being an $N \times 1$ vector and $\boldsymbol{\xi}_t$ and $\boldsymbol{\zeta}_t$ being $N \times 1$ vectors of irregular components, such that $\boldsymbol{\xi}_t \sim NID(\boldsymbol{0}, \boldsymbol{\Sigma}_\xi)$ and $\boldsymbol{\zeta}_t \sim NID(\boldsymbol{0}, \boldsymbol{\Sigma}_\zeta)$, where $\boldsymbol{\Sigma}_\xi$ and $\boldsymbol{\Sigma}_\zeta$ are $N \times N$ positive semi-definite covariance matrices with $\mathbb{E}_t(\boldsymbol{\xi}_t \boldsymbol{\zeta}'_{t-s}) = 0$ for $\forall s$.

The cyclical component of the model, $\tilde{\boldsymbol{c}}_t$, is defined as

$$\tilde{\boldsymbol{c}}_t = \left[\boldsymbol{A}, \boldsymbol{A}^*\right] \begin{bmatrix} \boldsymbol{c}_t \\ \boldsymbol{c}_t^* \end{bmatrix} \tag{4}$$

where $\boldsymbol{A}$ and $\boldsymbol{A}^*$ are arbitrary $N \times N$ matrices. As discussed by Rünstler and Vlekke (2018), such approach allows for the introduction of phase shifts between the cyclical components and therefore for cross variances among the cycles. The elements of vectors $\boldsymbol{c}_t = [c_{1,t}, \ldots, c_{N,t}]'$ and $\boldsymbol{c}_t^* = [c^*_{1,t}, \ldots, c^*_{N,t}]'$ are modeled as stochastic cycles based on sine and cosine waves.

As pointed out by Rünstler and Vlekke (2018) and other studies, the estimation of STSMs with a lot of parameters is costly.[12] Therefore, we limit the model to four observables, which are ordered as follows: GDP (capturing economic slack), credit, housing prices, and share prices. The cyclical component of the model, $\tilde{\boldsymbol{c}}_t = [\tilde{c}_{1,t}, \tilde{c}_{2,t}, \tilde{c}_{3,t}, \tilde{c}_{4,t}]'$, as expressed by Equation (4), is given by

$$\begin{bmatrix} \tilde{c}_{1,t} \\ \tilde{c}_{2,t} \\ \tilde{c}_{3,t} \\ \tilde{c}_{4,t} \end{bmatrix} = \begin{bmatrix} a_{11}c_{1,t} + a_{12}c_{2,t} + a_{13}c_{3,t} + a_{14}c_{4,t} + 0 + a^*_{12}c^*_{2,t} + a^*_{13}c^*_{3,t} + a^*_{14}c^*_{4,t} \\ a_{21}c_{1,t} + a_{22}c_{2,t} + a_{23}c_{3,t} + a_{24}c_{4,t} + a^*_{21}c^*_{1,t} + 0 + a^*_{23}c^*_{3,t} + a^*_{24}c^*_{4,t} \\ a_{31}c_{1,t} + a_{32}c_{2,t} + a_{33}c_{3,t} + a_{34}c_{4,t} + a^*_{31}c^*_{1,t} + a^*_{32}c^*_{2,t} + 0 + a^*_{34}c^*_{4,t} \\ a_{41}c_{1,t} + a_{42}c_{2,t} + a_{43}c_{3,t} + a_{44}c_{4,t} + a^*_{41}c^*_{1,t} + a^*_{42}c^*_{2,t} + a^*_{43}c^*_{3,t} + 0 \end{bmatrix}. \tag{5}$$

as a robustness check, we estimate the response of monetary policy to the constituent indicators of the financial cycle as well.

[11] Here we present the key elements of the model. A detailed description of the methodology can be found in Appendix A.

[12] We also estimated the model with the nominal interest rate. The number of parameters to be estimated increases considerably in such case and therefore makes the estimation unreliable.

Here, a_{ij} and a^*_{ij} for $i, j = 1, \dots 4$ are the elements of matrices $\boldsymbol{A}$ and $\boldsymbol{A}^*$ that govern the interaction between the individual variables. Since the characteristics of the business cycle and the financial cycle are different, and there is no clear distinction of whether the business cycle drives the financial cycle (or the other way around), as documented by, for example, Bulligan et al. (2019), we do not impose any ex-ante structural restrictions on the elements of matrices $\boldsymbol{A}$ and $\boldsymbol{A}^*$. The only exceptions are identification restrictions setting elements $a^*_{ij} = 0$ for $\forall i = j = 1, \dots, 4$ in line with Rünstler and Vlekke (2018) to normalize phase shifts between the variables. As is obvious from Equation (5) and the previous discussion, we allow for interaction among stochastic cycles with potentially different features.

4.2 Estimation Strategy and Results

The model specified by equations (1)–(4) can be cast into state-space form:

$$\boldsymbol{y}_t = \boldsymbol{H}\boldsymbol{s}_t + \boldsymbol{\varepsilon}_t, \tag{6}$$

$$\boldsymbol{s}_t = \boldsymbol{F}\boldsymbol{s}_{t-1} + \boldsymbol{\eta}_t. \tag{7}$$

The state-space form relates the measurement Equation (6) (which describes the relation between the observed variables $\boldsymbol{y}_t$ and the unobserved state variables $\boldsymbol{s}_t$) and the transition Equation (7) (describing the dynamics of the state variables). The link between the observed and unobserved variables is determined by matrix $\boldsymbol{H}$, while the dynamics of the state variables are characterized by matrix $\boldsymbol{F}$. We use a diffuse Kalman filter combined with Bayesian techniques to estimate the parameters of the model $\boldsymbol{\Sigma}_\varepsilon$, $\boldsymbol{\Sigma}_\xi$, $\boldsymbol{\Sigma}_\zeta$, $\boldsymbol{A}$, $\boldsymbol{A}^*$, and ρ_i, ϕ_i and λ_i for $i = 1, \dots, 4$.[13] Following Guarda and Moura (2019), we keep the assumption of mutually uncorrelated irregular components $\boldsymbol{\varepsilon}_t$, $\boldsymbol{\kappa}_t$, and $\boldsymbol{\kappa}^*_t$, with the exception of contemporaneous correlations among innovations to the trend and cyclical components $\boldsymbol{\xi}_t$ and $\boldsymbol{\zeta}_t$, throughout the estimation.

The model consisting of Equations (6) and (7) can be estimated for each variable separately or for all variables simultaneously. We start our analysis by fitting the univariate STSMs to understand the properties of the cyclical behavior of the variables without being influenced by cross effects stemming from cyclical interaction via matrices $\boldsymbol{A}$ and $\boldsymbol{A}^*$. Second, the estimates from this partial analysis serve as the underlying values used to set the priors in the multivariate models. Last but not least, we use the results from the univariate estimation to assess similar cyclical properties among the financial variables. We give the univariate estimation – along with a detailed discussion – in Appendix E.1 and focus on the multivariate estimation in the following paragraphs.

The main results of the multivariate estimation are provided in Table 1 and Figure 1.[14] In what follows, we focus on the length of the cycles and their volatility (measured by the standard deviation). We follow Rünstler and Vlekke (2018) and apply the spectral generating function, $G^c(\omega)$, implied by the estimated multivariate STSMs to derive the cyclical characteristics of $\tilde{\boldsymbol{c}}_t$. The average frequencies λ_i^G of a series $\tilde{c}_{i,t}$ for $i = 1, \dots, 4$ can be obtained from the weighted integrals

$$\left(\int_0^\pi \sqrt{G^C_{ii}(\omega) G^C_{jj}(\omega)}\, \mathrm{d}\omega\right)^{-1} \int_0^\pi \varphi_{ij}(\omega) \sqrt{G^C_{ii}(\omega) G^C_{jj}(\omega)}\, \mathrm{d}\omega \tag{8}$$

[13] Parameters ρ_i (a decay parameter), ϕ_i (an autoregressive root), and λ_i (a frequency parameter) characterize the cyclical component of the model. For details see Appendix A.

[14] The priors, along with the detailed estimation results, are summarized in Tables B1 and B2 in Appendix B and displayed in Figures C8–C14 in Appendix C. Following Rünstler and Vlekke (2018), we calibrate ϕ_1 to zero.

with auto spectra $G^C_{ii}(\omega)$, where φ_{ij} represent coherence or phase spectra and $G^C_{ij}(\omega)$ for $i, j = 1, \ldots, 4$ are the elements of the spectral generating function.[15]

Table 1 shows that the financial variables share longer cycles than the business cycle. Although the cycles of the individual financial variables are persistent, there are substantial differences between them. The financial variables can be sorted into two groups: (a) credit and housing prices, and (b) share prices. Credit and housing prices have generally longer cycles and are less volatile. The estimated lengths of the credit and housing price cycles are between 9.98 and 17.74 years, with an average length of 13.15 years, while the length of the share price cycle attains values between 6.82 and 9.76 years. The average standard deviations of the credit and housing price cycles are 0.056 and 0.09, respectively. On the other hand, the average standard deviation of the share price cycle is 0.23, which is considerably higher than for the other two financial measures.

Table 1: Properties of Cyclical Components – Results Based on Multivariate STSMs

	GDP		**Credit**		**Housing Prices**		**Share Prices**	
Country	**Length**	**SD**	**Length**	**SD**	**Length**	**SD**	**Length**	**SD**
Australia	7.84	0.014	9.98	0.039	10.48	0.068	8.35	0.224
Canada	9.45	0.022	11.36	0.046	10.02	0.078	7.39	0.155
Japan	6.68	0.018	17.74	0.052	17.7	0.082	7.73	0.29
New Zealand	9.52	0.028	10.91	0.082	13.38	0.11	9.76	0.261
Sweden	8.08	0.017	14.1	0.059	13.22	0.094	8.19	0.283
United Kingdom	8.83	0.025	13.13	0.069	14.49	0.139	9.23	0.24
United States	9.53	0.021	13.89	0.042	13.85	0.063	6.82	0.16
Average	8.56	0.021	13.02	0.056	13.31	0.09	8.21	0.23

Note: The length of the cycles is reported in years. SD stands for standard deviation. All variables in real terms, deflated by the GDP deflator.

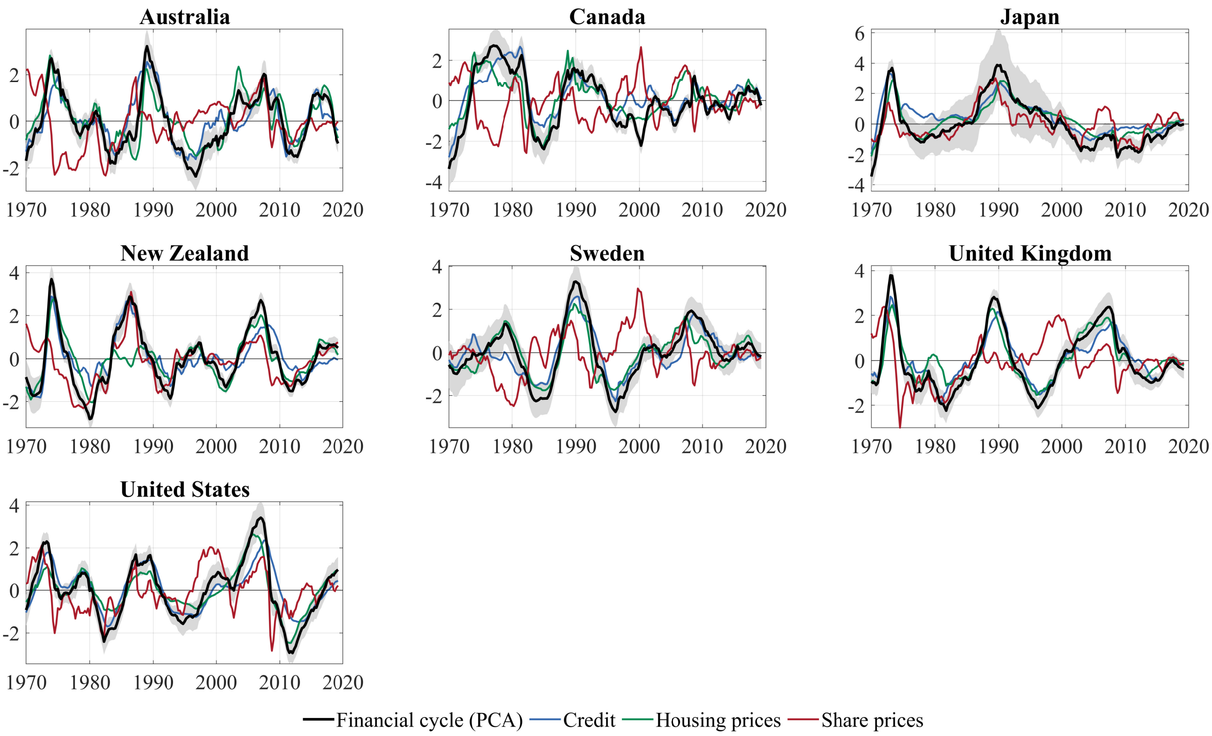
The business cycle length varies between 6.68 years (for Japan) and 9.53 years (for the United States). Our estimated medium-term cyclical property of the US business cycle is in line with, for example, Comin and Gertler (2006), who report a medium-cycle property for the US economy as well. The general notion that the typical business cycle ranges between 8 and 32 quarters is based on data through the 1970s. Since then, the average length of the business cycle has become longer compared with the distant past. Therefore, it is not surprising to report a cycle length of approximately 10 years for the United States. The average standard deviation of the business cycle attains a fair value of 0.021.[16] Overall, this analysis confirms that cycles of financial variables (credit and housing prices) are substantially longer and more volatile than the standard business cycle. Additionally, we report that share prices possess a short-term cyclical property similar to that of the business cycle.

[15] A detailed derivation and explanation is presented in Supporting Information Supplement A in Rünstler and Vlekke (2018).

[16] Although it is not the primary goal of this research paper to estimate output gaps, we report the results here to offer a consistency check. To ensure that the estimated output gaps are broadly in line with the "official" measures, Appendix C shows a comparison of the estimated output gaps based on the STSMs with the estimates of the IMF and the OECD.

The underlying cyclical components of the financial variables are then used to construct the overall financial cycle based on principal component analysis (PCA). Figure 1 displays the constituent cycles (rebased to the series' standard deviations) along with the resulting financial cycles for each country.[17] As is apparent from Figure 1, the credit and housing price cycles move together, while the share price cycle is less persistent and often moves in the opposite direction to the other two cycles. The cycles of the financial cycle components are rather more dispersed in Australia and Canada, as indicated by a lower Bayes factor for a similar cycle restriction (Table E3), so the resulting financial cycle series is somewhat less representative than in the other countries in our sample. A general observation from the PCA analysis is that the financial cycle is driven by credit and housing prices, while share prices do not play a substantial role. This finding is in line with previous studies, such as Drehmann et al. (2014), ECB (2014), and Galati et al. (2016), which report that the financial cycle can be well explained by the volume of credit and housing prices.

Figure 1: Financial Cycles and Cycles of Constituent Indicators – the STSM



Note: Quarterly data. The financial cycle is the first principle component of the three underlying indicators. All components are rebased to the series' standard deviations.
Source: Author's computations.

Regarding the relative contributions of credit and housing prices to the first principal component representing the financial cycle, Canada, New Zealand, and the United Kingdom form a block of countries where credit is the main driver of the overall financial cycle. On the other hand, house prices seem to be the dominant factor behind the financial cycles in Japan, Sweden, and the United States. Nevertheless, the differences between the cycles in housing prices and credit are negligible.

[17] The estimated financial cycles are in line with the estimates of, for example, Drehmann et al. (2014) and Stremmel (2015). Detailed results are displayed in Figure C15 in Appendix C.

To measure the synchronicity of the overall financial cycles across the countries, we compute pair-wise correlations.[18] These reveal the highest synchronicity to be between (1) the United Kingdom and the United States, (2) Australia and the United Kingdom, and (3) Australia and Sweden.[19]

5. Monetary Policy Reaction Function

To investigate the relative importance of the financial cycle for interest rate policies, we estimate the monetary policy reaction function augmented with a measure of the financial cycle extracted using the STSM model presented in the previous section. This section presents the estimation procedure and the results.

5.1 Time-Varying Monetary Policy Reaction Function

There are studies, for example, Boivin (2006), Kim and Nelson (2006), and Kishor (2012), documenting that monetary policy conduct may change over time. To assess whether the central banks in our data sample reacted to financial developments following some systematic pattern, we construct a forward-looking monetary policy rule with interest rate smoothing, inspired by the pioneering work of Clarida et al. (1998), and time-varying coefficients augmented with a measure of the financial cycle f_{t-1}.[20] In such a setting, the monetary authority reacts to price, economic and financial developments. The model takes the form

$$i_t = (1-\rho_t)(\alpha_{0,t} + \alpha_{\pi,t}\mathbb{E}_t\pi_{t+2} + \alpha_{y,t}\tilde{y}_t + \alpha_{f,t}f_{t-1}) + \rho_t i_{t-1} + \varepsilon_{i,t} \tag{9}$$

where i_t is the interest rate, $\rho \in [0,1]$ is the interest rate smoothing parameter, π_{t+2} is the future yoy inflation rate, $\tilde{y}_t$ stands for the output gap, and $\varepsilon_{i,t}$ is an irregular component such that $\varepsilon_{i,t} \sim N(0,\sigma_i^2)$. The selection of the time indices of the explanatory variables is motivated by Baxa et al. (2013).[21] In our setting, the reaction to financial developments is reactive rather than proactive, as the financial cycle enters the rule at time $t-1$.[22]

The time-varying coefficients are assumed to follow independent driftless random walk processes, that is,

$$\begin{bmatrix} \rho_t \\ \alpha_{0,t} \\ \alpha_{\pi,t} \\ \alpha_{y,t} \\ \alpha_{f,t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \rho_{t-1} \\ \alpha_{0,t-1} \\ \alpha_{\pi,t-1} \\ \alpha_{y,t-1} \\ \alpha_{f,t-1} \end{bmatrix} + \begin{bmatrix} \vartheta_{\rho,t} \\ \vartheta_{0,t} \\ \vartheta_{\pi,t} \\ \vartheta_{y,t} \\ \vartheta_{f,t} \end{bmatrix} \tag{10}$$

[18] The results can be found in Table B3 in Appendix B.

[19] The second finding is in line with Strohsal et al. (2019a), who report that the relation between the financial cycles of those countries has even intensified in recent years.

[20] Following Clarida et al. (1998), we suppose that the financial cycle variable f_{t-1} determines the optimal interest rate, so f_{t-1} appears in parentheses indicating the targeted interest rate.

[21] Inflation expectations are proxied by the ex-post inflation data $t+2$ quarters ahead. Such a setting is common in articles with similar research interests. Baxa et al. (2013) explain that there are at least two solid reasons for setting the index of inflation to a lower value, even though the monetary policy horizon of central banks lies in the interval of 4–6 quarters. First, given that the prediction error increases at longer horizons, the accuracy of inflation expectations in matching the actual outcome is higher at shorter horizons. Second, the endogeneity treatment (as described in the following paragraphs) requires a strong correlation between the endogenous regressors and their instruments. On top of these two reasons, the selection of the inflation index is in line with the theory provided by Batini and Nelson (2001), who report that the optimal monetary policy horizon lies two quarters ahead.

[22] Subsection 6.1 offers robustness checks for different settings of the time index.

where $\boldsymbol{\vartheta}_t = [\vartheta_{\rho,t}, \vartheta_{0,t}, \vartheta_{\pi,t}, \vartheta_{y,t}, \vartheta_{f,t}]'$ is a vector of irregular components such that $\boldsymbol{\vartheta}_t \sim N(\mathbf{0}, \boldsymbol{\Sigma}_\vartheta)$.

Given that the reaction function is (a) forward-looking and constructed using ex-post data, and (b) contains variables characterized by a two-sided relationship with monetary policy, endogeneity might occur (Baxa et al., 2013). As discussed by Kim and Nelson (2006), ignoring endogeneity would result in invalid inference of the model, mirrored in biased estimates of the model coefficients. Therefore, Kim (2006) proposes a Heckman-type two-step framework for time-varying models that delivers consistent estimates. First, the procedure involves estimating simple models capturing the relationship between potential endogenous regressors and their instruments. In the second step, the correction term (represented by the standardized prediction error) from the first step is used as another regressor in the estimation of the policy rule.

Following Kim and Nelson (2006), we regress the potentially endogenous variables π_{t+2} and $\tilde{y}_t$ on instruments $\boldsymbol{Z}_t$ (see Equations (11)–(12)). We use the following set of instruments: the first four lags of inflation, the first two lags of the output gap and the financial cycle, and one lag of the interest rate.

$$\pi_{t+2} = \boldsymbol{Z}'_{t-n}\boldsymbol{b}_\pi + \iota_{\pi,t} \tag{11}$$

$$\tilde{y}_t = \boldsymbol{Z}'_{t-n}\boldsymbol{b}_y + \iota_{y,t} \tag{12}$$

Here, $\boldsymbol{b}_w$ for $w = \pi, y$ are vectors of coefficients and $\iota_{w,t} \sim N(0, \sigma_w^2)$ are the respective irregular components.[23] We augment the initial monetary policy reaction function (given by Equation (9)) by the standardized prediction errors $\hat{\iota}^\sigma_{\pi,t}$ and $\hat{\iota}^\sigma_{y,t}$ resulting from the supplementary regressions to remedy for potential endogeneity. Then the monetary policy rule to be estimated takes the form

$$i_t = (1-\rho_t)(\alpha_{0,t} + \alpha_{\pi,t}\mathbb{E}_t\pi_{t+2} + \alpha_{y,t}\tilde{y}_t + \alpha_{f,t}f_{t-1}) + \rho_t i_{t-1} + \beta_\pi \hat{\iota}^\sigma_{\pi,t} + \beta_y \hat{\iota}^\sigma_{y,t} + \varepsilon_{i,t}. \tag{13}$$

As explained by, for example, Primiceri (2005) and Nakajima (2011), the TVP model results in a non-linear state-space form, and maximum likelihood (ML) estimation is therefore intractable. For such a case, Nakajima (2011) suggests employing a Bayesian technique implementing the Markov Chain Monte Carlo (MCMC) method for precise and efficient estimation of the TVP regression model. The estimation procedure of Nakajima (2011) is close to the original estimation algorithm of the TVP-VAR model proposed by Primiceri (2005). Equation (13), along with the time-varying coefficients defined by Equation (10), can be written in compact form as

$$i_t = \boldsymbol{D}'_t\boldsymbol{\alpha}_t + \boldsymbol{P}'_t\boldsymbol{\beta} + \varepsilon_{i,t}, \tag{14}$$

$$\boldsymbol{\alpha}_t = \boldsymbol{\alpha}_{t-1} + \boldsymbol{\vartheta}_t \tag{15}$$

where $\boldsymbol{\alpha}_t = [\alpha_{0,t}, \alpha_{\pi,t}, \alpha_{y,t}, \alpha_{f,t}, \rho_t]'$ and $\boldsymbol{\beta} = [\beta_\pi, \beta_y]'$ denote collections of time-varying and fixed parameters respectively, $\boldsymbol{D}_t$ and $\boldsymbol{P}_t$ represent collections of corresponding variables, $\varepsilon_{i,t}$ is an irregular component, and $\boldsymbol{\vartheta}_t$ is a vector of irregular components such that $\varepsilon_{i,t} \sim N(0, \sigma_i^2)$ and $\boldsymbol{\vartheta}_t \sim N(\mathbf{0}, \boldsymbol{\Sigma}_\vartheta)$.

