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## **DSGE Forecasts of the Lost Recovery**

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### **Abstract**

The years following the Great Recession were challenging for forecasters. Unlike other deep downturns, this recession was not followed by a swift recovery, but generated a sizable and persistent output gap that was not accompanied by deflation as a traditional Phillips curve relationship would have predicted. Moreover, the zero lower bound and unconventional monetary policy generated an unprecedented policy environment. We document the real-time forecasting performance of the New York Fed dynamic stochastic general equilibrium (DSGE) model during this period and explain the results using the pseudo real-time forecasting performance results from a battery of DSGE models. We find the New York Fed DSGE model's forecasting accuracy to be comparable to that of private forecasters and notably better, for output growth, than the median forecasts from the Federal Open Market Committee's Summary of Economic Projections. The model's financial frictions were key in obtaining these results, as they implied a slow recovery following the financial crisis.

Key words: DSGE models, real-time forecasts, Great Recession, financial frictions

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# 1 Introduction

The years following the Great Recession have been quite challenging from a forecasting point of view. The deep recession was not followed by a swift recovery, unlike in previous post-war recessions, but instead generated a persistent output gap. This large gap was however not associated with negative inflation, as a traditional Phillips curve relationship would have predicted, resulting in what Stock (2011) called the “missing disinflation” (see also Hall, 2011, Ball and Mazumder, 2011, Coibion and Gorodnichenko, 2015, and Del Negro et al., 2015). At the same time the federal funds rate was stuck at near zero levels for several years. This prompted the central bank to use tools that had never been used before, such as quantitative easing (henceforth, QE) and forward guidance. On top of all this, the U.S. economy found itself in the middle of both a demographic transition caused by the retirement of baby boomers, and a secular downward shift in the growth rate of total factor productivity, at least according to some authors (see, among others, Fernald, 2015; Fernald et al., 2017; Gordon, 2015).

This combination of unusual, far-from-steady-state conditions presented a challenging environment for any econometric model, but in particular for dynamic stochastic general equilibrium (DSGE) models in the tradition of Smets and Wouters (2003, 2007), due to their rigid structure and tight cross-equation restrictions. Over the past decade, these models have become part of many central banks’ forecasting and policy analysis toolbox, and the post-Great Recession setting provided an important real-time test of their predictive accuracy. So how did these models fare?

Against this backdrop, this paper pursues two objectives. The first objective addresses the above question as far as the Federal Reserve Bank of New York DSGE model (henceforth, NY Fed DSGE) is concerned. Specifically, Section 2 of the paper documents how the NY Fed DSGE model fared in terms of real-time forecasting accuracy relative to forecasters such as those surveyed in the Blue Chip survey or the Survey of Professional Forecasters (henceforth, SPF), as well as the Federal Reserve System’s Summary of Economic Projections (henceforth, SEP), and how researchers using the model coped with the difficulties discussed above. We should stress that the forecasting comparison exercise performed in Section 2 is done using *real* real-time forecasts—that is, forecasts that were generated at that time.<sup>1</sup> The

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<sup>1</sup>In this sense the exercise is similar to that conducted in several papers studying either official central bank forecasts or regularly published model-based forecasts, such as those from the FRB/US model of the Federal Reserve’s Board of Governors (e.g., Romer and Romer, 2000; Tetlow and Ironside, 2007; Romer and

advantage of this feature of our exercise is that there is by construction no look-ahead bias in the choice of model or observables. The disadvantage is that the results are based on the available sample of forecasts. Section 2 also discusses how the model changed to incorporate financial frictions and began to use financial data as observables.

The second objective of the paper complements this real real-time forecasting exercise with a *pseudo* real-time analogue. The main goal of this exercise, which is pursued in Section 3, is to understand what model features, and observables, explain the performance of the NY Fed DSGE model. In addition, this exercise extends the historical forecast accuracy comparison of Edge and Gürkaynak (2010a) and Del Negro and Schorfheide (2013) both in terms of the period and the models considered. These comparisons did not focus on the post-Great Recession years. They were not considered at all in Edge and Gürkaynak (2010a) and were barely included in Del Negro and Schorfheide (2013) (their sample ends in early 2011). Moreover, Edge and Gürkaynak (2010a) only consider the Smets and Wouters (2007) model while Del Negro and Schorfheide (2013) mainly focus on the performance of close variants of this model. Here, the centerpiece of our analysis will be models with financial frictions (e.g., Christiano et al., 2014; Del Negro et al., 2015, 2016) that incorporate corporate bond spreads as observables.<sup>2</sup>

We find that in the short and medium run—from one through eight quarters ahead—the NY Fed DSGE model’s root mean squared errors (henceforth, RMSEs) are comparable to the error of the median forecasts of both the Blue Chip and the SPF surveys. Relative to the median of the FOMC’s SEP, the NY Fed DSGE model performs much better in terms of the accuracy of output growth forecasts, especially at longer horizons (three years ahead). The NY Fed DSGE model’s inflation forecast performs worse than the median SEP up to a two year horizon, but better at a three year horizon and beyond. The results of the pseudo real-time forecasting exercise show that financial frictions play a major role, especially in Romer, 2008; Groen et al., 2009; Alessi et al., 2014). Edge et al. (2010) compare the accuracy of real real-time forecasts from the Board of Governors’ Green Book (the staff forecasts) and FRB/US to that of projections from EDO, the DSGE model used at the Board. In their case, however, the DSGE forecasts are constructed in a pseudo real-time environment. Iversen et al. (2016) is closest to this paper as it performs a truly real real-time exercise when comparing the forecasts of the Riksbank’s DSGE model to the judgmental forecasts published by the Riksbank and to those of a Bayesian vector autoregression for the period 2007-2013.