We estimate the TVP regression model by drawing 10,000 samples (after the initial 1,000 samples are discarded) and by assuming the following prior distributions, which can be considered rather diffuse and uninformative.

$$\boldsymbol{\beta} \sim N(0, 10 \times \boldsymbol{I}), \quad \sigma_i^2 \sim IG(2, 0.02), \quad \boldsymbol{\Sigma}_\vartheta \sim IW(6, 10 \times \boldsymbol{I}) \tag{16}$$

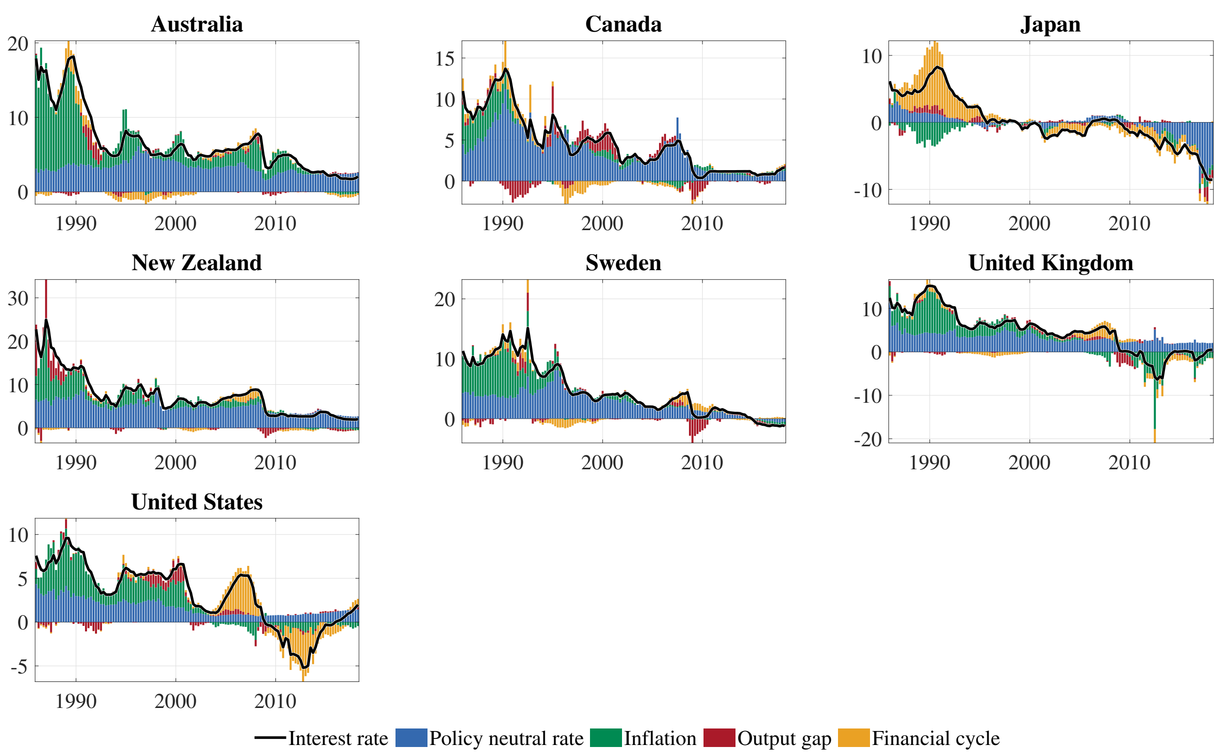
[23] F-test statistics assessing the strength of the instruments, along with p-values related to this exercise, can be found in Table B4 in Appendix B.

Here, IG denotes the inverse-Gamma distribution and IW denotes the inverse-Wishart distribution. Regarding the initial condition, we set $\boldsymbol{\alpha}_1 \sim N(\boldsymbol{\alpha}^0, 2 \times \boldsymbol{I})$, where $\boldsymbol{\alpha}^0$ is a specific vector of the initial condition for each country, based on the previous estimates of Baxa et al. (2013) and Franta et al. (2018). To check the MCMC simulation procedure, we monitor the sample autocorrelations, sample paths, and posterior densities.

5.2 Main Results

The impact of the variables included in the monetary policy reaction function given by Equation (13) is best understood from the historical decomposition of interest rate developments. The historical decomposition is obtained as the size of the variable multiplied by its respective time-varying parameter $\alpha_{l,t}$ for $l = 0, \pi, y, f$ and is presented in Figure 2. The colors represent the contributions of each variable, which sum to the actual value of the interest rate less the impact of the endogeneity correction terms. Therefore, we can also quickly derive the counterfactual interest rates that would exist if the financial cycle had no impact on interest rate setting.

Figure 2: Historical Decompositions of Interest Rates



Note: The historical decomposition is calculated as the product of the variable in the reaction function (Equation (13)) and its respective coefficient $\alpha_{l,t}$ for $l = 0, \pi, y, f$. The contributions of the variables are indicated by different colors and they sum to the actual level of the interest rate less the impact of the endogeneity correction terms.

Source: Author's computations.

Our results show that interest rates were driven mainly by the evolution of the policy-neutral interest rate in all countries. This outcome is not surprising, as our sample covers the period starting in the late 1980s, when the central banks under investigation aimed to stabilize inflation and, in some cases, implemented inflation targeting. Broadly speaking, starting in the late 1990s, inflation rates finally stabilized around the newly established inflation targets and inflation expectations became more anchored than in previous decades. Consequently, the relative contribution of inflation to interest rate setting gradually decreased to zero.[24] On top of that, the central banks' reactions to output gaps appear mainly in recessions and, in the cases of the United States and Canada, in the boom around 2000.

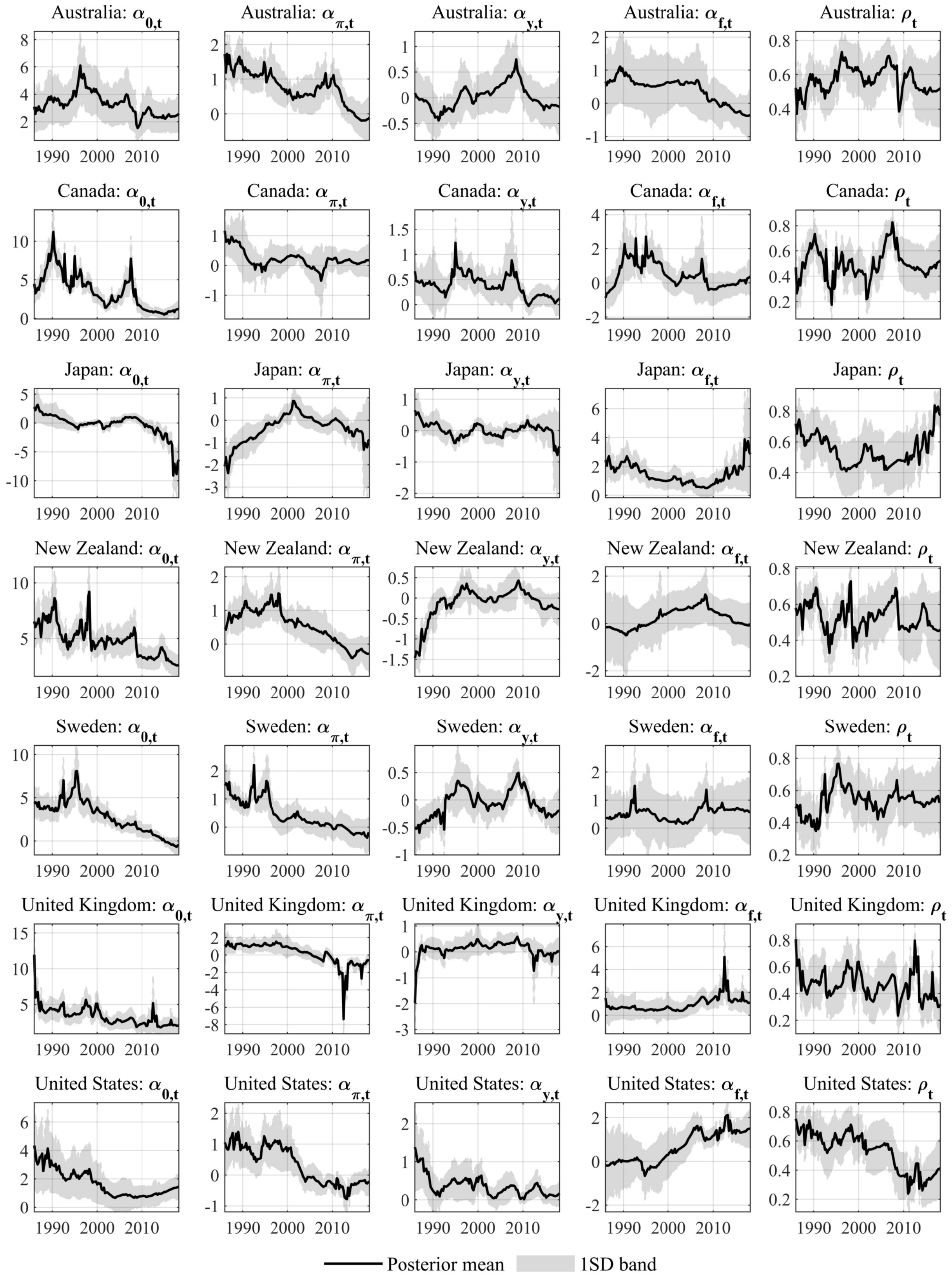
Regarding the impact of the financial cycle on interest rate policy, our results suggest that before 2000, the financial cycle played a dominant role primarily in Japan during the boom and subsequent bust of the Japanese stock market in 1990, which was accompanied by excessive loan growth. The stock market crash was preceded by a sharp increase in the policy rate when the central bank tried to control an already overheated stock market. Sweden and the United Kingdom experienced financial crises in the early 1990s too, but the priority of the central banks in these countries was to reduce the inflation rate, so the impact of the financial cycle on interest rate setting was much smaller than in Japan.[25]

After 2000, and before the financial crisis of 2008, we observe that interest rates reflected financial sector developments in the United States and the United Kingdom. For the United States, this result might be seen to conflict with the statements made by the Federal Reserve Board Chair Alan Greenspan, who frequently expressed skepticism about the potential of leaning against the wind interest rate policies (see Greenspan (2004) and Appendix D.7). However, the increases in the federal funds rate between 2004 and 2006 coincide with continuous increases in housing prices and the credit-to-GDP ratio. Conversely, inflation remained volatile, with several ups and downs, but gradually went up. Therefore, the time-varying parameter model does not reveal any significant reaction to inflation. Qualitatively, our results for the United States are consistent with the findings of Aastveit et al. (2017), who document a significant reaction of the Fed to stock and housing prices between 2000 and 2008. Somewhat similar results were obtained by Hafner and Lauwers (2017) and Filardo et al. (2019), who argue that the Fed's reactions to the financial cycle were not systematic and occurred on a few occasions when the misalignments were perceived as being large.

In the United Kingdom, rising housing prices were mentioned several times in the speeches given by the Bank of England Governor Mervyn King when discussing interest rate policy, although King shared Greenspan's conviction that it is better to solve the consequences of bursting bubbles than to try to act preemptively (King, 2002, 2004). We document similar developments in the reaction function before the 2008 financial crisis in Sweden and to a lesser extent in Australia and New Zealand as well.[26]

[24] More details about the evolution of the monetary policy reaction function under inflation targeting are provided in Baxa et al. (2014). The authors show that the response of interest rates to inflation was particularly strong when central bankers wanted to break a record of high inflation, but not necessarily after adopting inflation-targeting regimes, provided that inflation expectations became anchored to the targets.
[25] We summarize the historical evidence in Appendix D.
[26] We refer the reader to Appendix D for more detailed historical evidence of the central banks' attitudes to financial imbalances, based on speeches, policy reports, and journal articles written by the central bank governors and prominent economists.

Figure 3: Time-Varying Coefficients of the Monetary Policy Reaction Functions



Note: The estimated coefficients are depicted with 68% credible intervals.
Source: Author's computations.

In the last decade, monetary policy conduct was dominated by unconventional monetary policy measures in Japan, the United Kingdom, and the United States. These policies are approximated by shadow interest rates, which attain significantly negative values. The historical decompositions offer interesting insights. After the non-standard measures were implemented, the evolution of interest rate setting was characterized by different aspects. For Japan, the negative shadow rates are explained by movements in the financial cycle at first, followed by a decline in the policy-neutral rate. In the case of the United Kingdom, quantitative easing was motivated by the prospect of deflationary tendencies. By contrast, the Fed's policy could be characterized by the aim to offset deflationary tendencies and the intention to support the credit channel in the US economy after the Great Recession.

The estimated time-varying parameters of the monetary policy reaction functions are presented in Figure 3. The time variation in the policy-neutral rates ($\alpha_{0,t}$) reflects the disinflation trends, and the short-term variation is to some extent caused by drifts in the smoothing parameter ρ_t. The trajectories of $\alpha_{\pi,t}$ and $\alpha_{y,t}$ reflect the central banks' evolving priorities. Thus, the coefficients $\alpha_{\pi,t}$ on expected inflation are higher in the first half of the sample, when the central banks still conducted disinflationary policies, and lower afterward. Finally, the time-varying coefficients $\alpha_{f,t}$, representing the importance of the financial cycle for interest rate decisions, are often insignificant, with wide confidence intervals. The coefficient $\alpha_{f,t}$ is positive and significant in Canada and Japan in the 1990s and in all other countries besides Australia around 2008.

5.3 The Impact of Cycles in Credit, Housing, and Stock Prices on Interest Rates

To disentangle the impacts of the individual components of the financial cycle, we re-estimated the baseline model formulated in Equation (13) with cyclical components of credit, housing, and stock prices rather than one composite financial cycle indicator. The first lag of all the components was used.[27] The results are presented in the form of historical decompositions in Figure 4.[28] Generally, the inclusion of all three cyclical components as separate variables leads to a slightly more pronounced impact of financial cycles on the interest rate, especially in Australia and Canada, which have the lowest coherence across the components of the financial cycle, but the results are broadly consistent with our baseline model.

More specifically, the larger response of Australian monetary policy to house and stock prices before 2008 is consistent with the narrative evidence that the Reserve Bank of Australia gradually started to consider financial stability and the financial cycle in its interest rate policy (see Borio et al. (2019) and Appendix D.1). Interestingly, the Bank of Canada's reaction function implies responses to housing prices as well, despite the broad agreement among its board members that asset prices should be considered only to the extent that they provide information about future output and inflation.[29] In the case of the United Kingdom, the historical decomposition of the interest rate indicates a rather persistent impact of the subcomponents of the financial cycle on interest rates, although the individual components' contributions went against each other in the 1990s. Therefore, the reaction to the aggregate financial cycle presented in Section 5.2 appears to have been small in the 1990s. Also, our results confirm the historical evidence that before 2008, the Bank of England considered inflation of housing prices in its monetary policy decisions, probably as an indication of

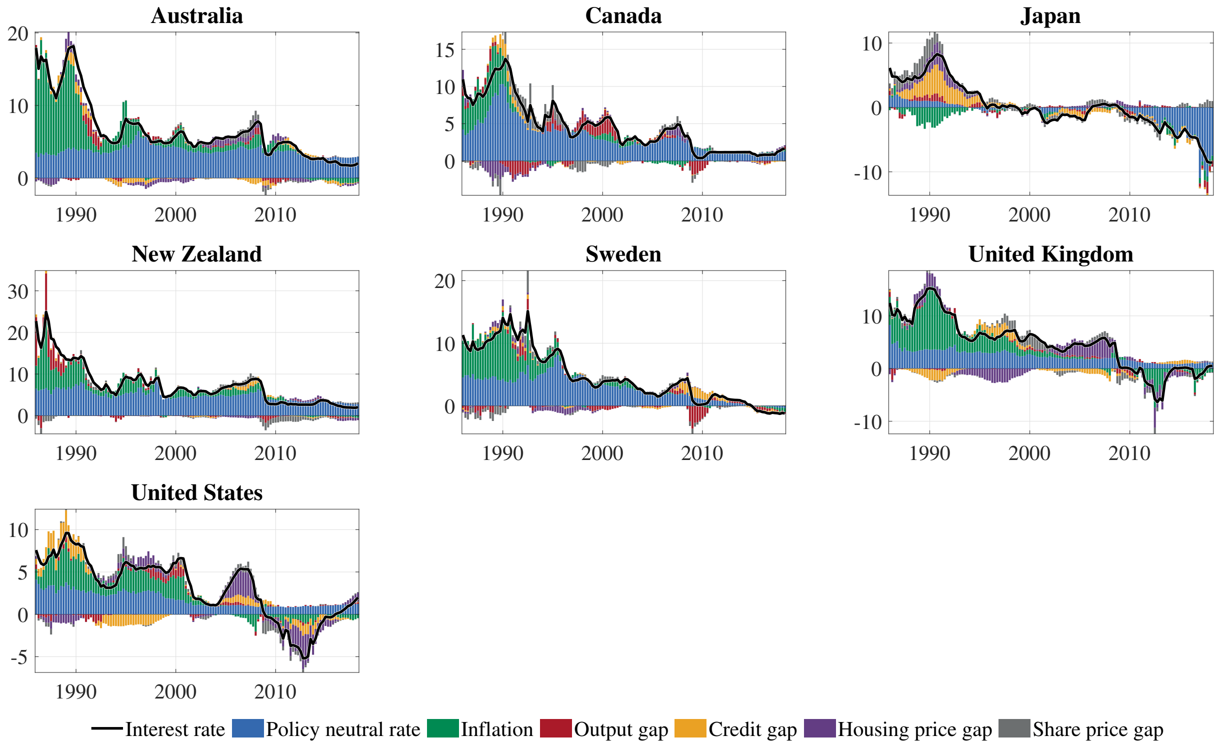
[27] Following Filardo et al. (2019), we also include credit and housing prices at time t and only stock prices at time $t-1$. However, the differences in the historical decompositions between these two alternative specifications were minor, with the reaction of the Fed's and BoE's monetary policies being somewhat larger to credit and somewhat smaller to stock prices. These results are presented in Figure C17 in Appendix C.

[28] Estimates of the individual time-varying coefficients can be found in Appendix C in Figure C16.

[29] See Appendix D.2 for more details.

inflation pressures in the economy. By contrast, the Fed's interest rate decisions reflected all three components of the financial cycle.

Figure 4: Historical Decompositions of Interest Rates with Subcomponents of the Financial Cycle



Note: All the subcomponents of the financial cycle are included at $t-1$. The historical decomposition is calculated as the product of the variable in the reaction function (augmented Equation (13)) and its respective coefficient $\alpha_{l,t}$ for $l = 0, \pi, y, cr, pH, pS$. The contributions of the variables are indicated by different colors and they sum to the actual level of the interest rate less the impact of the endogeneity correction terms.
Source: Author's computations.

5.4 Monetary Policy and the Financial Cycle before the Great Recession: Assessment

The estimates of the monetary policy reaction function suggest that almost all the central banks in our sample responded to financial imbalances before 2008 above and beyond their reactions to inflation or the output gap. The only exception was the Bank of Japan, in line with the different pattern of the financial cycle in Japan, which experienced no large booms in credit volumes and housing prices in the 2000s. As our historical decomposition shows, these responses were quantitatively large, ranging from 2 to 5.5 percentage points, and accounted for about 50% of the variation in interest rates.[30]

[30] The largest responses appear in the United States and the United Kingdom. Quantitatively, the results depend on whether the shadow interest rate is used for the calculation or not. When the conventional policy rate is used, the policy neutral rate remains close to 2% and does not decrease as much as it does when the shadow rate is used. Consequently, the contribution of the financial cycle to the interest rate hikes of 2004–2006 is smaller and the peak interest rate response to financial cycles is 3%. These results are available upon request.

Despite the similarities in the interest rate responses, resembling leaning against the wind, the post-2008 developments differed markedly. We present these outcomes in Table 2, along with the sizes of the interest rate responses to the financial cycle and its constituent components. Table 2 also reports whether the countries in our sample implemented macroprudential measures to address financial imbalances already before the Great Recession.[31]

First, all the countries experienced large synchronized falls in real share prices, with relatively slow recoveries. In Australia, Canada, and the United Kingdom, real share prices did not recover fully until the end of our sample (2019Q2). Real housing prices declined too, although significantly less than real share prices, and the developments were rather diverse across countries. Sweden, Canada, and Australia experienced declines of 5.5–7.5%, with prices decreasing for about a year. The recoveries took longer, but housing prices recovered after two years. On the contrary, real housing prices fell by 27.8% in the United States and 20.1% in the United Kingdom. Prices in real terms were decreasing for five years and gradually recovered over the next five years.

A similar pattern appeared in real credit, with mild and short-lived decreases in Canada and Sweden but substantial declines and slow recoveries in the United States and the United Kingdom. New Zealand is an intermediate case, having experienced declines in real credit and housing prices somewhere in between the less and more affected countries.

The cross-country differences in the magnitudes and durations of the declines match the differences in the countries' approaches to financial and macroprudential regulation. Although macroprudential policies were widely implemented after 2008, some countries experimented with various instruments before then (as the last column in Table 2 shows). In particular, Canada consistently applied restrictions on mortgage loan-to-value ratios, despite several loosenings in the 2000s. The same holds for Sweden, where the cap on the loan-to-value ratio was set at 75% in 2004 and not relaxed afterward. Australia had capital requirements depending on mortgage loan-to-value ratios since 1998 and adopted special measures for systemically important financial institutions in 2000–2001. Nevertheless, Lim et al. (2011) consider Australia to be a country with little or no intensity of use of macroprudential measures, perhaps due to an absence of prudential regulations on the borrower side. New Zealand introduced limits on the debt service-to-income ratio in 2007. In contrast, both the United States and the United Kingdom continued their deregulation efforts until the onset of the financial crisis and experienced the largest declines and slowest recoveries in our sample.

Furthermore, the differences in macroprudential policy also correspond to the outcomes of the 2008 financial crisis in countries with similar interest rate responses to financial imbalances before 2008. Four countries (Australia, Canada, New Zealand, and Sweden) increased the interest rate by 2–3%,[32] but they differed in their macroprudential policies. However, the declines in real credit and housing prices were three to five times smaller in Sweden and Canada than in New Zealand, and smaller than in Australia, too.

[31] We rely on the IMF Macroprudential Database and the country reports available at https://www.elibrary-areaer.imf.org/Macroprudential/Pages/Home.aspx, and on Lim et al. (2011). Note that the IMF Macroprudential Database does not mention the deregulation of the US financial sector due to the Gramm-Leach-Bliley Act, which lifted the barriers between commercial and investment banking and was passed without regulatory provisions. The exemption of investment banks from the leverage ratio rules in 2004 does not appear in the IMF database either.
[32] This interest rate response refers to column 3 "Sum of Impacts of Constituent Components" in Table 2.

Table 2: Monetary and Macroprudential Policies before the Great Recession and their Outcomes

Country	Interest Rate Decomposition		Real Share Prices			Real Credit			Real Housing Prices			Macroprudential Policy before 2008
				Duration			Duration			Duration		
	Impact of Aggregate Financial Cycle	Sum of Impacts of Constituent Components	Decline	Peak to Trough	Peak to Peak	Decline	Peak to Trough	Peak to Peak	Decline	Peak to Trough	Peak to Peak	
Australia	0.78%	1.95%	-49.98%	5	(-)**	-4.59%	7	10	-7.39%	4	6*	Limited: Capital (1998), SIFI (2001)
Canada	-0.01%	2.60%	-38.41%	6	(-)**	-1.66%	2	4	-6.06%	4	7	Active: LTV, LoanR (since 1990s)
Japan	-0.37%	0.59%	-54.91%	18	41	-1.97%	9	36	-7.15%	4	29	Limited: Capital (2007)
New Zealand	2.62%	2.29%	-46.37%	7	43	-7.25%	9	25	-15.00%	6	26	Limited: DSTI (2007)
Sweden	2.65%	3.03%	-54.37%	7	31	-1.19%	2	3	-5.52%	5	9	Active: LTV (2004)
United Kingdom	3.80%	4.05%	-40.80%	7	(-)**	-10.73%	23	(-)**	-20.11%	22	40	None
United States	5.36%	5.04%	-49.52%	5	37	-8.99%	16	34	-27.84%	21	(-)**	None

Note: * Australia's 2009 recovery in real housing prices was short-lived and was replaced in 2010 with another drop below the 2008 levels. Real HPIs finally recovered in 2013, 20 quarters after the peak in 2008Q1.

** (-) implies that the value of real share prices or real credit did not reach the 2008 peak until the end of our sample (2019Q2).

Interest rate decomposition = peaks of the effects of financial factors on policy rates from the historical decompositions in a 5-year window before the Great Recession (Figures 2 and 4).

Peak to trough = quarters from the peak to the trough in asset prices and real credit.

Peak to peak = quarters from the peak to the next quarter in which asset prices or real credit reached the values of the previous peak and sustained higher values for at least two consecutive quarters.

Macroprudential policy: Capital = capital requirements for banks; SIFI = measures taken to mitigate risks arising from global and domestic systemically important financial institutions; LTV = restrictions on loan-to-value ratios; LoanR = loan restrictions conditional on loan characteristics; DSTI = limits on debt-service-to-income or loan-to-income ratios. For more information, refer to IMF Integrated Macroprudential Policy database.

The classification None – Limited – Active refers to the authors' assessment of the intensity of use of macroprudential measures provided by Lim et al. (2011) and of the list of measures adopted in the IMF Integrated Macroprudential Policy database.

This discussion of monetary policy responses to the financial cycle and macroprudential policies suggests that the financial crisis of 2008 had less of an impact on credit and real housing prices in countries where the interest rate responses to financial cycles were complementary to existing macroprudential measures. Conversely, in the absence of attempts to regulate risk-taking on financial markets, even relatively significant interest rate increases preceding the 2008 crisis were followed by large falls in housing prices and longer durations of recoveries. Moreover, our results suggest that the existing evidence pointing to limited effects of monetary policy on asset prices in the United States (Galí and Gambetti, 2015; Paul, 2020) should not be generalized to other countries and that the appropriate policy response needs to be judged in the context of other complementary policies.[33]

6. Robustness Checks

To check the robustness of our results and investigate the central banks' reactions to financial cycles more deeply, we perform the following exercises. First, we inspect how the estimates of the financial cycle coefficients vary with different timing of the financial cycle in the reaction functions. Second, we address possible backward-looking elements of monetary policy conduct. Third, we add a proxy for bank-related stress to the reaction function, along with the financial cycle variable, to see whether or not the financial cycle matters more to central banks than financial instability. Finally, we employ pseudo real-time estimates of the output gaps and financial cycles in the reaction function.[34]

6.1 Effects of Alternative Timings, Backward-Looking Behavior, and Financial Stress

In our baseline setting, we let the financial cycle enter the model in the first lag, $t-1$. In such a setting, the reaction of the central bank is supposed to be reactive. This choice is motivated by the fact that policy actions related to financial issues are likely to be implemented based on observed data rather than future outlooks. Additionally, the transmission mechanism in terms of the financial system is fast compared with the propagation mechanism to inflation. In our first sensitivity check, we employ the current value t and the first lead $t+1$ of the financial cycle to investigate whether any of the central banks aimed to react preemptively to financial sector developments.

Therefore, we re-estimate the model given by Equation (13), that is,

$$i_t = (1-\rho_t)(\alpha_{0,t} + \alpha_{\pi,t}\mathbb{E}_t\pi_{t+2} + \alpha_{y,t}\tilde{y}_t + \alpha_{f,t}\mathbb{E}_t f_{t+m}) + \rho_t i_{t-1} + \beta_\pi \hat{\imath}^\sigma_{\pi,t} + \beta_y \hat{\imath}^\sigma_{y,t} + \beta_f \hat{\imath}^\sigma_{f,t} + \varepsilon_{i,t} \quad (17)$$

[33] Several reasons for the limited response of asset prices to monetary policy have been highlighted in the literature. Galí and Gambetti (2015) explains the small responses using the theory of rational bubbles. Filardo et al. (2019) stress the reaction channel, where the response of asset prices depends on market participants' policy expectations. If market participants believe that the central bank will stabilize financial imbalances, they adjust their behavior and do not invest in overvalued assets for speculation or value storage. Thus, asset prices should stabilize or even decrease. However, in line with the pre-crisis consensus (summarized in Smets, 2014 and Mishkin, 2017), our results suggest that the credibility channel of monetary policy transmission to asset prices appears to be rather weak when monetary policy is not complemented by macroprudential policy and a sound regulatory framework.

[34] Besides that, we complemented our analysis with standard GMM estimates of the time-invariant monetary policy reaction functions. The estimation procedure and results are summarized in Section E.5 in Appendix E. As expected, the GMM estimates overestimate the values of the smoothing parameters, which are around 0.9 in all countries. Consequently, the values of the other coefficients are not directly comparable with their time-varying counterparts. Regarding the impact of the financial cycle, the coefficients are usually positive and significant, except for the United Kingdom and New Zealand with negative signs. Nevertheless, it is not very realistic to assume a time-invariant response of the central banks in our sample to the financial cycle, given the prevailing consensus that the financial conditions should only be considered when there is information about future inflation or output gaps.

where we set m to 0 and 1. As with future inflation, the central bank's expectation for the financial cycle is proxied by the future observed value. We compare the estimates with the baseline results (that is, for $m = -1$).[35] The contributions of the financial cycle to the historical decomposition of the interest rate for the models with financial cycles at t and at $t+1$ are presented in Figure 5.

As expected, the impact of the financial cycle f_t and f_{t+1} is lower in comparison to our benchmark model with f_{t-1}. In Australia, Canada, and New Zealand, the financial cycle's impact on the interest rate virtually disappears. However, the evidence from Sweden, the United Kingdom, and the United States still supports the view that monetary policy reacted to the financial cycle before the financial crisis of 2008. These results confirm the view that the central banks in our sample adjusted interest rates mainly to future inflation rather than trying to lean against the wind consistently on the financial markets. Our results are also consistent with the hypothesis presented by Filardo et al. (2019) that the pre-2008 monetary policies were not considered credible and committed to preventing asset price bubbles. Thus, they did not affect the expectations of market participants.

In our second robustness check, we consider possible *backward-looking aspects* of monetary policy conduct as discussed by Neuenkirch and Tillmann (2014) and Paloviita et al. (2021). The authors stress that there are at least three potential reasons why past inflation developments may play a role. First, if inflation has been off target for a long time, policymakers could find a need for faster adjustments to prices to achieve the inflation target. Second, if inflation has persistently deviated from the target, policymakers may react more aggressively to maintain credibility and commitment to the inflation target. Third, forward guidance, which has been active primarily since the Great Recession, could be represented by the backward-looking element in the monetary policy reaction function.

Following Neuenkirch and Tillmann (2014), we construct a backward-looking inflation gap that measures the magnitude of the deviation of inflation from the target in recent quarters.[36] This measure could also be understood as a "credibility loss term" (CL_t) and is modeled as follows

$$CL_t = (\bar{\pi}_{t-1,t-4} - \pi_t^*)|\bar{\pi}_{t-1,t-4} - \pi_t^*| \tag{18}$$

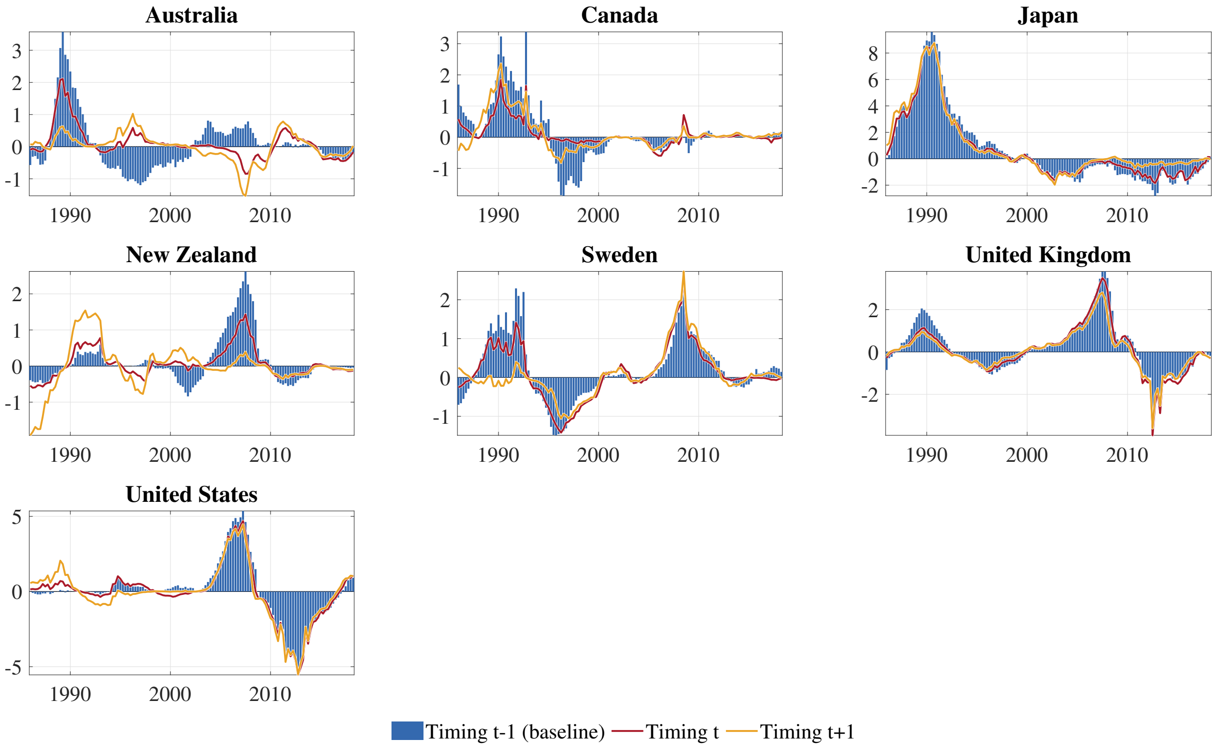
where $\bar{\pi}_{t-1,t-4}$ is the average past inflation between periods $t-1$ and $t-4$, and π_t^* represents the inflation target. The credibility loss term is constructed symmetrically on either side of the target. However, it is non-linear, as it penalizes large deviations from the target more than small ones (captured by the absolute term). We amend the original monetary policy reaction function by including the CL_t term. The results of this robustness analysis are depicted in Figure 6. Here, we observe that, on the one hand, our main result – that especially the BoE and the Fed used interest rates to lean against the wind – holds at least implicitly. On the other hand, including the credibility loss term somewhat affects the resulting trajectory of the $\alpha_{f,t}$ coefficient for Sweden.

Third, we extended the baseline model to account for *an index of financial stress* to determine whether our time-varying parameter $\alpha_{f,t}$ reflects the financial cycle but not financial instability as approximated by a stress index or high-frequency fluctuations in markets that go beyond the financial cycle.

[35] We also add an endogeneity correction term for the financial cycle compared with the baseline specification of the TVP model.

[36] As the inflation-targeting frameworks in the countries inspected were adopted in different years, this analysis is based on different sample lengths compared with the baseline estimations. The inflation target data were taken from the central banks' official websites. In the case of the United States, we use the estimates of Leigh (2008) to prolong the data sample by using implicit inflation targets for the 1990s and early 2000s.

Figure 5: Different Timing of Financial Cycles in the Policy Reaction Function



Note: Bars (representing the baseline) and lines (depicting the robustness estimations) display the contributions of the financial cycle to the historical decomposition of the interest rate, that is, the product $\alpha_{f,t} \times \mathbb{E}_t f_{t+m}$, and are presented in percentage points.
Source: Author's computations.

There are several research papers that construct various financial stress indices, such as Cardarelli et al. (2011), Duca and Peltonen (2013), or Baxa et al. (2013). The common pattern among these studies is that they try to introduce financial stress measures that capture various financial market phenomena. The ambition here is to construct not a comprehensive financial stress index but rather a simple index that accounts for different movements on financial markets other than those characterized by the financial cycle as measured in this work.

We follow Duca and Peltonen (2013) in the design of the financial stress index.[37] We account for the following set of components of financial stress in an economy: (a) the spread – the difference between short-term money market rates and long-term interest rates on government bonds maturing in ten years, (b) the time-varying volatility of changes in the NEER from the GARCH(1,1) model, and (c) the time-varying volatility of changes in the main stock market index[38] from the GARCH(1,1) model. Such a setting allows us to account for the main segments of financial markets: the banking, foreign exchange, and securities markets. Each component $j = 1, 2, 3$ of the index in each quarter is transformed into a number in the range of 0 to 3 based on the specific quartile of the distribution to which the observation at quarter t belongs. The financial stress index (FSI_t) is constructed as the

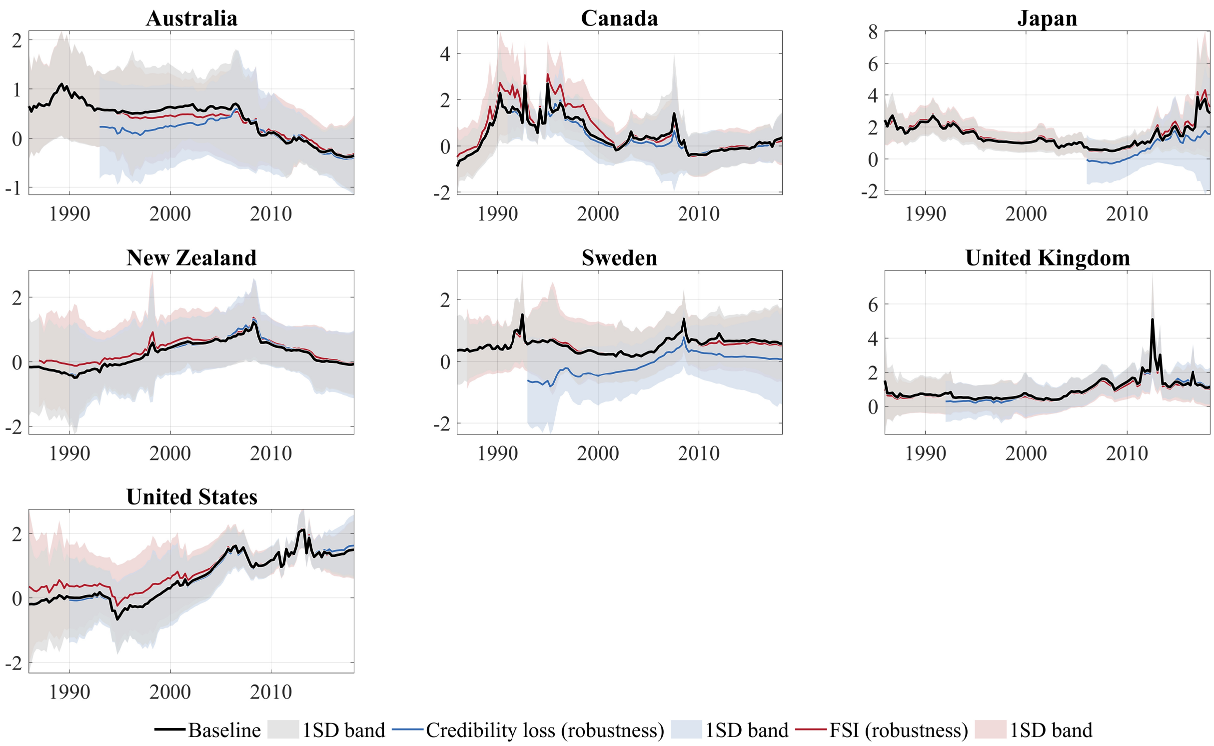
[37] We use a slightly simplistic approach consisting of three variables instead of the five examined by Duca and Peltonen (2013).
[38] We choose the following indices: Australia – XAO, Canada – S&P/TSX Composite, Japan – Nikkei 225, New Zealand – S&P/NZX All, Sweden – OMX Stockholm 30, United Kingdom – FTSE 100, United States – S&P 500.

simple average of the transformed variables as follows

$$FSI_t = \frac{\sum_{j=1}^{3} q_{j,t}(ind_{j,t})}{3} \tag{19}$$

where $q_{j,t}$ is the specific quartile of the distribution and $ind_{j,t}$ is the respective component of the financial stress index. The standardization method based on quartiles is more robust than other standard methods when the number of components is low (Hollo et al., 2012). The resulting financial stress index enters the reaction function in the same manner as the credibility loss term. The financial stress index is included in lag $t-1$ and is not subject to interest rate smoothing.[39]

Figure 6: Time-Varying Coefficients of the Monetary Policy Reaction Functions with the Credibility Loss Term and the Financial Stress Index



Note: The estimated coefficients are depicted with 68% credible intervals.
Source: Author's computations.

The results are summarized in Figure 6 as well. We can observe that our benchmark results remain almost identical. The only clearly visible (but still not significant) differences with respect to the baseline estimation can be found in the case of Canada, New Zealand, and the United States at the beginning of the samples. Most importantly, the coefficient $\alpha_{f,t}$ attains the same values around the year 2008. Therefore, we can conclude that our empirical methodology identified the financial cycle's impact on interest rate setting and not the impact of financial stress, including high-frequency fluctuations on financial markets.[40]

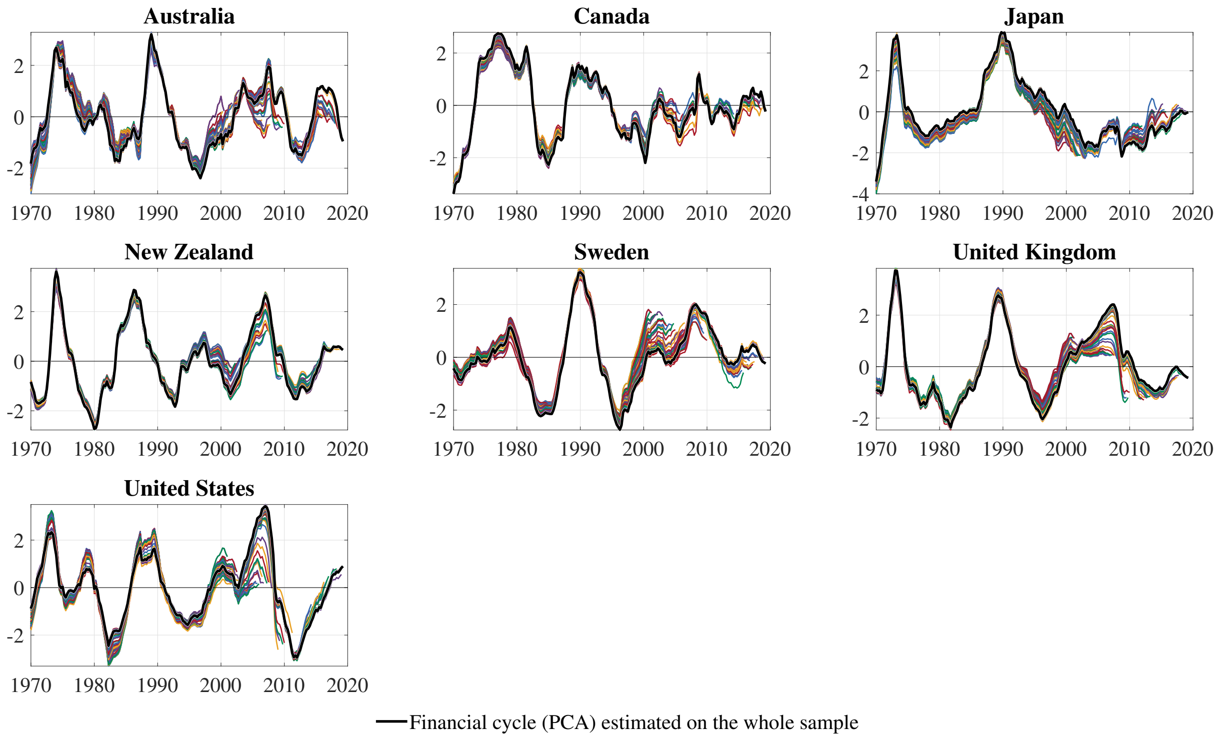
[39] We also performed exercises with different timing of the financial stress index in the reaction function. The results remain robust.

[40] On top of the exercises presented here, we performed an additional estimation employing the deviations of inflation from the target instead of inflation itself. Moreover, in the case of the United States, we explored the

6.2 Monetary Policy and the Financial Cycle in Real-Time

There is a voluminous literature pointing to the importance of data uncertainty in real-time policy decisions. It dates to Orphanides (2001), who showed that estimated policy reaction functions based on ex-post data provide misleading descriptions of policy, as they are based on information that is not available to central banks in real time.[41] We re-estimate the monetary policy reaction functions with pseudo real-time estimates of financial cycles and output gaps obtained recursively from our multivariate structural time series models to tackle this issue. For the United States, we also use the Greenbook forecasts of inflation and the output gap in a separate estimation, so all the variables used in the TVP regression are precisely those which were known or could have been known in real time.[42]

Figure 7: Recursive Estimates of Financial Cycles



Note: Quarterly data. The financial cycle is the first principle component of the three underlying indicators. The recursive estimates of the financial cycle start with the 1970q1–2000q1 vintage.
Source: Author's computations.

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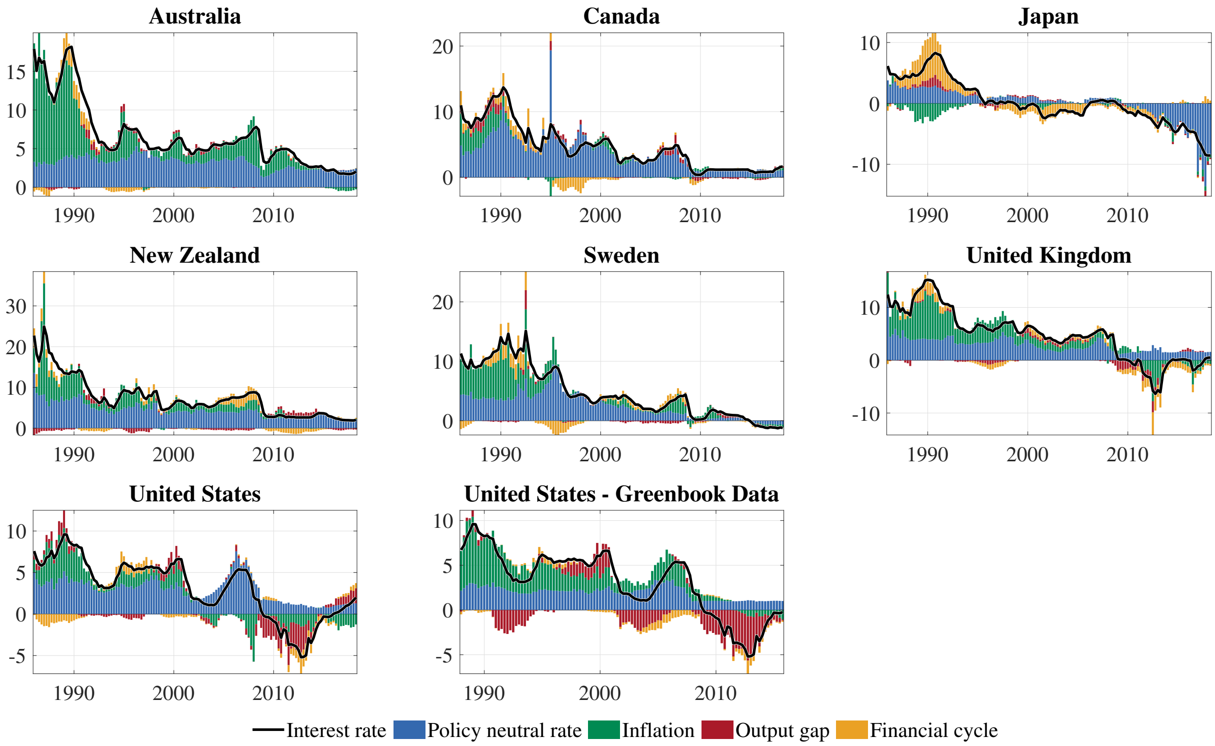
sensitivity of the results to replacing CPI inflation in the reaction function by alternative indicators, including PCE inflation, PCE core inflation, CPI inflation at $t+4$ rather than $t+2$, and the Greenbook inflation forecasts. The results remain robust and are available upon request.

[41] Note that Orphanides' results were challenged by Boivin (2006), who showed that when time-varying parameters are used, the difference in the estimates of the US monetary policy reaction function decreases with either ex-post or real-time data. Therefore, real-time data lead to similar implications about the changes in US monetary policy documented by Clarida et al. (2000) with the help of fixed-coefficients and ex-post data.

[42] The exercise presented here relies on the same estimation strategy as shown in the previous subsection. We employ the multivariate STSM with the same assumptions about the prior distributions as made during the Bayesian estimation. The simulations are purely mechanical and do not rely on any other expert measures. Thus, the only difference lies in the length of the data samples used for the estimations.

Our recursive estimations start with the 1970q1–2000q1 sample. In each subsequent estimation, we prolong the initial data sample by one quarter to obtain 86 recursive estimates for each country. Figure 7 compares the recursive estimates of the financial cycles with their ex-post counterparts.

Figure 8: Historical Decompositions of Interest Rates Based on Pseudo Real-Time Estimates



Note: The historical decomposition is calculated as the product of the variable in the reaction function (Equation (13)) and its respective coefficient $\alpha_{l,t}$ for $l = 0, \pi, y, f$. The contributions of the variables are indicated by different colors and they sum to the actual level of the interest rate less the impact of the endogeneity correction terms. The recursive estimates of the financial cycle start with the 1970q1–2000q1 vintage.
Source: Author's computations.

The results reveal different findings across countries. The recursive estimates of the financial cycles seem to be quite consistent with the ex-post data only in Canada, Japan, and New Zealand. In Sweden, the increase in real housing prices after 2000 helps the model indicate an overheating well ahead of 2008. On the other hand, we document under-estimation of the boom in the financial cycle before the global financial crisis of 2008 in the United States, the United Kingdom, and Australia. There, the structural model was not able to signal the incoming overheating of the real estate market and the unsustainability of the credit boom that stands out with the ex-post data. Such findings support the conclusion of Rivas and Perez-Quiros (2015), who find that the credit boom related to the financial crisis of 2008 was challenging to detect in real time. Nevertheless, since 2008, the real-time and the ex-post estimates of the financial cycles are more consistent in most countries of our sample.

The endpoints of the vintages of our recursive estimates of the financial cycles and output gaps form the time series which we include in the reaction function Equation (13).[43] The historical decompositions of interest rates with our recursive estimates of the output gaps and financial cycles are presented in Figure 8, and they mirror the ability of the STSM model to track financial cycles in real time. Particularly in the United States, monetary policy does not appear to be driven by financial cycles before the crisis of 2008. Instead, the mid-2000s increases in interest rates are attributed to a rise in the policy-neutral rate or expected inflation in the case of the Greenbook forecasts.[44] After 2008, the response to the output gap drives the dynamics of the shadow rate.

However, in New Zealand and to a lesser extent in Sweden and the United Kingdom, even our pseudo real-time estimates indicate the boom phases of the financial cycles before 2008. Consequently, in these cases, the pseudo real-time data lead to similar conclusions as the ex-post data, and the central banks' responses to financial cycles are corroborated, although the Bank of England's response to the financial cycle decreased markedly in comparison to the ex-post data. Interestingly, the historical evidence from speeches and reports supports the conclusion that these central banks considered variables underlying the financial cycle in their interest rate decisions, along with concerns about inflation. Therefore, it seems that when the central banks were able to monitor the financial cycle correctly in real time, they reacted to it.

7. Conclusions

In this paper, we used the multivariate structural time series model to estimate the financial cycles in several countries with monetary policies characterized by inflation targeting: Australia, Canada, Japan, New Zealand, Sweden, the United Kingdom, and the United States. We then estimated the monetary policy reaction functions with time-varying parameters extended for the financial cycles. We aimed to explore the extent to which the central banks appear to have already experimented with leaning against the wind in the past, both with ex-post data and pseudo real-time data.

Our estimates of the financial cycles obtained using the multivariate structural time series model have similar properties to those obtained by other methods. They are longer than the real GDP cycles, and driven mainly by credit expansions and housing prices. In contrast, share prices exhibit more volatility and are less synchronized with other variables. Also, the estimated financial cycles reflect the historical evidence of financial booms and busts quite well, and our estimates for the United States are in line with the other literature. Therefore, we concluded that our estimated financial cycles are reasonable approximations and can be used to analyze past monetary policies.

We then set up time-varying monetary policy reaction functions extended for financial cycles and accounting for potential endogeneity between the policy rate and the independent variables by including endogeneity correction terms. We derived historical decompositions and variance decompositions of interest rates from the estimated parameters to show which variables were the most important drivers for policy decisions. We showed that from the late 1990s on, interest rates were driven mainly by the evolution of the policy-neutral rate, as the inflation rate had been largely stabilized and brought close to the inflation targets.

However, we identified periods in which interest rate decisions bear a resemblance to "leaning against the wind" of asset price and credit booms. In particular, we showed that the central banks

[43] The resulting time series are depicted in Figure C18 in Appendix C.

[44] The data from the Greenbooks are presented in Figure C19 in Appendix C. As the Greenbooks only provide data up to 2015, the data sample is shorter than the sample used in the pseudo real-time data estimation.

increased interest rates beyond their responses to expected inflation and output gap imbalances in response to the financial booms of the early 1990s. Similarly, all the central banks in our sample except the Bank of Japan seemingly aimed to suppress the financial bubble before the global financial crisis of 2008. Quantitatively, the responses to the financial cycle explain more than 50% of interest rates before 2008 in our baseline model with ex-post data.

The result that the central banks appear to have already responded to asset price and credit booms by raising interest rates was confirmed by several sensitivity checks, in which we controlled for financial instability, replaced the interest rate with the shadow interest rate, and considered alternative timings of the financial cycles in the reaction functions.

Finally, we estimated the financial cycles recursively to obtain a pseudo real-time assessment of the financial cycles. Several important differences stood out. First, we confirmed that there is considerable uncertainty in assessing the stages of financial cycles and financial imbalances in general in real time. Especially in the United States, the cyclical nature of the 2000s asset price boom, fueled by a credit expansion, was hard to identify in real time. As the Greenbook data show, the real-time assessment of the output gap was also different. Consequently, the reaction function re-estimated on the samples of pseudo real-time data detects monetary policy reactions to financial cycles only when the central banks recognized financial imbalances in a timely fashion, such as in Sweden, New Zealand, and, to a lesser extent, the United Kingdom. When the cycles were not recognized, the interest rate increases were attributed to expected inflation or, in the case of the United States, to the output gap and the policy-neutral rate.

Our results have several implications for the debate on whether central banks should use interest rates to "lean against the wind" of asset price and credit booms and whether macroprudential policies should be used to prevent financial imbalances, with interest rate policy focused mainly on inflation and output stabilization. We show that interest rate policy has been used in the past. These findings are supported by mentions of developments in credit, housing, and asset prices in monetary policy decisions and the speeches of several central bank governors. Consequently, the use of interest rate policy in the context of financial imbalances should not be considered a novelty, particularly in countries other than the United States. Furthermore, the outcomes of the 2008 crisis differed across countries quite significantly. While all the countries in our sample experienced falls in real share prices, the developments in real credit and housing prices were diverse. When comparing Australia, Canada, New Zealand, and Sweden, which showed quantitatively similar responses to the constituent components of financial cycles, the impact of the crisis was smaller and less persistent in Sweden and Canada with their active use of macroprudential measures since the 1990s and early 2000s.

However, it remains unclear to what extent macroprudential policy can serve to prevent the emergence of excessive financial imbalances, especially when conducted independently of interest rate policy, and whether prudential measures should be adjusted over the cycle. Therefore, we conclude that central banks should focus on having a credible overall mix of macroprudential and interest rate policies, rather than choosing between the two, as using one of them exclusively might not be enough to prevent excessive financial imbalances in the future.

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Appendix A: Multivariate Structural Time Series Model (STSM)

The estimation procedure employed in this paper closely follows that of Rünstler and Vlekke (2018). The multivariate structural time series model (STSM) is given by

$$\boldsymbol{y}_t = \boldsymbol{\tau}_t + \tilde{\boldsymbol{c}}_t + \boldsymbol{\varepsilon}_t \tag{A1}$$

where $\boldsymbol{y}_t$ is an $N \times 1$ vector of observed variables, $\boldsymbol{\tau}_t$ is an $N \times 1$ vector of stochastic trend components, $\tilde{\boldsymbol{c}}_t$ is an $N \times 1$ vector of cyclical components, and $\boldsymbol{\varepsilon}_t$ is an $N \times 1$ vector of irregular components, such that $\boldsymbol{\varepsilon}_t \sim NID(\mathbf{0}, \mathbf{\Sigma}_\varepsilon)$, where $\mathbf{\Sigma}_\varepsilon$ is an $N \times N$ non-negative definite covariance matrix. The stochastic component, $\boldsymbol{\tau}_t$, of the model specified in Equation (A1) is modeled as a multivariate local linear trend model with time-varying drift, $\boldsymbol{\beta}_t$, following a random walk, that is,

$$\boldsymbol{\tau}_t = \boldsymbol{\beta}_{t-1} + \boldsymbol{\tau}_{t-1} + \boldsymbol{\xi}_t, \tag{A2}$$

$$\boldsymbol{\beta}_t = \boldsymbol{\beta}_{t-1} + \boldsymbol{\zeta}_t \tag{A3}$$

with $\boldsymbol{\beta}_t$ being an $N \times 1$ vector and $\boldsymbol{\xi}_t$ and $\boldsymbol{\zeta}_t$ being $N \times 1$ vectors of irregular components, such that $\boldsymbol{\xi}_t \sim NID(\mathbf{0}, \mathbf{\Sigma}_\xi)$ and $\boldsymbol{\zeta}_t \sim NID(\mathbf{0}, \mathbf{\Sigma}_\zeta)$, where $\mathbf{\Sigma}_\xi$ and $\mathbf{\Sigma}_\zeta$ are $N \times N$ positive semi-definite covariance matrices with $\mathbb{E}_t(\boldsymbol{\xi}_t \boldsymbol{\zeta}'_{t-s}) = 0$ for $\forall s$.

The cyclical component of the model, $\tilde{\boldsymbol{c}}_t$, is defined as

$$\tilde{\boldsymbol{c}}_t = \left[\boldsymbol{A}, \boldsymbol{A}^*\right] \begin{bmatrix} \boldsymbol{c}_t \\ \boldsymbol{c}^*_t \end{bmatrix} \tag{A4}$$

where $\boldsymbol{A}$ and $\boldsymbol{A}^*$ are arbitrary $N \times N$ matrices. As discussed by Rünstler and Vlekke (2018), such approach allows for the introduction of phase shifts between the cyclical components and therefore for cross variances among the cycles. The elements of vectors $\boldsymbol{c}_t = [c_{1,t}, \dots, c_{N,t}]'$ and $\boldsymbol{c}^*_t = [c^*_{1,t}, \dots, c^*_{N,t}]'$ are modeled as stochastic cycles

$$(1 - \phi_i L)\left(\boldsymbol{I}_2 - \rho_i \begin{bmatrix} \cos\lambda_i & \sin\lambda_i \\ -\sin\lambda_i & \cos\lambda_i \end{bmatrix} L\right) \begin{bmatrix} c_{i,t} \\ c^*_{i,t} \end{bmatrix} = \begin{bmatrix} \kappa_{i,t} \\ \kappa^*_{i,t} \end{bmatrix} \tag{A5}$$

for $i = 1, \dots, N$, where $0 < \rho_i < 1$ and $0 < \phi_i < 1$ are the parameters and $0 < \lambda_i < \pi$ are the frequencies of the cycles. $\boldsymbol{I}_2$ is the 2×2 identity matrix and L is the lag operator. The inclusion of the autoregressive root, ϕ_i, is motivated by accounting for higher persistence of financial variables. The vector of irregular components $\tilde{\boldsymbol{\kappa}}_{i,t} = [\kappa_{i,t}, \kappa^*_{i,t}]' \sim NID(\mathbf{0}, \mathbf{\Sigma}_\kappa)$ with $\mathbf{\Sigma}_\kappa = \sigma^2_{i,\kappa}\boldsymbol{I}_2$, that is,

$$\begin{bmatrix} \kappa_{i,t} \\ \kappa^*_{i,t} \end{bmatrix} \sim NID\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}; \begin{bmatrix} \sigma^2_{i,\kappa} & 0 \\ 0 & \sigma^2_{i,\kappa} \end{bmatrix}\right). \tag{A6}$$

Innovations $\boldsymbol{\kappa}_t = [\kappa_{1,t}, \dots, \kappa_{N,t}]'$ and $\boldsymbol{\kappa}^*_t = [\kappa^*_{1,t}, \dots, \kappa^*_{N,t}]'$ are assumed to be uncorrelated, that is, $\mathbb{E}_t(\boldsymbol{\kappa}_t \boldsymbol{\kappa}^{*'}_t) = 0$.

We include GDP (capturing economic slack), credit, house prices, and share prices in the analysis. The variables are ordered as follows: GDP, credit, house prices, share prices. The vector of cyclical components, $\tilde{\boldsymbol{c}}_t = [\tilde{c}_{1,t}, \tilde{c}_{2,t}, \tilde{c}_{3,t}, \tilde{c}_{4,t}]'$, is then given by

$$\begin{bmatrix} \tilde{c}_{1,t} \\ \tilde{c}_{2,t} \\ \tilde{c}_{3,t} \\ \tilde{c}_{4,t} \end{bmatrix} = \begin{bmatrix} a_{11}c_{1,t} + a_{12}c_{2,t} + a_{13}c_{3,t} + a_{14}c_{4,t} + 0 + a^*_{12}c^*_{2,t} + a^*_{13}c^*_{3,t} + a^*_{14}c^*_{4,t} \\ a_{21}c_{1,t} + a_{22}c_{2,t} + a_{23}c_{3,t} + a_{24}c_{4,t} + a^*_{21}c^*_{1,t} + 0 + a^*_{23}c^*_{3,t} + a^*_{24}c^*_{4,t} \\ a_{31}c_{1,t} + a_{32}c_{2,t} + a_{33}c_{3,t} + a_{34}c_{4,t} + a^*_{31}c^*_{1,t} + a^*_{32}c^*_{2,t} + 0 + a^*_{34}c^*_{4,t} \\ a_{41}c_{1,t} + a_{42}c_{2,t} + a_{43}c_{3,t} + a_{44}c_{4,t} + a^*_{41}c^*_{1,t} + a^*_{42}c^*_{2,t} + a^*_{43}c^*_{3,t} + 0 \end{bmatrix}. \tag{A7}$$

Appendix B: Additional Tables

Table B1: Multivariate STSMs – Main Parameter Estimates

		Prior			Posterior			
Country	**Parameter**	**Type**	**Mean**	**SD**	**Mode**	**Mean**	**90% interval**	
Australia	λ_1	N	0.2	0.05	0.17	0.18	0.11	0.25
	$\lambda_2 = \lambda_3$	N	0.1	0.05	0.09	0.08	0.03	0.13
	λ_4	N	0.15	0.05	0.13	0.15	0.08	0.22
	ρ_1	β	0.8	0.1	0.75	0.82	0.66	0.98
	$\rho_2 = \rho_3$	β	0.8	0.1	0.96	0.83	0.71	0.96
	ρ_4	β	0.6	0.1	0.69	0.66	0.51	0.81
	$\phi_2 = \phi_3$	β	0.8	0.1	0.93	0.81	0.66	0.95
	ϕ_4	β	0.7	0.1	0.78	0.82	0.72	0.93
Canada	λ_1	N	0.25	0.05	0.28	0.27	0.18	0.36
	$\lambda_2 = \lambda_3$	N	0.1	0.05	0.08	0.09	0.03	0.15
	λ_4	N	0.15	0.05	0.17	0.18	0.09	0.26
	ρ_1	β	0.85	0.1	0.83	0.81	0.67	0.94
	$\rho_2 = \rho_3$	β	0.8	0.1	0.95	0.81	0.62	0.98
	ρ_4	β	0.6	0.1	0.65	0.63	0.47	0.79
	$\phi_2 = \phi_3$	β	0.8	0.1	0.86	0.84	0.68	0.99
	ϕ_4	β	0.7	0.1	0.78	0.79	0.67	0.93
Japan	λ_1	N	0.2	0.05	0.21	0.19	0.13	0.26
	$\lambda_2 = \lambda_3$	N	0.1	0.05	0.13	0.12	0.05	0.19
	λ_4	N	0.1	0.05	0.11	0.12	0.05	0.19
	ρ_1	β	0.85	0.1	0.92	0.91	0.85	0.98
	$\rho_2 = \rho_3$	β	0.8	0.1	0.91	0.9	0.85	0.96
	ρ_4	β	0.7	0.1	0.67	0.68	0.54	0.84
	$\phi_2 = \phi_3$	β	0.8	0.1	0.97	0.92	0.85	0.99
	ϕ_4	β	0.75	0.1	0.73	0.77	0.62	0.92
New Zealand	λ_1	N	0.2	0.05	0.26	0.21	0.13	0.29
	$\lambda_2 = \lambda_3$	N	0.1	0.05	0.16	0.13	0.06	0.21
	λ_4	N	0.1	0.05	0.13	0.12	0.06	0.19
	ρ_1	β	0.85	0.1	0.91	0.85	0.73	0.97
	$\rho_2 = \rho_3$	β	0.9	0.1	0.97	0.9	0.86	0.95
	ρ_4	β	0.7	0.1	0.81	0.79	0.7	0.89
	$\phi_2 = \phi_3$	β	0.9	0.1	0.91	0.88	0.82	0.96
	ϕ_4	β	0.7	0.1	0.8	0.8	0.69	0.91

Table B2: Multivariate STSMs – Main Parameter Estimates

		Prior			**Posterior**			
Country	**Parameter**	**Type**	**Mean**	**SD**	**Mode**	**Mean**	**90% interval**	
Sweden	λ_1	N	0.2	0.05	0.21	0.19	0.12	0.27
	$\lambda_2 = \lambda_3$	N	0.1	0.05	0.14	0.0	0.06	0.15
	λ_4	N	0.1	0.05	0.11	0.13	0.05	0.21
	ρ_1	β	0.8	0.1	0.79	0.81	0.69	0.95
	$\rho_2 = \rho_3$	β	0.9	0.1	0.98	0.96	0.92	0.99
	ρ_4	β	0.7	0.1	0.71	0.71	0.59	0.83
	$\phi_2 = \phi_3$	β	0.85	0.1	0.94	0.83	0.67	0.99
	ϕ_4	β	0.75	0.1	0.78	0.79	0.66	0.93
United Kingdom	λ_1	N	0.2	0.05	0.19	0.19	0.12	0.26
	$\lambda_2 = \lambda_3$	N	0.1	0.05	0.09	0.09	0.03	0.17
	λ_4	N	0.1	0.05	0.1	0.09	0.05	0.15
	ρ_1	β	0.85	0.1	0.76	0.91	0.72	0.98
	$\rho_2 = \rho_3$	β	0.85	0.1	0.86	0.89	0.8	0.95
	ρ_4	β	0.7	0.1	0.92	0.89	0.75	0.94
	$\phi_2 = \phi_3$	β	0.85	0.1	0.89	0.88	0.79	0.98
	ϕ_4	β	0.7	0.1	0.93	0.67	0.49	0.88
United States	λ_1	N	0.3	0.05	0.18	0.29	0.23	0.37
	$\lambda_2 = \lambda_3$	N	0.1	0.05	0.08	0.11	0.08	0.15
	λ_4	N	0.2	0.05	0.09	0.24	0.15	0.33
	ρ_1	β	0.8	0.1	0.76	0.86	0.76	0.97
	$\rho_2 = \rho_3$	β	0.9	0.1	0.86	0.97	0.95	0.99
	ρ_4	β	0.5	0.1	0.92	0.51	0.39	0.63
	$\phi_2 = \phi_3$	β	0.75	0.1	0.89	0.8	0.73	0.87
	ϕ_4	β	0.8	0.1	0.93	0.81	0.67	0.95

Table B3: Synchronicity of Financial Cycles

	Australia	Canada	Japan	New Zealand	Sweden	United Kingdom	United States
Australia	1						
Canada	0.513	1					
Japan	0.262	0.176	1				
New Zealand	0.336	-0.172	0.166	1			
Sweden	0.704	0.561	0.158	-0.144	1		
United Kingdom	0.707	0.027	0.399	0.378	0.584	1	
United States	0.572	0.005	0.232	0.448	0.347	0.739	1

Note: The table displays the pair-wise correlations between the financial cycles of the respective countries.

Table B4: TVP Estimation – Treating Endogeneity

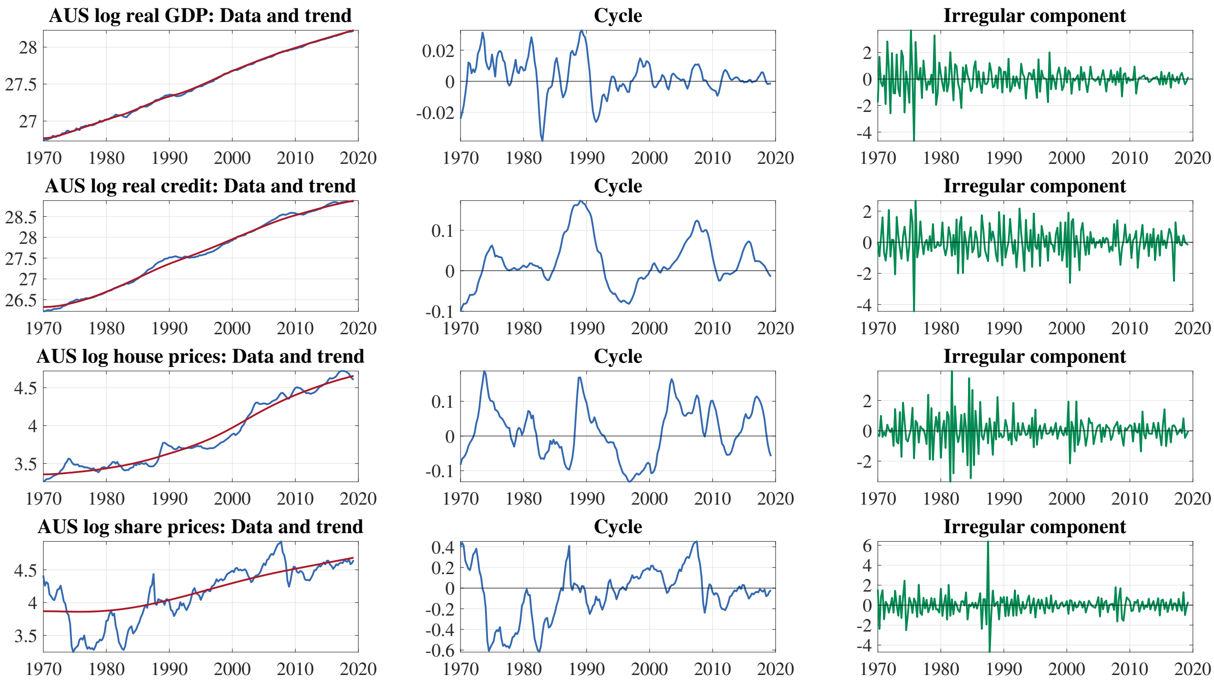
	Inflation (π_{t+2})		**Output gap ($\tilde{y}_t$)**	
Country	**F-statistic**	**p-value**	**F-statistic**	**p-value**
Australia	40.7	0.000	61.4	0.000
Canada	17.5	0.000	73.7	0.000
Japan	27.6	0.000	64.4	0.000
New Zealand	30.7	0.000	50.4	0.000
Sweden	56.6	0.000	76.4	0.000
United Kingdom	43.7	0.000	75.6	0.000
United States	12	0.000	88.8	0.000

Note: Number of observations – 132, degrees of freedom – 122, 5% significance level.

Appendix C: Additional Figures

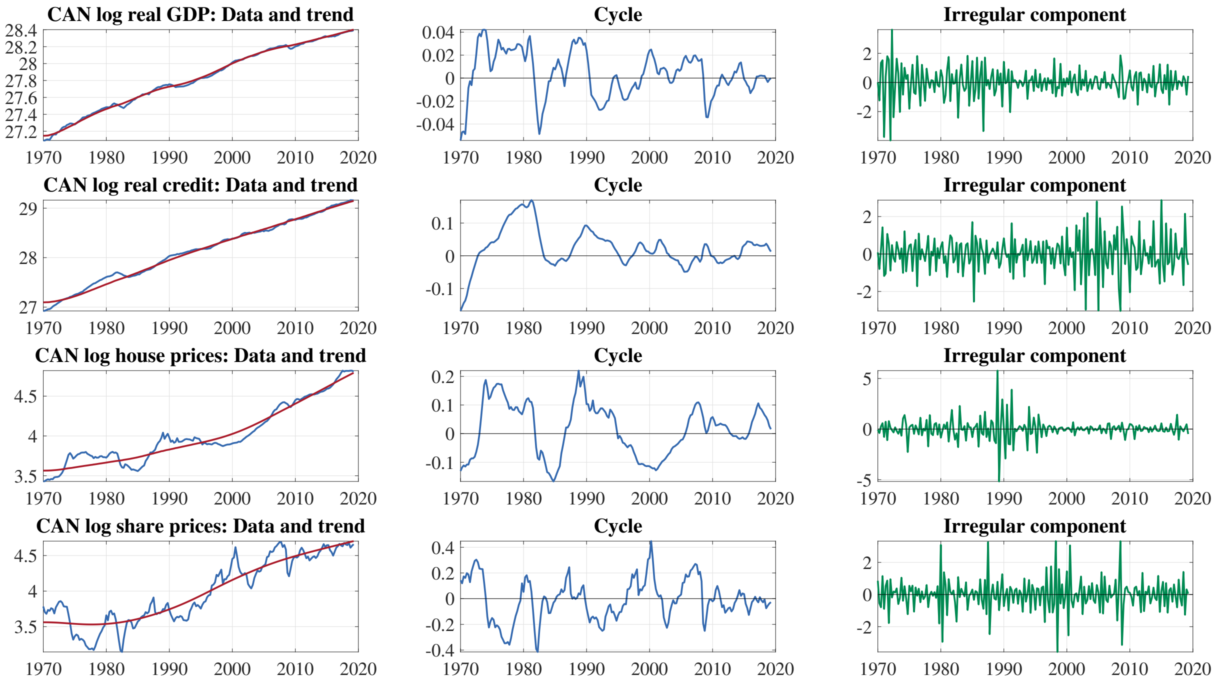
C.1 Univariate STSM

Figure C1: Univariate STSM – Decomposition for Australia



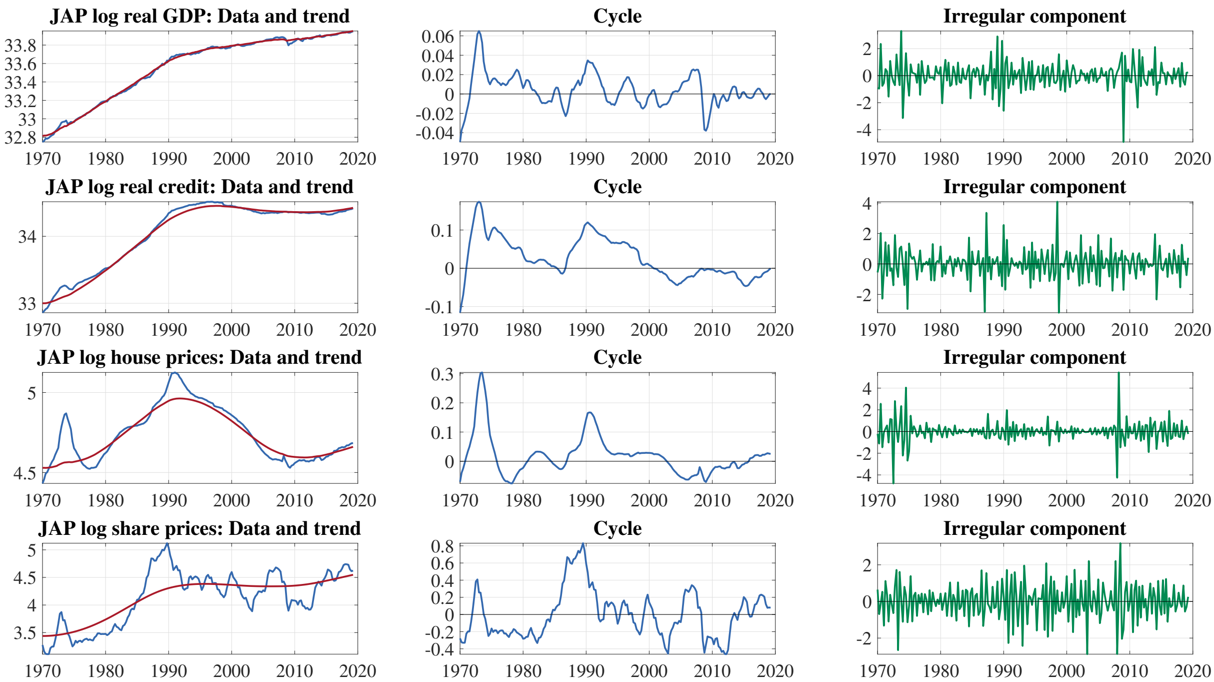
Note: Quarterly data.
Source: Authors' computations.

Figure C2: Univariate STSM – Decomposition for Canada



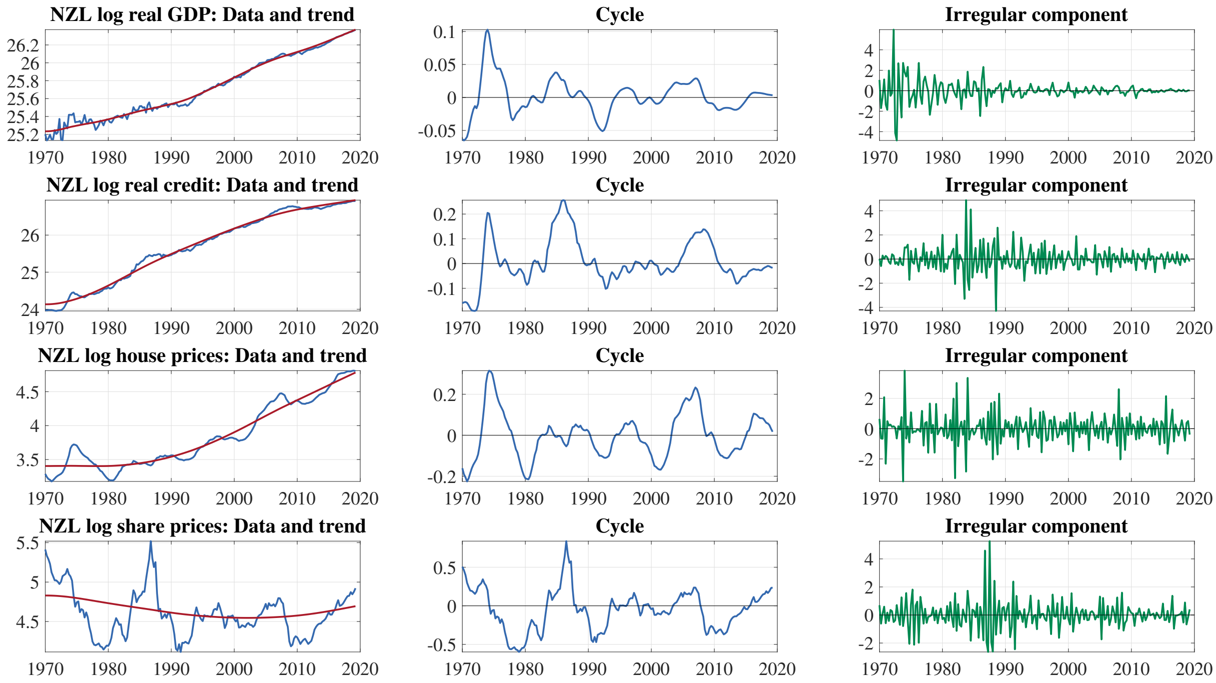
Note: Quarterly data.
Source: Authors' computations.

Figure C3: Univariate STSM – Decomposition for Japan



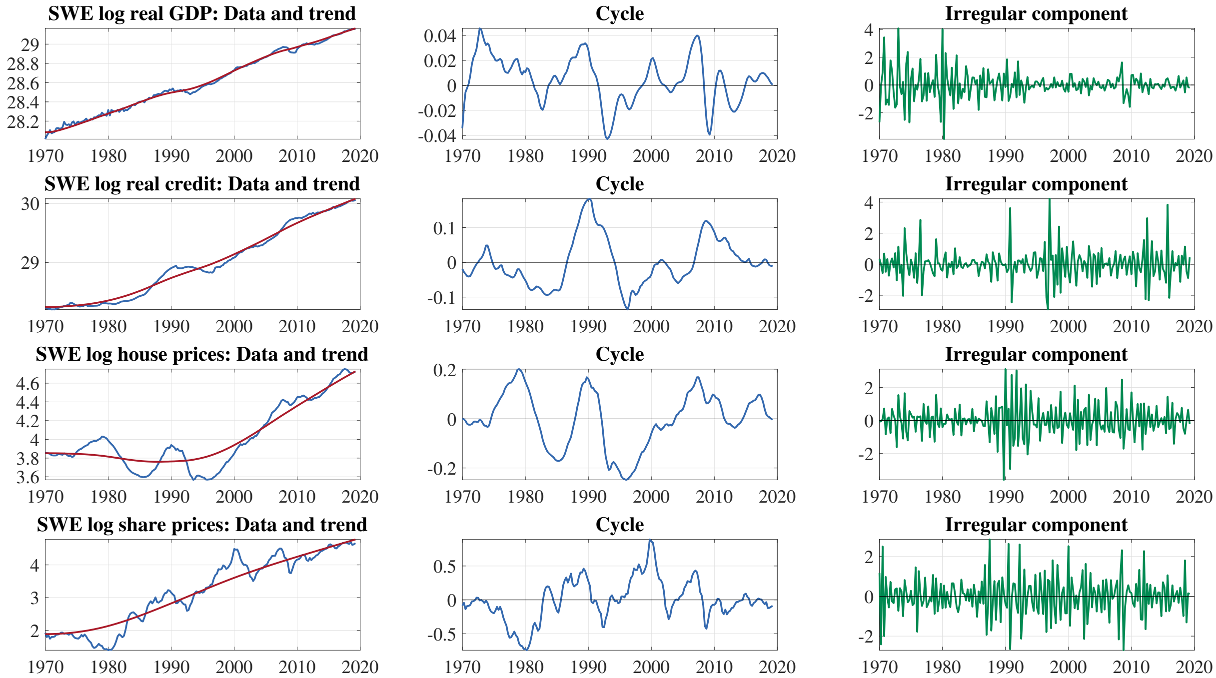
Note: Quarterly data.
Source: Authors' computations.

Figure C4: Univariate STSM – Decomposition for New Zealand



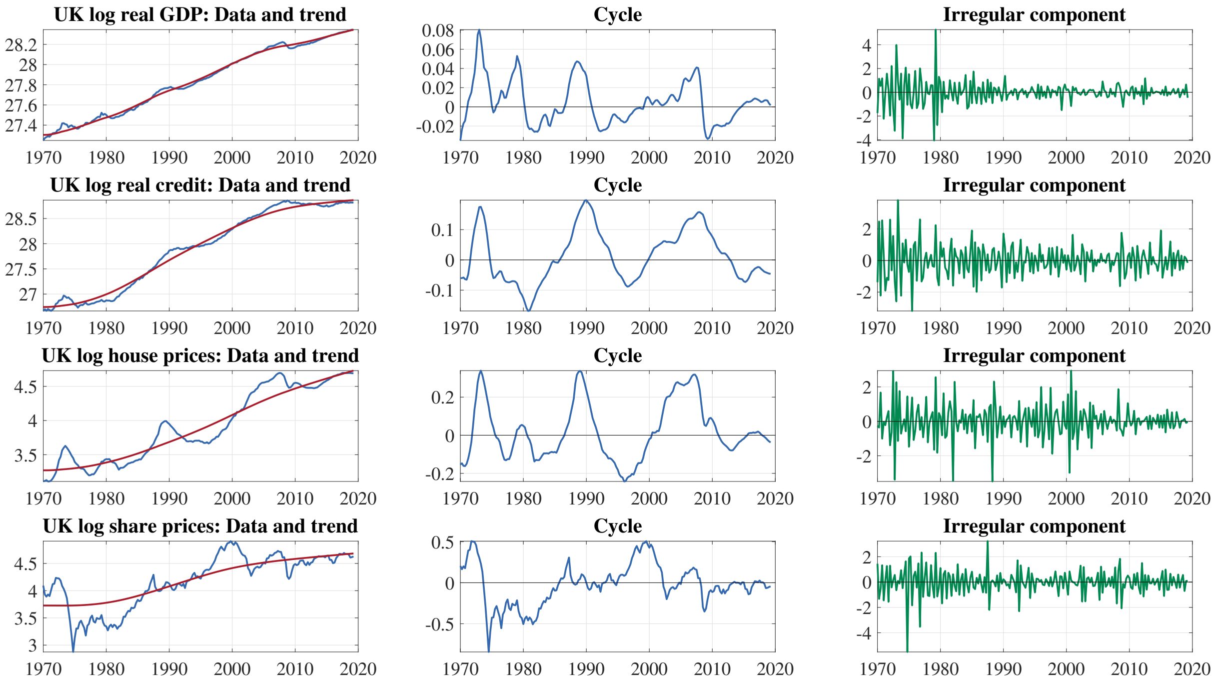
Note: Quarterly data.
Source: Authors' computations.

Figure C5: Univariate STSM – Decomposition for Sweden



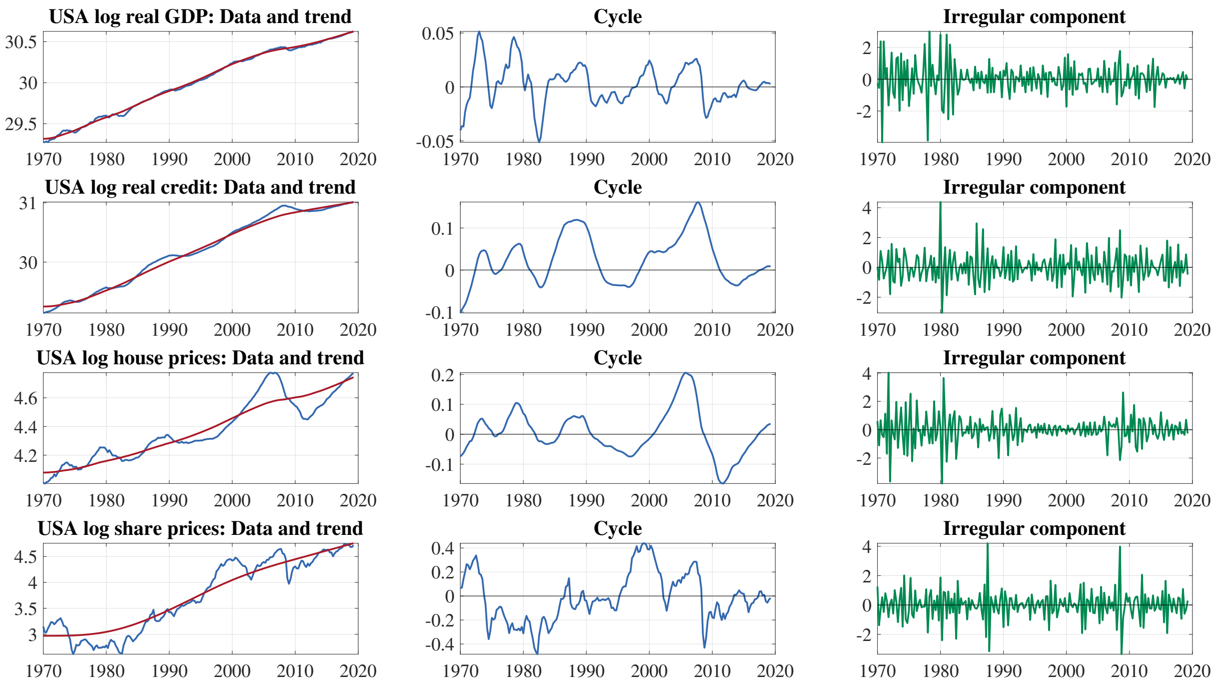
Note: Quarterly data.
Source: Authors' computations.

Figure C6: Univariate STSM – Decomposition for the United Kingdom



Note: Quarterly data.
Source: Authors' computations.

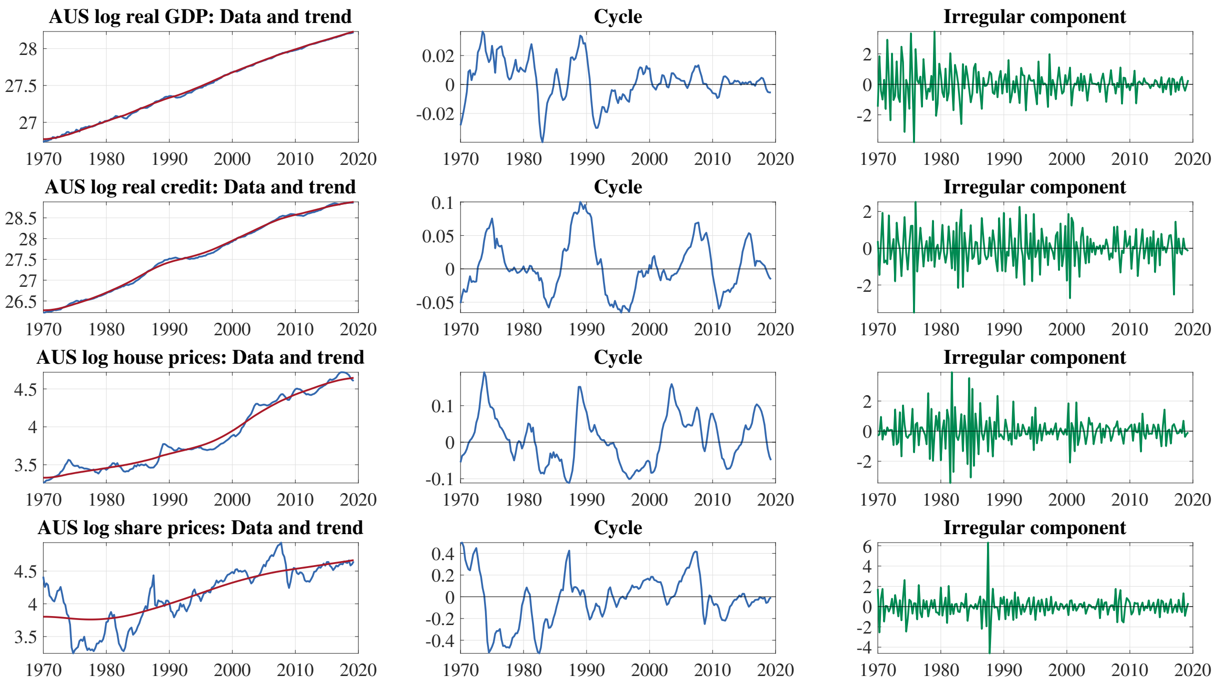
Figure C7: Univariate STSM – Decomposition for the United States



Note: Quarterly data.
Source: Authors' computations.

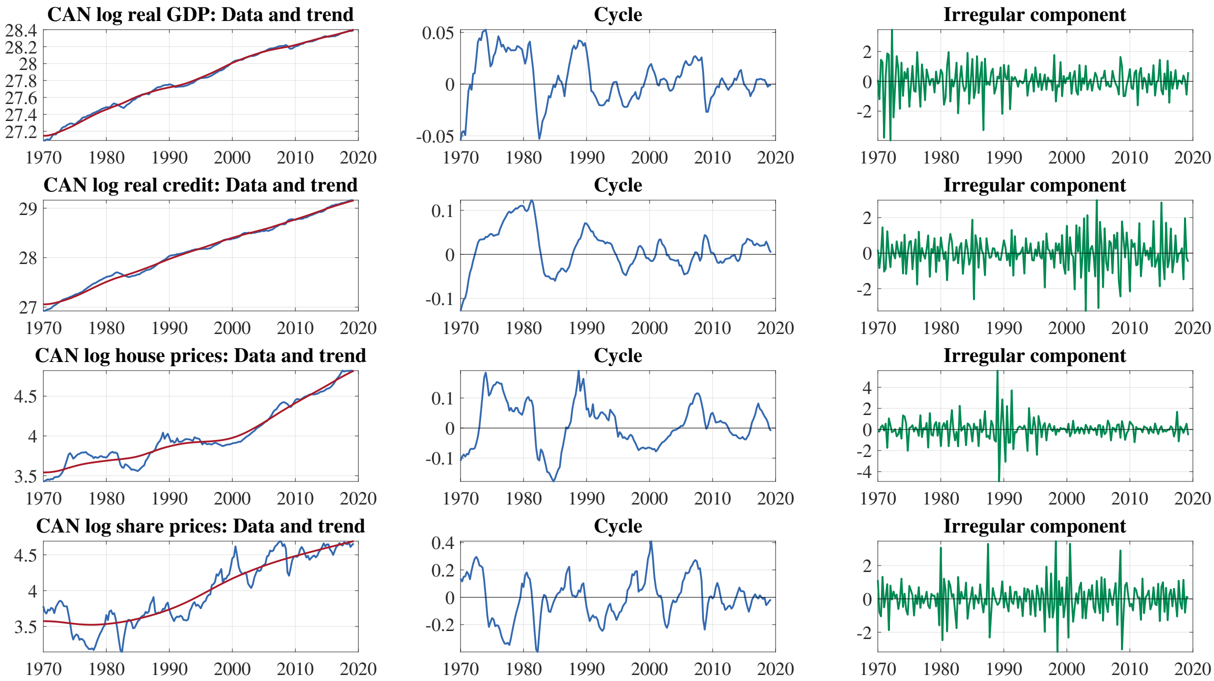
C.2 Multivariate STSM

Figure C8: Multivariate STSM – Decomposition for Australia



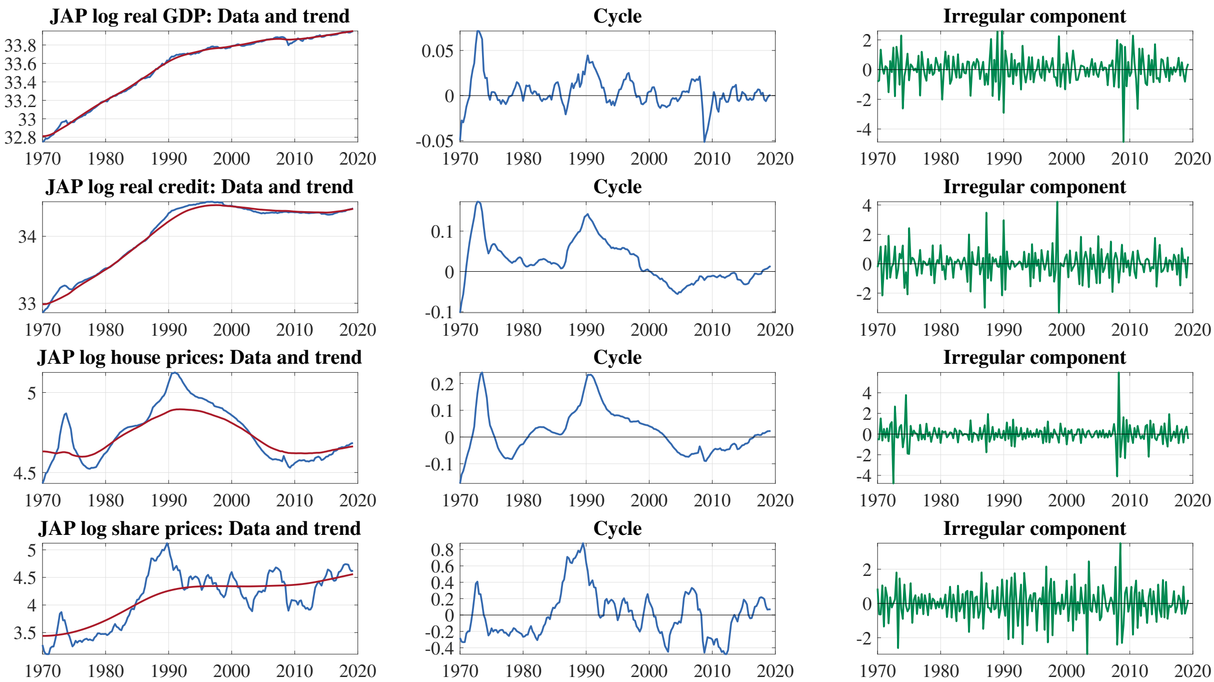
Note: Quarterly data.
Source: Authors' computations.

Figure C9: Multivariate STSM – Decomposition for Canada



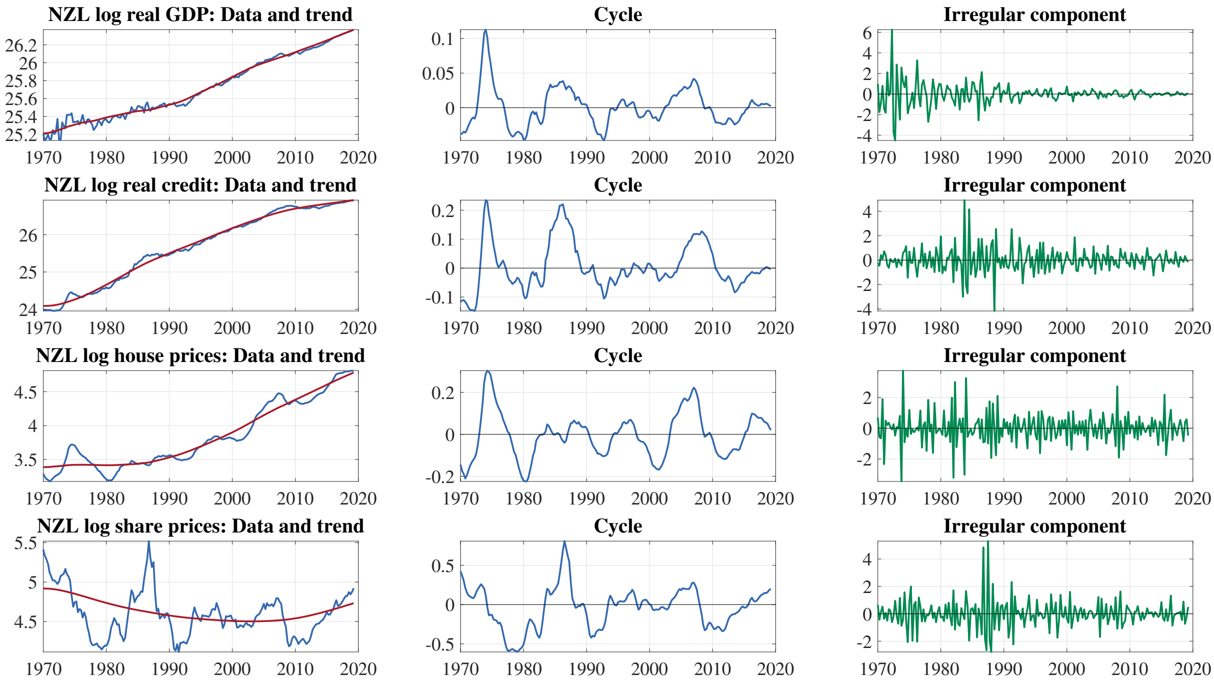
Note: Quarterly data.
Source: Authors' computations.

Figure C10: Multivariate STSM – Decomposition for Japan



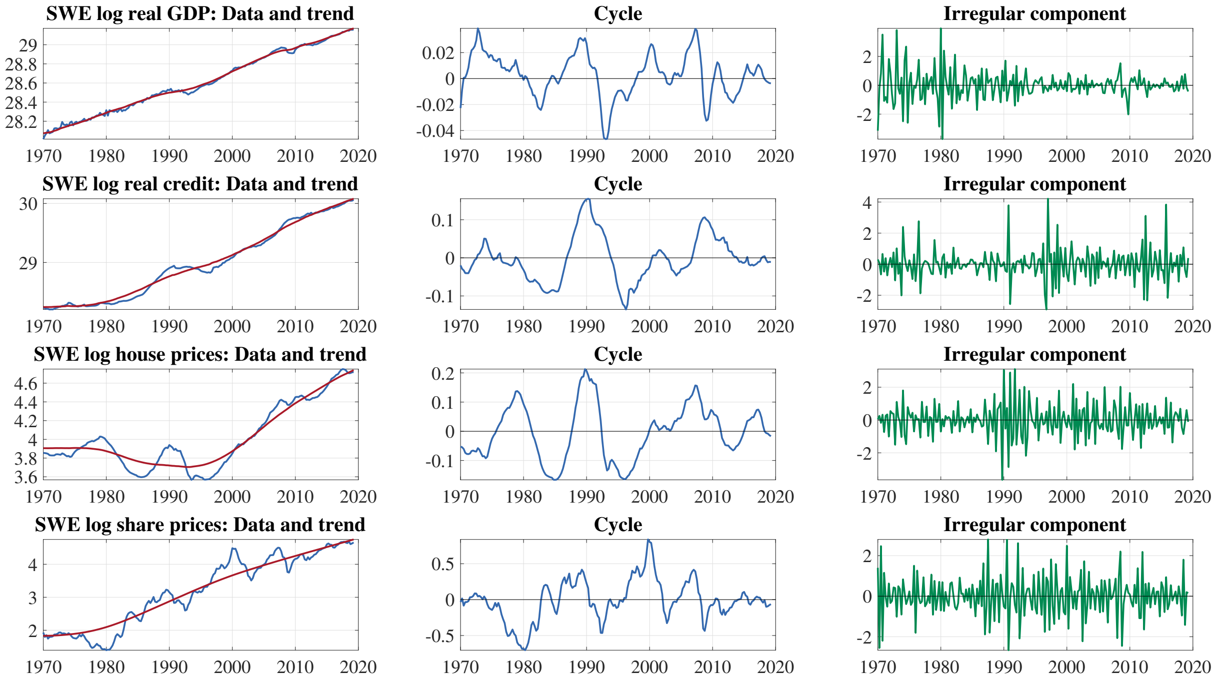
Note: Quarterly data.
Source: Authors' computations.

Figure C11: Multivariate STSM – Decomposition for New Zealand



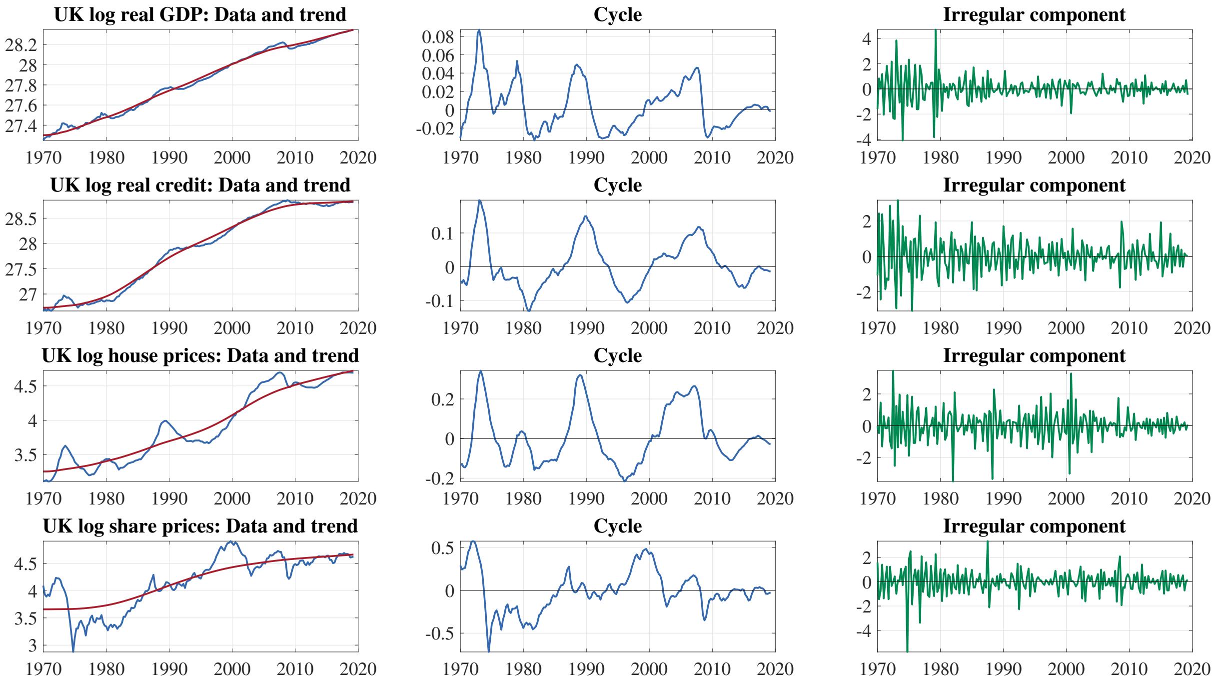
Note: Quarterly data.
Source: Authors' computations.

Figure C12: Multivariate STSM – Decomposition for Sweden



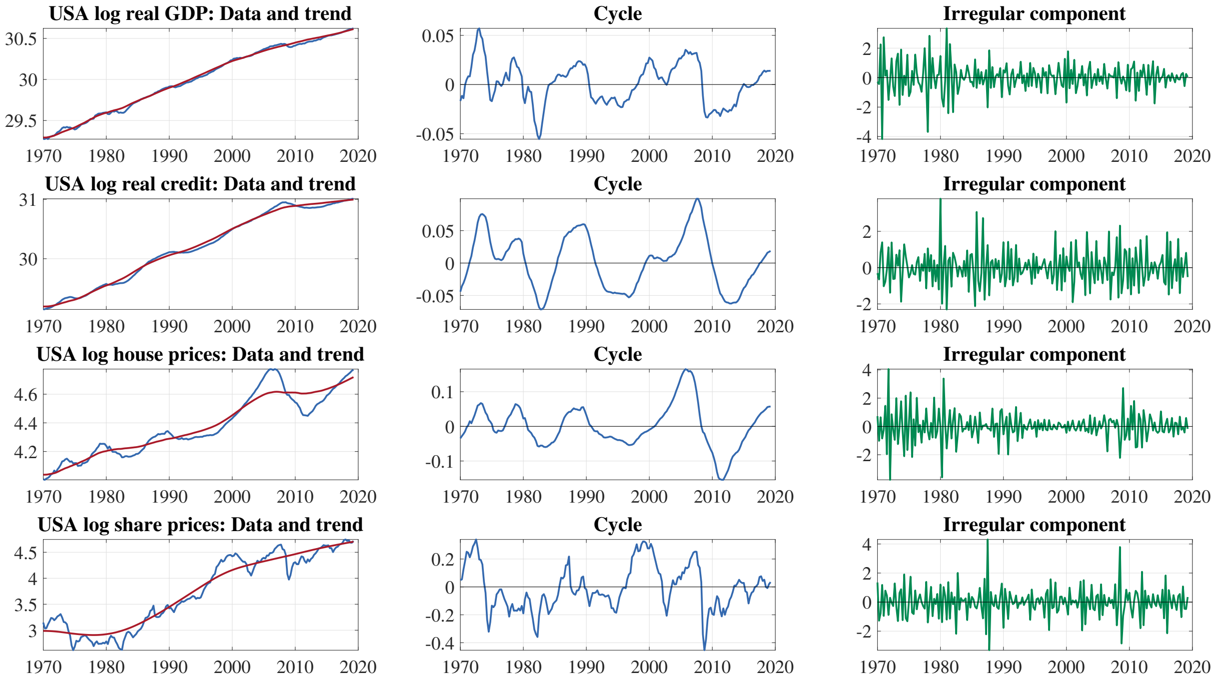
Note: Quarterly data.
Source: Authors' computations.

Figure C13: Multivariate STSM – Decomposition for the United Kingdom



Note: Quarterly data.
Source: Authors' computations.

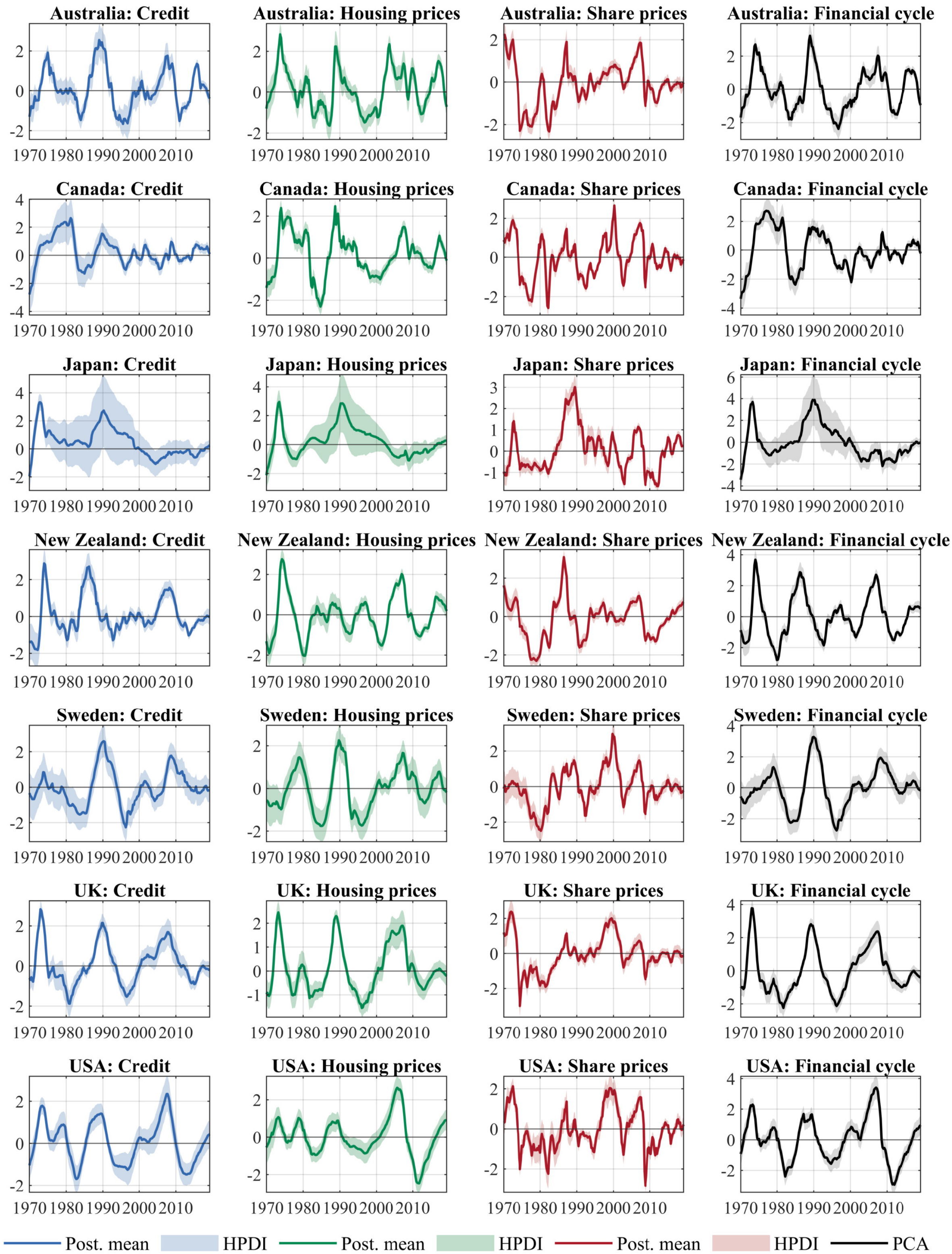
Figure C14: Multivariate STSM – Decomposition for the United States



Note: Quarterly data.
Source: Authors' computations.

C.3 Financial Cycles

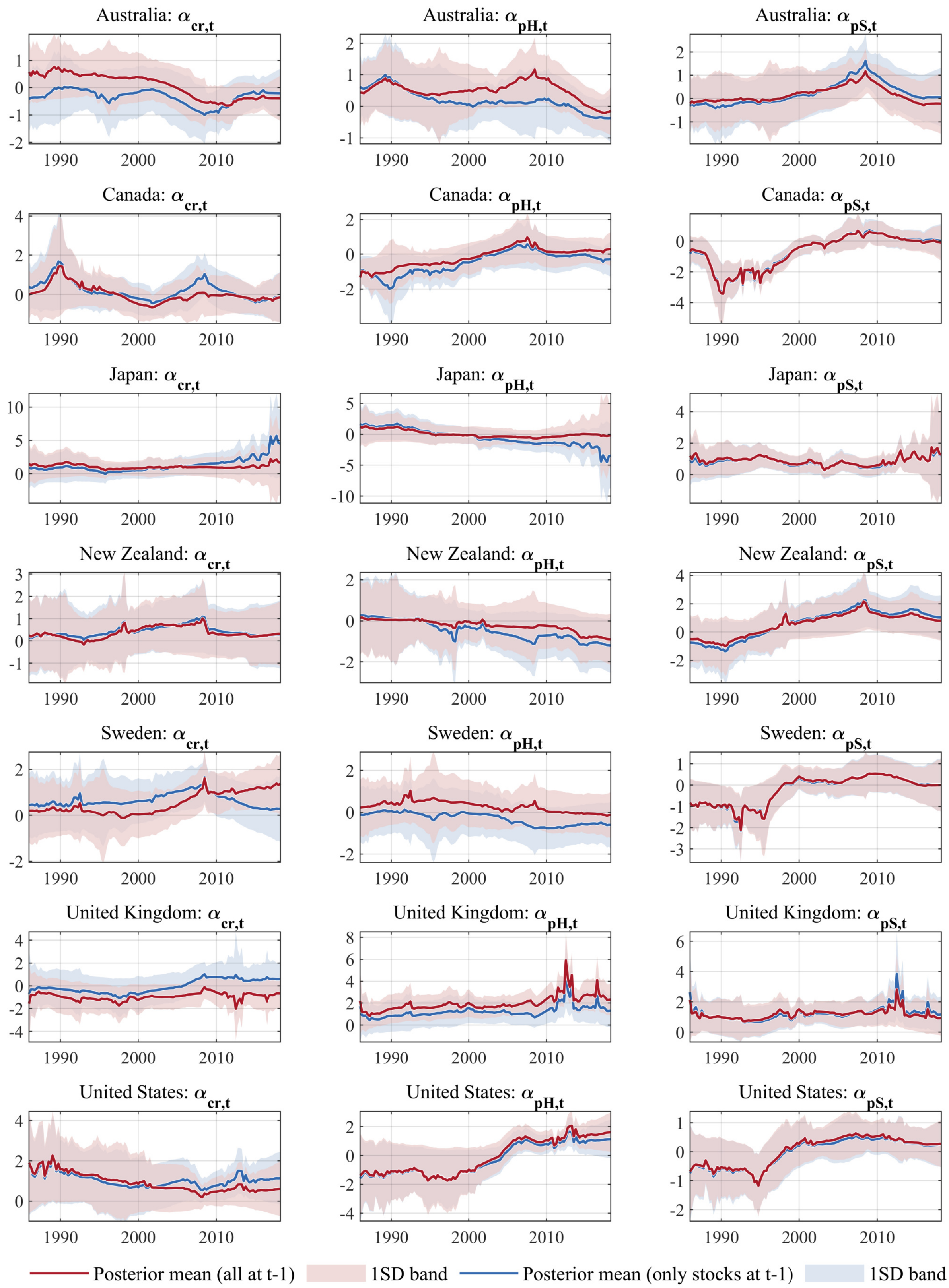
Figure C15: Financial Cycles and Cycles of Constituent Indicators – the STSM



Note: Quarterly data.
Source: Authors' computations.

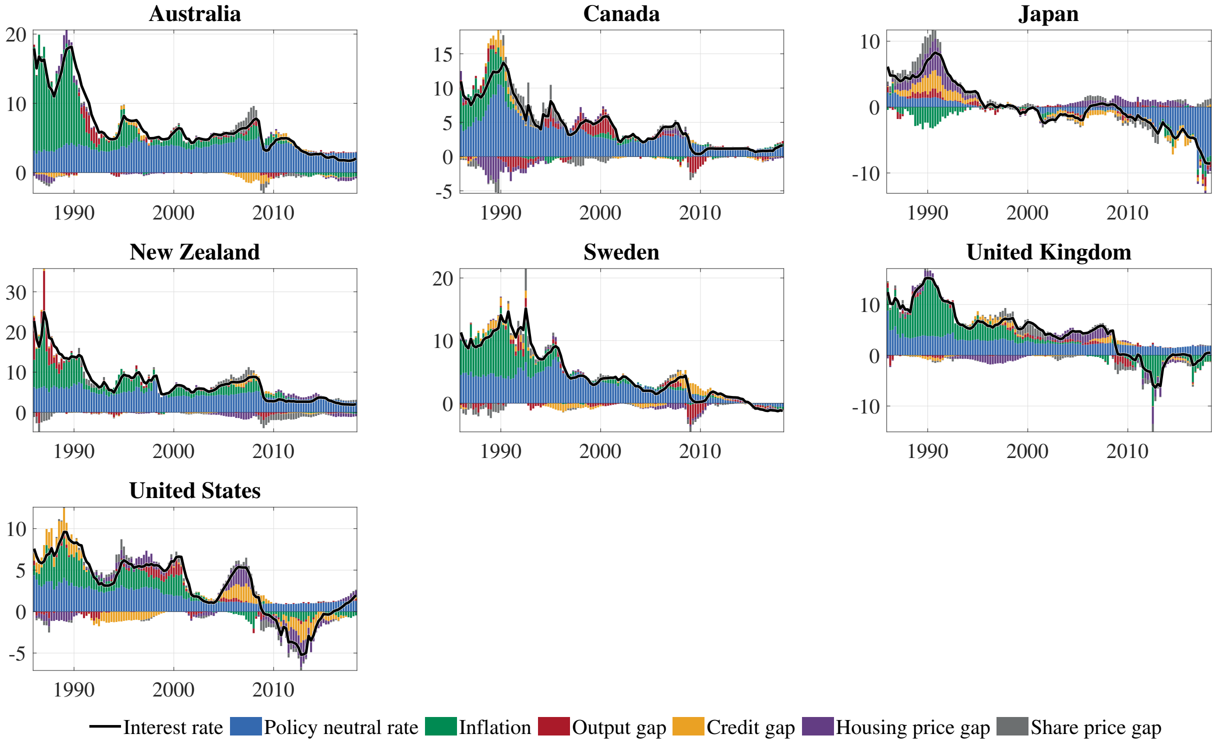
C.4 TVP Monetary Policy Rules

Figure C16: Time-Varying Coefficients of Individual Components of the Financial Cycle



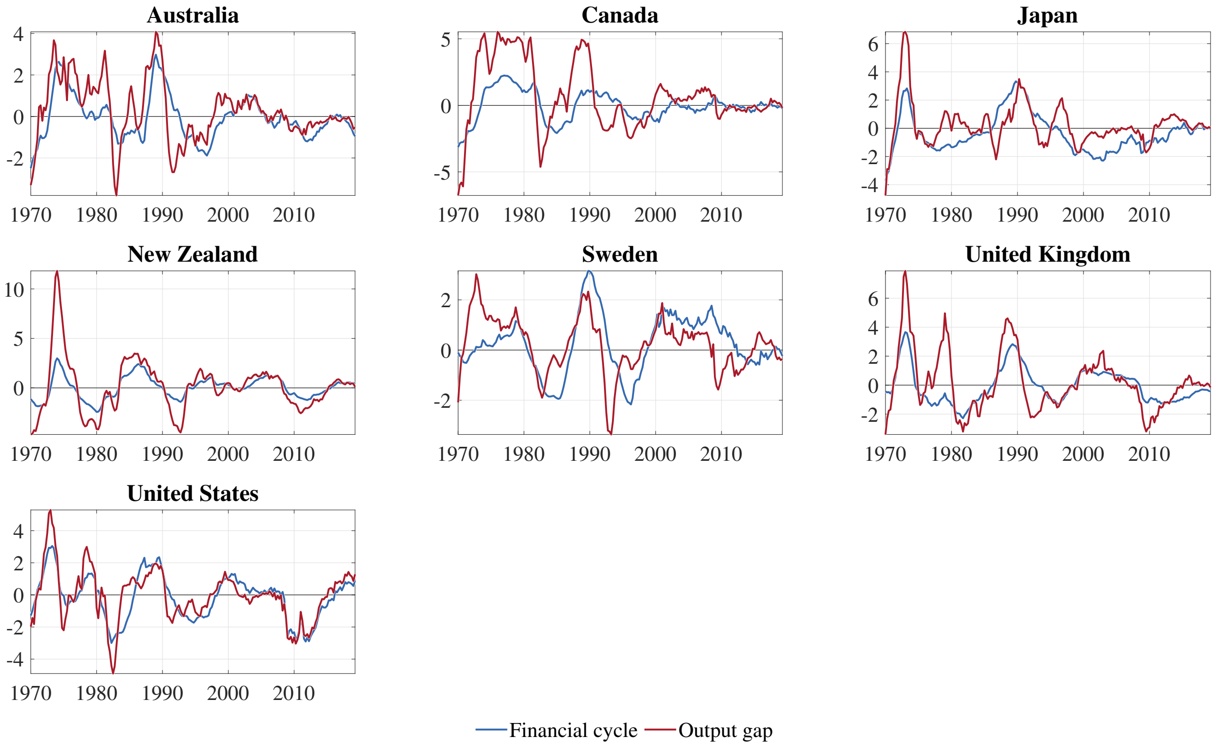
Note: The estimated coefficients are depicted with 68% credible intervals.
Source: Authors' computations.

Figure C17: Historical Decompositions of Interest Rates with Subcomponents of the Financial Cycle



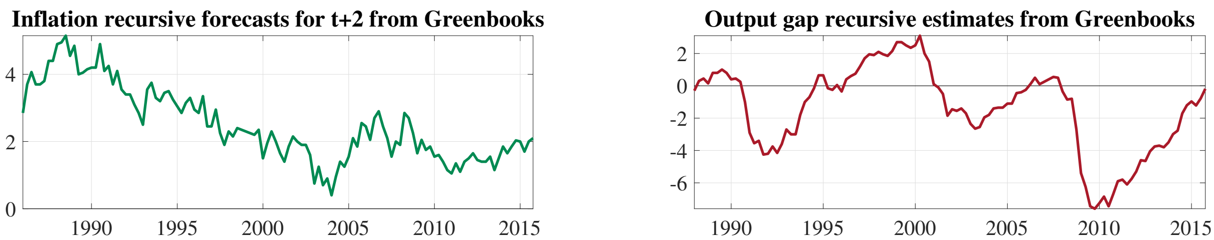
Note: The credit and house price gaps are included at t and the stock price gap at $t-1$. The historical decomposition is calculated as the product of the variable in the reaction function (augmented Equation (13)) and its respective coefficient $\alpha_{l,t}$ for $l = 0, \pi, y, cr, pH, pS$. The contributions of the variables are indicated by different colors and they sum to the actual level of the interest rate less the impact of the endogeneity correction terms.
Source: Authors' computations.

Figure C18: Pseudo Real-Time Financial Cycle and Output Gap Based on the STSM



Source: Authors' computations.

Figure C19: Real-Time Data from Greenbooks for the United States



Note: Inflation is measured as the quarter-on-quarter annualized change in the consumer price index, as the Greenbooks do not offer inflation forecasts on a year-on-year basis. The output gap is defined as the difference between actual and potential output expressed as a percent of potential output.
Source: Greenbooks.

Appendix D: Monetary Policy and Financial Cycles – An Overview of Attempts to Control Asset Price Bubbles

D.1 Australia

Australia experienced several periods of rapidly increasing house prices: 1988/1989, 2000–2004, and 2014–2018. However, those increases were not followed by steep declines (there was a minor decrease in 2019). The rising housing prices were often attributed to fundamentals such as immigration, demographic changes, and a decreasing size of the average household, or (temporary) limits on supply in metropolitan areas (Berry and Dalton, 2004; Kohler and Merwe, 2015; Lowe, 2017). Nevertheless, the RBA governor Ian Macfarlane acknowledged some contribution of rising amounts of credit to housing prices (Bell, 2004, on p. 393). However, speculative motives seem to have been acknowledged mainly retrospectively (Macfarlane, 2020).

The Reserve Bank of Australia (RBA) closely monitored the housing market developments, rising household debt, and leverage. In contrast to the United States, it focused on setting and enforcing strong lending standards and applied restrictions on interest-only mortgages and similar regulations.[45]

According to official communications, interest rate policy remained largely unaffected by the housing market developments. The RBA stressed that housing prices affected interest rate decisions only through their estimated impact on inflation expectations and future inflation, broadly in line with the Jackson Hole consensus. More specifically, in the 2002–2004 period, when housing prices were rapidly increasing, RBA officials resisted describing the conditions on the housing market as a "bubble". They insisted that while they monitored the evolution of housing prices, interest rates were not raised in response to increases in housing prices (Berry and Dalton, 2004).

More recently, rising housing prices were interpreted as being generally positive for the economy due to their wealth effect on consumption, provided that they remained sustainable: *"The falling housing prices were one of the factors that had contributed to sluggish growth in 2019. (...) It remains to be seen how long this will continue, but sustainable increases in asset prices support household balance sheets and encourage spending through positive wealth effects. Higher housing prices can also encourage additional residential construction. But as housing prices rise again, we will be monitoring lending standards closely. We would be concerned if there were to be a deterioration in these standards, but there are few signs of this at the moment."* (Lowe, 2021).[46]

Other asset prices, mainly share prices, were not considered relevant for monetary policy (see King (1998) for a broader summary).

Our results, however, provide a somewhat more nuanced perspective, with traces of a moderate interest rate response first to housing prices around the middle of the 2000s and later to share prices around 2008.

[45] Australia experimented with macroprudential policy before 2008, too. The RBA implemented capital requirements depending on mortgages' LTV ratios already in 1998, and adopted more specific measures targeting the financial stability of systemically important financial institutions in 2001 (see the IMF's Macroprudential Database). Nevertheless, Lim et al. (2011) does not find any intensive use of macroprudential instruments in Australia before 2008.

[46] Note that this perspective was presented at a time when the RBA was expecting housing prices to increase by 30% over the next few years. Early in 2021, the RBA also declined to follow the Reserve Bank of New Zealand's decision to explicitly consider house prices when setting interest rates. https://www.afr.com/policy/economy/why-the-rba-won-t-target-house-prices-like-nz-20210225-p575pq

D.2 Canada

Canada was the second country to adopt a formal inflation-targeting regime. The history of the Canadian experience with inflation targeting is summarized by Carter et al. (2018). Briefly, inflation targeting helped stabilize inflation and inflation expectations and increased the predictability of monetary policy decisions.

The role of asset prices and possibly longer horizons over which the central bank should aim to return inflation to the target were extensively discussed in the mid-2000s. As a result, the Bank of Canada converged to the consensus shared with other central banks that asset prices should be reflected in monetary policy *"only to the extent that they provided information about future output and inflation, though large asset price shocks might require 'sacrificing something in terms of inflation performance over the usual horizon' in return for 'greater financial, economic, and inflation stability over a somewhat longer horizon'"* (Carter et al., 2018, citing Bank of Canada, 2006).

Furthermore, concerning financial bubbles, it was argued that *"the best contribution that central banks can make to economic stability in the context of an asset-price bubble is to minimize the damage associated with the bursting of a bubble by reacting with timely remedial action after it has occurred"* (Bank of Canada, 2006, p. 9). Potentially important roles of rising indebtedness and leverage for financial instability became acknowledged in the 2011 renewal of the inflation-targeting policy (Bank of Canada, 2011).

To conclude, there is not much historical evidence that the Bank of Canada used interest rate policies to tame financial imbalances beyond its inflation-targeting mandate, although the historical decomposition presented in Figure 4 points to a moderate interest rate response to real housing and share prices prior to 2008.

Nevertheless, Canada has a long tradition of macroprudential policies. Loan-to-value ratios were introduced before the year 2000, and, although loosened several times before 2008, the restrictions on borrowers were never dismantled. Also, Canada quickly adopted and strengthened a macroprudential framework after the 2008 crisis.

D.3 Japan

Japanese economic policy was determined by the asset price bubble of the late 1980s and its subsequent burst in 1990. These dramatic events led to an economic decline referred to first as the Lost Decade and later as the Lost Decades.[47] Starting in the mid-1990s, Japan also experienced low inflation rates, and deflation appeared in the 2000s.

The causes of the Japanese financial bubble are usually seen in a combination of failures in financial regulation, which led to overleveraging of both households and firms (Ito, 2004), and the consequences of the Plaza Accord of 1985, which led to an immense appreciation of the yen (Okina et al., 2001). Initially, the Bank of Japan wanted to support the economy; it cut the policy rate and kept it low until May 1989 despite rapidly rising asset prices and double digit credit growth. But the policy rate was then quickly increased from 2.5% to 4.25% by the end of the year. After several additional monetary tightenings in the 1990s, the policy rate peaked at 6%. The Nikkei index started

[47] Note that technically, the periods of negative growth were relatively short-lived. Thus, the developments correspond to a protracted recession or stagnation rather than to the sharp declines experienced in several post-communist and developing countries.

to fall and by August 1990 had lost 50% from its peak in early 1990. Other assets followed the fall of the Nikkei index.

During this period of monetary tightening, the Bank of Japan aimed to regain some control over asset prices. From 1985 on, the inflation rate remained below 2%, with just a temporary increase to the 2–3% range in 1989.[48]

The bursting of the bubble had significant impacts on both highly leveraged corporations and households. They suffered capital losses and were unable to repay their loans. Consequently, the share of non-performing loans increased rapidly. In response to the crisis, many alternative policies were adopted to stimulate the economy and restore economic growth. The priority was to support employment, at the cost of further accumulation of non-performing loans. A survey of the policy responses is provided by Ito (2004).

The monetary policy framework went through numerous changes as well. Until 1997, the Bank of Japan's main goal was to maximize potential economic growth. Following a revision of the Bank of Japan Act passed in 1997, the Bank of Japan gained independence and its mandate was changed to price stability. Additionally, various measures were adopted to strengthen the transparency and accountability of the Bank to the public, including the publication of minutes and voting records with a one-month delay. However, until 2012, the Bank of Japan resisted adopting inflation targeting as an official regime for various reasons. Members of the board considered the inflation-targeting regime to be a too simple-minded reflation policy. Second, they feared that the Bank would not be able to move from deflation to inflation, thus risking its credibility. Moreover, the Bank's officials were skeptical that purely announcing an inflation target would change inflation expectations (Ito, 2004). Inflation targeting was officially announced in February 2012. The inflation target was initially at 1% and was increased to 2% in January 2013 (Nakata, 2020).

D.4 New Zealand

The Reserve Bank of New Zealand (RBNZ) adopted inflation targeting in 1989, with the first inflation target set for 1990. Over time, the operational framework was repeatedly extended and the mandate broadened. Since 1999, the RBNZ has been tasked with seeking to avoid unnecessary instability in output, interest rates, and the exchange rate. Since 2012, it has also had to have regard to the efficiency and soundness of the financial system. In February 2021, the RBNZ became required to consider the impact on housing prices when making monetary and financial policy decisions. An overview is provided by McDermott and Williams (2018).

New Zealand also experienced rapidly rising housing prices in the 2000s. At that time, the RBNZ governor Alan Bollard became concerned about the situation right at the start of the housing boom (Bollard, 2003). He argued that the rise of prices exceeded the trajectory dictated by fundamentals such as immigration, internal migration from the South to the North, and demographic changes.

However, housing prices started to be fueled, according to Bollard, by accelerating growth of credit and rising debt-to-income ratios, and there were signs that part of the demand was driven by *"would-be investors. The newspapers are running advertisements for seminars offering to coach people on how to invest in property, often promising significant returns. I am concerned, as I said at the*

[48] *"However, in view of stable prices indicated by various related indices, those who were concerned with inflationary pressure had difficulty in reconciling stable price indices with concern over future inflation. Furthermore, there did not exist a commonly shared understanding as to what exactly are problems caused by the increase in asset prices."* (Okina et al., 2001, p. 396).

release of the Reserve Bank's Monetary Policy Statement last week, that this could end in disappointment, especially for unsophisticated investors who are rushing to get on the housing-investment bandwagon." While Bollard acknowledged that asset prices should not be driving central banks' interest rate decisions, he explained that there are times when *"things get more difficult and asset prices move well out of line with underlying economic fundamentals"* (Bollard, 2004). Regarding potential policy responses, Bollard (2004) was skeptical about the efficiency of interest rate and prudential policies. At the same time, he declared he would use his powers to lean against the wind if necessary, despite the risk of reducing the rate of economic growth: *"That said, as I interpret my mandate, it does permit me to take such risks in rare circumstances."*

Thus, the signs of a housing bubble were recognized by the RBNZ already in real time, although the Bank used rather unsophisticated ways to detect it. Some of the interest rate increases that occurred in the following years, although not all of them, can be attributed to attempts to cool down the housing market. In particular, Governor Bollard mentioned housing prices along with other inflation pressures when interest rates were increased in October 2005,[49] and housing prices were supposed to dictate future interest rate increases again in January 2007.[50] Nevertheless, for example, the interest rate increases in 2004 *"were just part of the normal operation of monetary policy to ensure continuing consumer price stability"* (Bollard, 2004).

Although interest rate policy was apparently used to tame the housing bubble, the policy actions were not entirely successful (Murphy, 2011). The impact of interest rate policy was evaluated by Shi et al. (2014), who found that real interest rates are significantly and positively related to real housing prices, indicating that increases in the policy rate may not be effective in depressing real housing prices. The limits of interest rate policy were recognized by the RBNZ, too, and Governor Bollard and his successors recommended the adoption of speculation taxes and other measures against speculative demand (Swire, 2009).

The last broadening of the RBNZ mandate of 2021 came in response to sharply rising real estate prices in New Zealand. However, the principal instruments are supposed to include primarily macroprudential measures rather than interest rate policy (Robertson, 2021). Some of these macroprudential policies, however, were already in use. Armstrong et al. (2019) evaluated the impact of the loan-to-value ratio restrictions adopted in 2013–2016 on house prices. They found that the policy prevented housing prices from rising by an additional 50%.

D.5 Sweden

Swedish monetary policy was affected by the experience of the banking and economic crises of the early 1990s. The financial liberalization of the 1980s contributed to an overheating of the Swedish economy, and a housing bubble arose. Under the fixed exchange rate policy, the Riksbank could not lean against the wind in timely fashion, and fiscal policy remained expansionary despite increasing debts. After the resignation of the then finance minister, Kjell-Olof Feldt, who had been frustrated by the impossibility of passing restrictive policy, the Riksbank finally increased interest rates to curb inflation. The policy rate increases were followed by a tax reform that increased after-tax interest rates even more. The conditions on the housing market changed quickly – the ratio of non-performing mortgages grew, and a full-fledged banking crisis emerged (Englund, 1999).

[49] Reserve Bank increases OCR to 7.00 percent. Reserve Bank of New Zealand press release, October 27, 2005, archived at https://www.centralbanking.com/central-banking/news/1411855/rbnz-increases-ocr-cent or https://www.scoop.co.nz/stories/PO0510/S00216.htm?from-mobile=bottom-link-01.

[50] OCR unchanged at 7.25 percent. Reserve Bank of New Zealand press release, January 25, 2007, https://www.rbnz.govt.nz/news/2007/01/ocr-unchanged-at-7-25-percent.

The banking crisis quickly affected the whole economy, Sweden was forced to leave the ERM, and since January 1993, the Riksbank has followed an inflation-targeting policy with a target set at 2%.

Nevertheless, the restored economic growth led to another credit boom that started in the late 1990s, and household debt started to rise again in relation to disposable income. Credit growth and household debt started to worry the Riksbank early in the 2000s. Giavazzi and Mishkin (2006) and Svensson (2013) review the Bank's reports and statements of the 2000s and document that concerns about rising housing prices led to rising interest rates starting in 2006 (with some earlier indications of this intention already in 2003), with the Bank mixing inflation targeting with attempts to restrain housing prices and household debt. However, both housing prices and the household debt-to-income ratio continued to rise.

The impact of the 2008 financial crisis was relatively moderate. Sweden managed to escape the crisis with a relatively low impact on the housing market and without a credit crunch. Credit continued to expand, and the Riksbank started to be concerned about the rising household debt-to-income ratio and began to lean against the wind in the summer of 2010. Svensson (2014) considered these policy rate increases to be *aggressive* and supposedly leading to higher unemployment, lower inflation, and – most strikingly – to a higher debt-to-income ratio as well.

Our estimates are consistent with the historical evidence. The time-varying coefficient on the lagged financial cycle starts rising in 2006, becoming significant at 1SD in 2007. Although the coefficient decreases shortly after the financial crisis of 2007/2008, it remains at higher levels than in the first half of the 2000s. The historical decomposition suggests higher interest rates due to the financial cycle from 2007 to 2013, mainly driven by the credit gap.

After 2010, Sweden also gradually improved its legal framework for crisis prevention and crisis resolution mechanisms, following the policy recommendations arising from a review of the Riksbank's monetary policy (Goodhart and Rochet, 2011). The Swedish financial supervisory authority (Finansinspektionen) was given the power to set micro- and macroprudential policies and introduced a cap on the loan-to-value ratio at 85%, and the Financial Stability Council was created.

Low – and in 2015–2020 even negative – interest rates contributed to a renewal of credit growth and affected housing prices as well. Overall, real housing prices more than tripled between 1995 and 2015 (Andersson and Jonung, 2016). This time, monetary policy was again relatively lenient toward the growth of housing prices, with a majority of the board favoring lower interest rates while consumer price inflation remained below the 2% target and a minority viewing the developments in the housing market as a threat to financial stability and recommending increasing interest rates. However, the tensions in the Riksbank's board on monetary policy priorities were undeniable (Goodfriend and King, 2016), and the priorities have changed more recently (Emanuelsson, 2019).

D.6 United Kingdom

The Bank of England's pre-crisis policy is often considered to have been similar to the Fed's approach, focused on mitigating the negative consequences of bursting bubbles rather than acting preemptively, mainly due to skepticism about the ability to detect asset price bubbles in real time.[51]

Also, the governor of the Bank of England, Mervyn King, shared many views with Alan Greenspan, including those on financial bubbles: *"It is hard to forecast asset price movements accurately or to*

[51] A summary of British monetary policy during the first decade of inflation targeting is provided in King (2002).

identify asset price 'bubbles'. Even if we could identify them, it is not clear how effectively we could in practice control them. (...) Most of the tightenings (...during the Greenspan era) were followed by a rise in equity prices, leading to the conclusion that only a severe rise in short-term rates, and the associated economic downturn, would have been able to keep the stock-price 'bubble' in check." (King, 2004).

Nevertheless, King (2004), as well as the former chief economist at the BoE Charles Bean (2003), were aware of the consequences of speculative bubbles and also of potential conflicts between inflation targeting and attempts to mitigate financial imbalances while praising the enhanced flexibility of the inflation-targeting regime.[52]

Furthermore, Mervyn King was concerned about the buildup of a housing price bubble in the United Kingdom in 2004–2005. Those concerns can be traced to his speeches from that period. In particular, in January 2004, King (2004b) explicitly argued that although the newly adopted benchmark inflation measure, CPI, was indicating inflation below the target, the Bank of England would not ease its monetary policy because of the rise in housing prices. Thus, the policy rate was increased gradually between 2004 and 2008, despite muted core inflation and a short-lived upswing in headline CPI due to an oil shock in 2008. However, even the rising interest rates did not stop the housing price bubble from growing.[53]

After the crisis, King also concluded that price stability does not guarantee the stability of the economy as a whole and that central banks need tools to pursue financial stability goals, that is, a macroprudential toolkit. Also, he contributed to the transfer of many macroprudential regulatory powers to the Bank of England. At the same time, King believed that inflation targeting remained a helpful policy framework, one which should, however, be augmented: *"Setting Bank Rate to maintain price stability was successful in itself, but did not prevent a recession induced by a financial crisis. But let's not throw out the baby with the bathwater. The period prior to the crisis was the most stable economic environment for generations. And, unlike most previous recessions, this crisis wasn't preceded by an unsustainable boom in output. In the five years leading up to the crisis, overall GDP growth remained close to its long-run average and inflation differed from the 2% target on average by only 0.2 percentage points. Diverting monetary policy from its goal of price stability risks making the economy less stable and the financial system no more so. To argue that monetary policy should be directed to counter inadequately priced risk is to argue that unemployment is a price worth paying to tame the banking system."* (King, 2009).

Moreover, King saw the main cause of the crisis in failures of financial regulation before the crisis: *"But banks entered the crisis with historically low levels of liquid assets, and inadequate levels of capital with which to absorb losses. Moreover, in the United Kingdom, the financial sector became too big and too highly leveraged. First, the size of our banking system was, as a proportion of GDP, five times that in the United States, and the risks to the UK taxpayer correspondingly greater. Second, the process of reducing very high leverage is doing great damage to the rest of the economy. (...) Third, interconnections between institutions create potential fragilities across the system (...). Fourth, the risks associated with large-scale proprietary trading are probably harder to control in*

[52] *"The horizon over which inflation is brought back to target may need to be extended to prevent a buildup of financial imbalances. This may mean that the central bank is willing to sacrifice a small deviation from the inflation target in the short run in order to mitigate the risk of a larger deviation of inflation further ahead."* (King, 2004).

[53] Despite the awareness of rising housing prices, King is said not to have seen the financial crisis coming even in summer 2008 (David Blanchflower, former external member of the Monetary Policy Committee, https://www.newstatesman.com/politics/2012/04/mervyn-king-tyrant-who-will-succeed-him-bank).

limited liability companies. So we need instruments to prevent the size, leverage, fragility and risk of the financial system from becoming too great." (King, 2009).

Overall, our results indicating a relatively strong housing price component in the interest rate decisions of the Bank of England seem to fit the idea that the BoE considered not only inflation per se, but also housing price inflation. However, the impact on housing prices remained limited, mainly because of regulatory failures that undermined the effects of rising interest rates. These regulatory failures were probably the cause of the limited efficiency of interest rate increases on the housing market.

D.7 United States

Alan Greenspan, the former chair of the Federal Reserve Board, often expressed skepticism about the notion that increasing interest rates can tame asset price bubbles. In his experience, monetary tightening was often followed by increasing asset prices. Even a 300 basis point increase in short rates had not prevented stock prices from rising after 1994 (Greenspan, 2004, Footnote 6). Therefore, he was persuaded that *"there appears to be enough evidence, at least tentatively, to conclude that our strategy of addressing the bubble's consequences rather than the bubble itself has been successful"* (Greenspan, 2004, p. 36), despite acknowledging the need to assess a wide range of risks to output and inflation.[54]

The Fed's policy responses to bursting bubbles have been based on massive liquidity injections into stressed financial markets. The additional liquidity has been expected to prevent asset prices from falling and avert a full-blown financial crisis. This policy, referred to as the "Greenspan put", has been repeated in response to every significant episode of market turmoil in recent decades – in 1987, shortly after Greenspan's appointment, during the savings and loan crisis, during the Gulf War, and after the Mexican crisis. A massive injection was also made after the collapse of LTCM in 1998.

Furthermore, Greenspan used to be against strict forms of financial regulation, believing in the efficient market hypothesis. Therefore, it has been claimed that provision of liquidity to financial markets leads to moral hazard and perverse incentives on financial markets. For example, Miller et al. (2002) identify the response to the LTCM collapse as a trigger of the dot-com bubble.

The dot-com bubble burst of 2000 happened shortly after Greenspan announced a plan to raise interest rates aggressively in February 2002. Investors started to fear that technology companies would not deliver the expected profits when their borrowing costs increased. A fall of the market became only a question of time. The market started to drop in mid-March 2000, and by November it was down by 75%.[55]

[54] *"For such judgment, policymakers have needed to reach beyond models to broader, though less mathematically precise, hypotheses about how the world works. For example, inferences about how market participants and, hence, the economy might respond to a monetary policy initiative may need to be drawn from evidence about past behavior during a period only roughly comparable to the current situation."* (Greenspan, 2004, p. 38).

[55] *"When the risk premium in the US stock market fell substantially, Shiller (2000) attributed this to a bubble driven by psychological factors. An alternative explanation is that the observed risk premium may be reduced by one-sided intervention policy on the part of the Federal Reserve which leads investors into the erroneous belief that they are insured against downside risk. By allowing for partial credibility and state dependent risk aversion, we show that this 'insurance' – referred to as the Greenspan put – is consistent with the observation that implied volatility rises as the market falls. Our bubble is not so much 'irrational exuberance' as exaggerated faith in the stabilizing power of Mr. Greenspan."* (Miller et al., 2002, quoting Robert Shiller's book Irrational Exuberance).

Nevertheless, there is not much evidence that interest rates were raised to curb the bubble. Paul Krugman highlights that the interest rate increases were not accompanied by prudential measures, such as margin requirements for stock market investors (Krugman, 2009, p. 142). However, it should be noted that Greenspan did not believe that such margin requirements could cool down market enthusiasm (Greenspan, 2004, Footnote 7).

After the dot-com bubble, the Fed focused on buying mortgage-backed securities, again directly stimulating asset price inflation, this time especially in housing prices. The housing bubble was also fueled by tax reforms, financial deregulation, and loosening credit standards across the US banking industry. Historically low interest rates also facilitated investments in housing after 2000. However, between 2004 and 2006, interest rates increased from just 1% to 5.25%, making mortgage payments much more difficult for many. Shortly after that, in 2007, the housing market conditions changed and the market dropped, causing the most significant financial crisis since the Great Depression.

Greenspan revised his views on financial bubbles and regulation quite markedly after the financial crisis of 2007–2008. On the growing housing price bubble, he later said: *"I really didn't get it until very late in 2005 and 2006."* (Felsenthal, 2007).

Leonhardt (2008) reported that Greenspan had acknowledged that he had been "partially" wrong in opposing regulation in his Congressional testimony on October 23, 2008. Greenspan stated: *"Those of us who have looked to the self-interest of lending institutions to protect shareholders' equity – myself especially – are in a state of shocked disbelief."* Referring to his free-market ideology, Greenspan said: *"I have found a flaw. I don't know how significant or permanent it is. But I have been very distressed by that fact."* Representative Henry Waxman (D-CA) pressed him to clarify his words: *"In other words, you found that your view of the world, your ideology, was not right, it was not working." "Absolutely, precisely,"* Greenspan replied. *"You know, that's precisely the reason I was shocked, because I have been going for 40 years or more with very considerable evidence that it was working exceptionally well."*

Appendix E: Complementary Analyses

E.1 Univariate Estimation of STSMs

We start our analysis by fitting the univariate STSMs. First, this exercise allows us to understand the properties of the cyclical behavior of the variables without being influenced by cross effects stemming from cyclical interaction via matrices $\boldsymbol{A}$ and $\boldsymbol{A}^*$. Second, the estimates from this partial analysis serve as the underlying values used for setting the priors in the multivariate models. Last but not least, it also allows us to assess whether financial variables share similar cyclical properties, which would result in the same values of the parameters governing the persistence and the length of the cycles, ρ_i, ϕ_i, and λ_i.

Table E1: Estimation of Univariate STSMs – Priors

Parameter	Distrib.	Mean	SD	Parameter	Distrib.	Mean	SD
λ_1	Γ	0.2	0.10	ϕ_1	β	0.7	0.15
λ_2	Γ	0.1	0.07	ϕ_2	β	0.65-0.8	0.15
λ_3	Γ	0.1	0.07	ϕ_3	β	0.8	0.15
λ_4	Γ	0.1	0.07	ϕ_4	β	0.6-0.7	0.15
ρ_1	β	0.7	0.15	σ_ε	inv-Γ	0.005	∞
ρ_2	β	0.65-0.8	0.15	σ_ξ	inv-Γ	0.001	∞
ρ_3	β	0.8	0.15	σ_ζ	inv-Γ	0.001-0.002	0.0002
ρ_4	β	0.6-0.7	0.15				

The setting of the priors for the main parameters of the univariate models is summarized in Table E1. Since our data sample covers economies that exhibit different characteristics, certain priors differ slightly across the countries. Even though the literature offers relatively rich evidence on the cyclical behavior of the variables included in our analysis, the priors on the parameters are set with relatively high standard deviations to let the data speak. The priors on the cycle frequencies, λ_i, follow Gamma distributions. The means of the priors for the frequencies of the cycles of GDP and financial variables are set at 0.2 and 0.1, respectively. This selection is motivated by the estimates of Galati et al. (2016) and Rünstler and Vlekke (2018), who report that the financial cycle is almost twice as long as the business cycle. The priors of the parameters ρ_i and ϕ_i are inspired by Rünstler and Vlekke (2018). In general, we assume less persistence in the business cycle and share prices, and higher persistence in credit and housing prices. The priors of innovations originate in Harvey et al. (2007). The priors of irregular components are assumed to follow inverse-Gamma distributions. The priors for the volatility of the stochastic slope innovation, $\boldsymbol{\zeta}_t$,[56] and the time-varying drift are set at a lower value than the prior volatility of the innovation $\boldsymbol{\varepsilon}_t$. Following Rünstler et al. (2018), the standard deviations of innovations $\boldsymbol{\kappa}_t$ and $\boldsymbol{\kappa}_t^*$ are calibrated at 1.

The results of the estimation of the univariate models are summarized in Table E2. Figures C1–C7 in Appendix C offer trend and cycle decompositions. The table shows that, except for the United States, the credit cycle is characterized by a lower frequency than the cycle of housing prices. Additionally, the frequencies of both mentioned financial variables attain significantly lower values

[56] As explained by Guarda and Moura (2019), the relatively tight prior of the stochastic slope innovation, $\boldsymbol{\zeta}_t$, ensures that the STSMs identify trends that are relatively smooth without any abrupt kinks and evolve slowly over time.

compared to the business cycle. The persistence parameters (ρ and ϕ) turn out to be 0.85 on average, suggesting high persistence in the cyclical behavior of both financial variables. Lastly, the cycle of housing prices tends to be more volatile than the credit cycle. The results are not so unified in the case of share prices. In general, the estimates of the persistence parameters are substantially lower compared to credit and housing prices. On the one hand, Canada, Sweden, and the United States form a cluster characterized by high frequency compared to the other two financial measures. On the other hand, the share price cycles in the rest of the countries have similar frequencies as their credit counterparts. Overall, the results suggest that credit and housing prices tend to move together and could be characterized by similar estimates governing the persistence and frequencies of cyclical behavior.

Table E2: Main Parameter Estimates from Univariate STSMs

Country	Variable	ρ	ϕ	λ	Volatility (σ_c)
Australia	Credit	0.863	0.805	0.062	0.024
	Housing prices	0.805	0.835	0.098	0.042
	Share prices	0.702	0.594	0.068	0.129
Canada	Credit	0.855	0.864	0.061	0.027
	Housing prices	0.763	0.729	0.073	0.039
	Share prices	0.622	0.683	0.129	0.104
Japan	Credit	0.905	0.889	0.071	0.029
	Housing prices	0.9	0.877	0.104	0.104
	Share prices	0.688	0.787	0.076	0.145
New Zealand	Credit	0.79	0.801	0.079	0.043
	Housing prices	0.919	0.818	0.145	0.053
	Share prices	0.728	0.697	0.078	0.132
Sweden	Credit	0.838	0.859	0.065	0.027
	Housing prices	0.903	0.854	0.077	0.043
	Share prices	0.699	0.786	0.084	0.156
United Kingdom	Credit	0.876	0.868	0.073	0.036
	Housing prices	0.886	0.889	0.098	0.068
	Share prices	0.553	0.818	0.084	0.141
United States	Credit	0.943	0.939	0.102	0.027
	Housing prices	0.926	0.892	0.075	0.029
	Share prices	0.534	0.859	0.188	0.127

Note: The table summarizes the parameter estimates related to the financial variables (that is, credit, housing prices, and share prices) from the univariate STSMs. In the univariate setting, the volatility of cycles is given by $\sigma_c = \sigma_\kappa / \sqrt{(1-\rho^2)(1-\phi^2)}$, as shown by Rünstler and Vlekke (2018).

To assess the degree of similarity of the cyclical properties of the financial variables,[57] we estimate the univariate STSMs jointly for all four time series in two setups: an unrestricted model (m_u)

[57] Given the preliminary results discussed in the previous paragraph, we do not perform the test of similar cycle properties for all the financial variables. Additionally, we do not test the similarity with GDP, since the business

and a restricted model (m_r). Under the restricted model, we impose restrictions on the parameters defining the cyclical characteristics of credit and housing prices, such that $\rho_2 = \rho_3$, $\phi_2 = \phi_3$ and $\lambda_2 = \lambda_3$. The priors on the common parameters are selected as the average estimates stemming from the estimation of the unrestricted model. The final estimates from both models are then used in the computation of the Bayes factor to determine the relative fits of the models (see, for example, An and Schorfheide, 2007). The Bayes factor (BF) is calculated as

$$BF = \frac{\exp\{LL(Y|m_r)\}}{\exp\{LL(Y|m_u)\}} \tag{E1}$$

where $LL(Y|m_z)$ for $z = r, u$ represents the log-likelihood for the observed data Y conditional on the model m_z. The log-data density is computed using Laplace approximation. The results of this analysis are displayed in Table E3. Compared to the unrestricted case, the estimations under restricted models yield less mixed results across the countries regarding the persistence parameters. The main differences can be seen in the cycle frequencies.

Table E3: Financial Variables – Assessment of Similar Cycles

Country	Variable	ρ	ϕ	λ	BF
Australia	Credit, housing prices	0.832	0.827	0.068	3.235
Canada	Credit, housing prices	0.845	0.723	0.064	4.229
Japan	Credit, housing prices	0.908	0.916	0.069	13.366
New Zealand	Credit, housing prices	0.875	0.877	0.114	26.891
Sweden	Credit, housing prices	0.884	0.871	0.062	5.362
United Kingdom	Credit, housing prices	0.887	0.897	0.09	18.534
United States	Credit, housing prices	0.938	0.924	0.095	7.888

Note: Values of the Bayes factor (BF) greater than one indicate evidence in favor of the restricted model.

The last column of Table E3 shows the Bayes factor values for each country. The Bayes factor suggests similar cycle restrictions (indicated by values greater than one) in all countries.[58] The most significant evidence for similarity between cycles is found for New Zealand and the United Kingdom, while less supportive evidence is given for Australia and Canada. We use the results of this partial analysis in the estimations of the multivariate STSMs; that is, we assume similar cyclical properties of credit and real housing prices for all the countries in our data sample.

E.2 The Bandpass Filter

To gain a basic idea about the cyclical behavior of the individual financial variables, we start by applying a simple tool of spectral analysis – a bandpass filter. The results of this exercise serve as a benchmark for further analysis and comparison. We apply the bandpass filter to three financial time series – credit, house prices, and share prices. These variables should capture various features of the financial cycle, as argued by Bulligan et al. (2019). The selection is also motivated by ECB (2014). Following Drehmann et al. (2014) and Verona (2016), we apply the filter introduced by Christiano

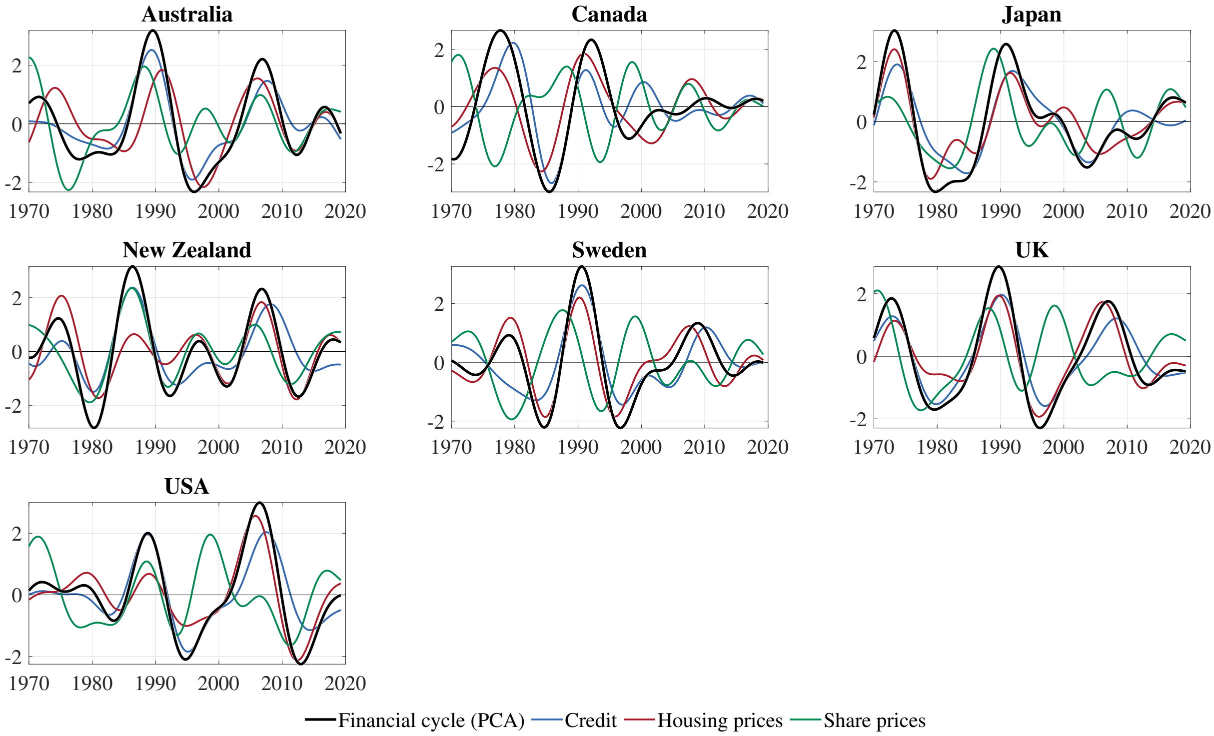
cycle exhibits very different behavior compared to the financial variables, as discussed and tested by, for example, Rünstler and Vlekke (2018).

[58] Such results are in line with the findings of Rünstler and Vlekke (2018), who report similar cycle properties for the United States and several other European countries.

and Fitzgerald (2003) to extract financial cycles. We set the frequency band at 32–120 quarters in accordance with the said studies to capture the medium-term frequencies.

Figure E1 depicts the results of the univariate filtering exercise. In both cases, the estimated cycles prove to be larger and more persistent than the typical business cycle. This is not surprising, since the bandpass filter suppresses the high-frequency component of the time series.

Figure E1: Financial Cycles and Cycles of Constituent Indicators – The Bandpass Filter

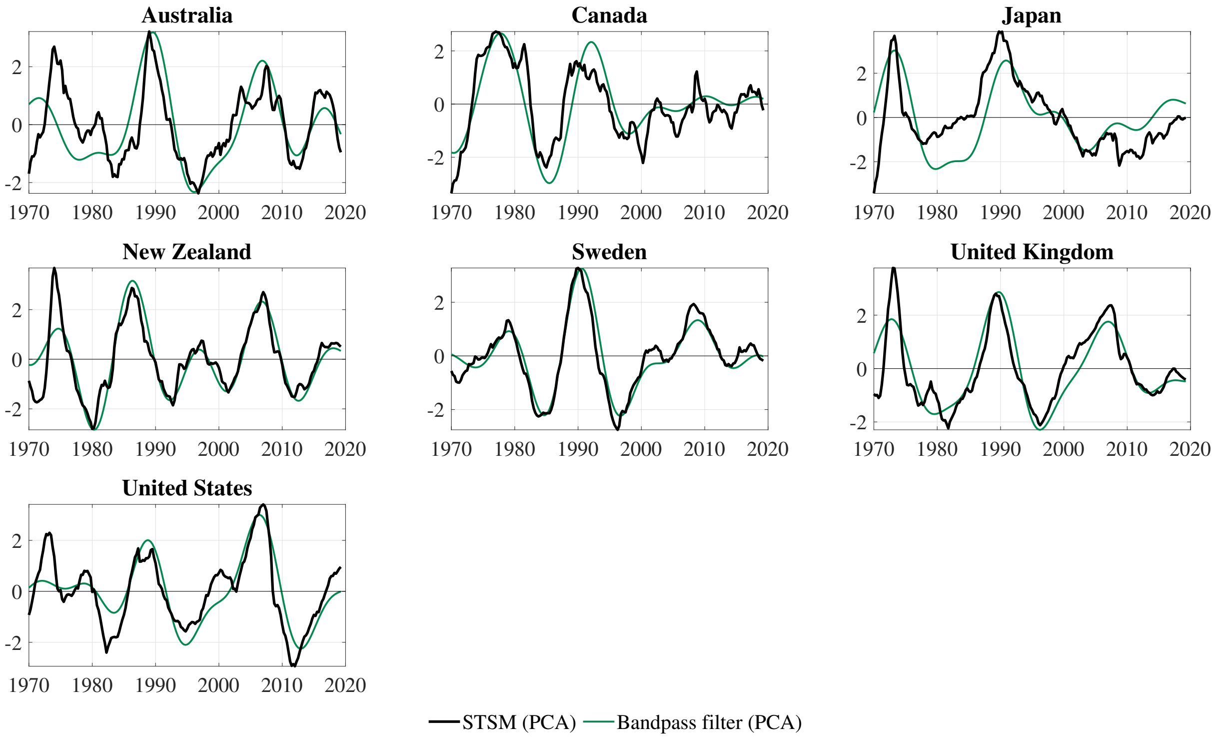


Note: Quarterly data. The financial cycle is the first principle component of the three underlying indicators.

E.3 The Bandpass Filter vs the STSM

Figure E2 depicts the graphical representation of the financial cycles resulting from the application of the bandpass filter and the multivariate stochastic trend and cycle model. From the individual subfigures, it can be seen that the bandpass filter delivers the same results as the structural model for New Zealand, Sweden, and the United Kingdom. Conversely, there are substantial differences in the case of Australia, Canada, and Japan. In the first case, the financial cycle is even qualitatively different in specific periods. The differences lie mainly in the smoother cycles delivered by the bandpass filter. An apparent divergence between the cycles resulting from the two presented methods can be identified at the beginning of the data sample.

Figure E2: Financial Cycles – The Bandpass Filter and the STSM

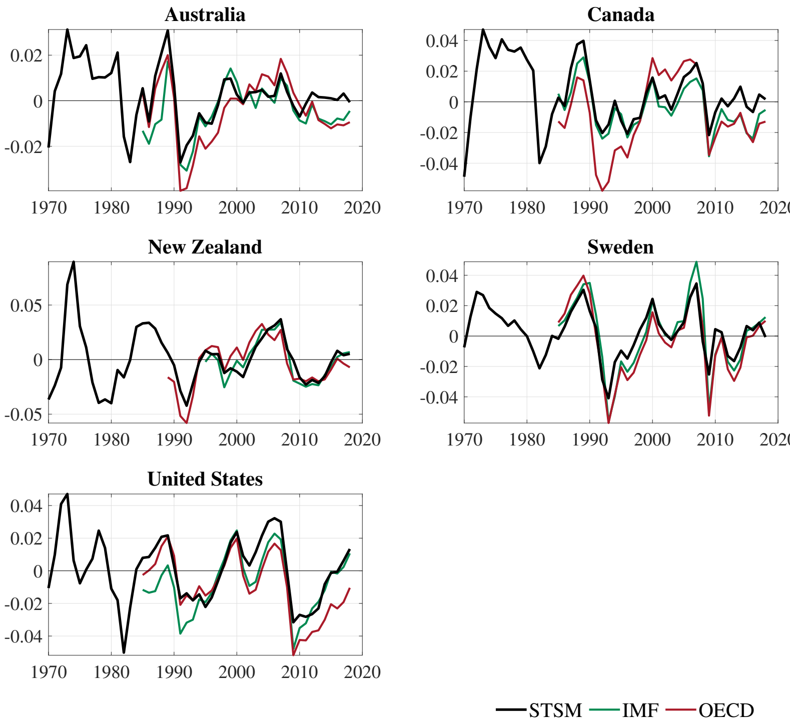


Note: Quarterly data.

E.4 Output Gap Estimates – STSM, IMF, and OECD Comparison

Figure E3 shows the estimates of the output gaps from the multivariate STSM and offers a comparison with the "official" estimates of the IMF and the OECD. Since both "official" output gaps are available only on a yearly basis, we transform our estimated cycles from quarterly to yearly data. As can be seen from Figure E3, the multivariate STSM delivers plausible results in all cases. The estimated gaps for New Zealand, Sweden, and the United Kingdom are almost identical to those delivered by the IMF and the OECD. Even though the estimates for the other countries differ more or less in certain phases, the overall impression remains satisfactory.

Figure E3: Comparison of the Estimated Output Gaps with the IMF and OECD Estimates



Note: Yearly data.

E.5 GMM Estimation of the Reaction Functions

We re-estimated the forward-looking monetary policy rule in Equation (9) with constant parameters using a two-step generalized method of moments (GMM). Under the assumption of rational expectations, the estimation of the model rests on the orthogonality condition

$$\mathbb{E}_t[i_t - (1-\rho)(\beta_0 + \beta_\pi \pi_{t+2} + \beta_y \tilde{y}_t - \beta_f f_{t-1}) - \rho i_{t-1}|u_t] = 0 \tag{E2}$$

where u_t is the set of instruments. The parameters ρ, β_0, β_π, β_y, and β_f are estimated by a two-step GMM. Inspired by Franta et al. (2018), we use the following set of instruments: a vector of ones, the first four lags of inflation, the output gap, the financial cycle, the interest rate, the growth of the real effective exchange rate, the growth of commodity prices, and the effective federal funds rate. Given the extensive international trade between the United States and Canada, the first four lags of the CAD/USD exchange rate replace the federal funds rate in the set of instruments for Canada. The list of instruments for Sweden does not include the federal funds rate. The results of the estimation, along with a test for overidentifying restrictions (the J-test), are reported in Table E4.

Table E4: Estimates Based on a Two-Step GMM

Country	β_π	β_y	β_f	ρ	**J-statistic**
Australia	0.991	1.591	1.281	0.926	12.909
	(0.219)	(0.462)	(0.532)	(0.014)	(0.967)
Canada	2.312	1.706	3.225	0.931	15.684
	(0.327)	(0.484)	(0.772)	(0.017)	(0.971)
Japan	-1.332	0.731	2.517	0.956	16.293
	(1.316)	(0.469)	(0.703)	(0.020)	(0.877)
New Zealand	1.206	0.593	-1.108	0.874	8.783
	(0.339)	(0.217)	(0.322)	(0.026)	(0.998)
Sweden	1.225	1.492	2.743	0.961	15.144
	(0.568)	(0.854)	(2.207)	(0.018)	(0.916)
United Kingdom	2.976	2.756	-0.196	0.959	13.171
	(0.831)	(0.939)	(0.911)	(0.011)	(0.963)
United States	1.924	1.572	0.066	0.937	14.513
	(0.393)	(0.304)	(0.443)	(0.010)	(0.934)

Note: Standard errors are displayed in parentheses; the p-value is reported below the J-statistic. The null hypothesis for the t-test is that the coefficients equal zero, except for the coefficient on inflation, which is set to one.

Appendix F: Data

The data set used in this paper combines time series from three primary data sources – the BIS, Federal Reserve Economic Data, and the OECD. We employ seasonally adjusted time series, or we perform seasonal adjustment using the X-12 ARIMA procedure when seasonally adjusted time series are not directly available and statistical tests detect seasonality. Our data sample covers seven economies – Australia, Canada, Japan, New Zealand, Sweden, the United Kingdom, and the United States – to capture the heterogeneity among inflation-targeting countries and provide international evidence. The data sample captures the period 1970q1–2019q2 for the estimation of financial cycles and 1986q1–2019q2 for the estimation of reaction functions, both on a quarterly basis.[59]

Table F1: Data

Variable	Description	Source
CR_t	Nominal total credit to private non-financial sector	BIS statistics
$ER_t^{CAD/USD}$	Nominal CAD/USD exchange rate	OECD data
i_t	3-month interest rate	OECD data
i_t^{FED}	Effective federal funds rate	FRED database
i_t^{L}	Long-term interest rates on government bonds (10 years)	OECD data, BoJ[60]
i_t^{shadow}	Shadow interest rates (for Japan, Sweden, UK, and USA)	Rezende and Ristiniemi (2020), Krippner (2020)[61]
$NEER_t$	Nominal effective exchange rate	BIS database
P_t	Consumer price index	OECD data
$P_{H,t}$	Nominal house price index	OECD data
$P_{S,t}$	Nominal share price index	OECD data
$PCOMM_t$	Producer price index (all commodities)	FRED database
$PGDP_t$	GDP deflator	OECD data
π_t^*	Inflation target	Central banks' websites
π_t^{green}	Greenbook forecasts of inflation (for USA)	Greenbook data
$REER_t$	Real effective exchange rate (manufacturing CPI)	FRED database
Y_t	Nominal gross domestic product	OECD data
$\hat{y}_t^{green}$	Greenbook estimates of output gap (for USA)	Greenbook data

To estimate the financial cycle, we choose three underlying financial variables – credit, housing prices, and share prices. The selection of the variables is motivated by ECB (2014) and Juselius and Drehmann (2020), who report that those financial variables provide a reasonable and sufficient decomposition of the financial cycle.[62] Credit comes from the BIS Database and is represented by total credit to the private non-financial sector for all sectors. The OECD Database is the source

[59] Given that financial cycles are longer than the usual business cycle, the longest possible period should be covered to obtain reliable estimates. Since we are limited by the availability of data on interest rates, the data sample is shorter in the case of the estimation of reaction functions.

[60] We also use official data from the Bank of Japan (BoJ) to complete our data set. Since the BoJ does not provide data for government bonds maturing in 10 years before 1986, we use 9-year maturity for 1985 instead.

[61] Shadow rates for Japan, the United Kingdom, and the United States are available on Leo Krippner's personal website ljkmfa.com.

[62] The selection also resembles previous studies, such as Claessens et al. (2010).

of the other two underlying financial variables. The nominal house price index, which captures residential real estate prices, is used to measure housing prices. This index covers prices for the sale of newly-built and existing dwellings. Share prices are proxied by the nominal share price index, which conveys condensed information about the respective national financial market. The last input into the financial cycle analysis is gross domestic product, which is measured using the expenditure approach and comes from the OECD Database.

We employ two sets of variables in the estimation of reaction functions (monetary policy rules). The first set is used to estimate the baseline rules, while the second set is employed for robustness checks. The dependent variable is the 3-month interbank interest rate, which is closely related to the official policy rate. The selection of this interest rate helps us overcome issues related to the global financial crisis of 2008–2009. Conventional interest rates were not, however, the only source of monetary policy implementation in the last decade, as unconventional monetary policy measures have become an integral part of the monetary policy conduct of several central banks in our data sample.[63] Therefore, we replace the short-term interest rates of Japan, Sweden, the United Kingdom, and the United States with *shadow interest rates*.[64] We use the estimates of short-term shadow rates provided by Krippner (2020) for Japan, the United Kingdom, and the United States and by Rezende and Ristiniemi (2020) for Sweden.

Inflation is measured as the year-on-year change in the consumer price index. We employ the Hamilton (2018) regression filter to obtain estimates of output gaps.[65] We also use several other variables in the robustness analyses – the inflation target, the real effective exchange rate, commodity prices, the effective federal funds rate, the CAD/USD exchange rate pair, and the Greenbook datasets on inflation and the output gap.[66] Last but not least, long-term interest rates on government bonds maturing in 10 years, nominal effective exchange rates, and selected main stock market indices[67] are used to construct a simplified financial stress index (FSI), which is used in one of the robustness checks of our results.

The variables and data sources are summarized in Table F1. We further modify the input data for estimation purposes. We transform all the variables, except for interest rates, the inflation target, the real and nominal effective exchange rates, and the leading stock market indices, into real quantities by dividing them by the GDP deflator, and we also transform them into natural logarithms. We convert the real and nominal effective exchange rates, the leading stock market indices, and commodity prices into logarithmic differences.

[63] The Bank of Japan became the first central bank in the world to implement quantitative easing (QE) in 2001. The Swedish Riksbank started to purchase nominal government bonds in February 2015. The Bank of England launched QE in late 2009 after hitting the zero lower bound. The Fed eased its monetary policy during 2008–2014 via three rounds of QE programs and started to normalize its monetary policy in 2017.

[64] Shadow rates coincide with short-term interest rates if unconventional monetary policy measures are not implemented.

[65] Although we also estimate output gaps as part of the estimation of the financial cycle, we resort to a standard output gap extraction method used in the literature.

[66] One of the robustness exercises in Section 6 presents a real-time perspective on the Fed's monetary policymaking. To offer such a view, we use data vintages from the Greenbooks of the Federal Reserve Board of Governors.

[67] The data for leading stock market indices are retrieved from the platforms Yahoo Finance and investing.com.

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