<sup>2</sup>In addition to the articles we already mentioned, there are several other papers assessing pseudo real-time forecasts of DSGE models, some of which are used in central banks. Examples are Adolfson et al. (2007); Christoffel et al. (2010); Lees et al. (2011); Wieland and Wolters (2012); Kolasa et al. (2012); Kolasa and Rubaszek (2015); Fawcett et al. (2015); Kilponen et al. (2016). Fair (2018) is a recent paper examining the information content of DSGE forecasts, including those presented in this paper.

terms of the projections for economic activity, as they imply a slow recovery from financial crisis—a result reminiscent of the findings of Reinhart and Rogoff (2009).

Forecasts in this paper are generated by a micro-founded structural model. This implies that they can always be explained in terms of “impulse and propagation” of structural shocks. Over the course of this paper we will sometimes take advantage of this feature and describe the DSGE forecasts in these terms, using shock-decompositions and impulse response functions. Some readers may find this commingling of story-telling and forecasting confusing, as most forecasting papers do not usually concern themselves with explaining the model’s forecasts. But, this is arguably a strength of forecasting with DSGE models—the story and the forecast go together. This implies that we can learn which model features may have resulted in an inaccurate forecast. We will elaborate further on this in the remainder of the paper.

## 2 Real Real-Time Forecasts of NY Fed DSGE Model

This section begins with a brief description of the main features of the NY Fed DSGE model and of how they evolved over time. For the sake of brevity this description acts as a broad-level overview, whereas all of the technical details are relegated to the Appendix and to other sources. The section then continues by documenting the model’s forecasting accuracy from 2011, which was the first year in which the model was used to produce regular projections.

### 2.1 A Short History of the New York Fed DSGE Model

The New York Fed DSGE model came to existence around 2004 as a three-equation New Keynesian model (see Sbordone et al., 2010). At the time, the model was used for a variety of policy analysis exercises but not for forecasting. In 2008, that model was replaced by a medium-scale (that is, similar to the model by Smets and Wouters, 2007, in terms of features) New Keynesian DSGE model built along the lines of Del Negro and Schorfheide (2008) and estimated with Bayesian methods using five time series: real GDP growth, core PCE inflation, hours, the labor share, and the federal funds rate.<sup>3</sup>

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<sup>3</sup>Del Negro and Schorfheide (2008) and Del Negro et al. (2013) provide a detailed description of the model, priors, data, and estimation procedure.

In mid-2010, the model began to be used internally for forecasting the U.S. economy, and from the end of 2010 onward, the model’s forecasts have been produced systematically almost every FOMC cycle and incorporated into internal policy documents. At the time the zero lower bound on nominal interest rates (henceforth, ZLB) was an important constraint on monetary policy (and remained so for another six years). We incorporated this constraint into the DSGE forecasts by augmenting the measurement equation with federal funds rate expectations obtained from financial markets, following the approach described in Del Negro and Schorfheide (2013) and Del Negro et al. (2012). This approach amounted to forcing the model’s expectations for the policy instrument to coincide with market expectations. Since the latter of course took the ZLB into account, so did the DSGE projections. In order to enhance the model with the ability to accommodate federal funds rate expectations, the policy rule in the model was augmented with anticipated policy shocks as used in Laseen and Svensson, 2011. These policy “news” shocks capture constraints on future policy, whether they are contractionary (i.e., when the anticipated policy rate is higher than predicted by the reaction function) or stimulative (i.e., when the anticipated policy rate is lower than predicted by the reaction function, as under a “forward guidance” policy).

In 2010, the model was further transformed by the addition of financial frictions, following the work of Christiano et al. (2003, 2014). In the aftermath of financial crisis we felt that this addition was overdue (Section 3.2 makes the case that this was definitely an good idea from the perspective of forecasting performance in the years following the crisis). Specifically, the model incorporated a financial accelerator à la Bernanke et al. (1999), implying that firms’ ability to invest is constrained by their leverage and more broadly by financial market conditions. In order to capture financial conditions quantitatively, we added the spreads between the yields of Baa corporate bonds and Treasuries to the model’s set of observables. In June 2011, the NY Fed DSGE forecasts obtained from the model with financial frictions became part of a [memo](#) produced four times a year for the FOMC (Dotsey et al., 2011; see also page 2 of the [June 2011 FOMC Minutes](#)).

The model built in 2010, which is described in some detail in Del Negro et al. (2013), continued to be the main workhorse for DSGE projections and policy analysis at the NY Fed until the end of 2014. It was then replaced by another New Keynesian model with financial frictions – referred to henceforth as the SWFF model and used in Del Negro and Schorfheide (2013) and Del Negro et al. (2015). Relative to the financial friction model introduced in 2010, SWFF was closer to the original Smets and Wouters (2007) model in terms of the specification of the household’s utility function and other modeling details.

Importantly, its forecasting accuracy, especially in periods of financial stress such as the financial crisis, had been demonstrated in Del Negro and Schorfheide (2013) and Del Negro et al. (2016). In addition, it had the advantage of adding investment and consumption to the set of observables.<sup>4</sup> This addition was the main rationale behind the change.

The SWFF model itself was never actually used in production at the NY Fed. Rather, we adopted a variant of this model, which we will call SWFF<sup>+</sup>. This was partly because the SWFF model used in academic papers measured inflation using the GDP deflator. However, the core PCE deflator was a more relevant measure for policy purposes. We therefore added this variable to the set of observables under the assumption that inflation in the model is the common component between these two empirical measures of inflation.<sup>5</sup> Moreover, at the time a debate on a possible secular decline in productivity growth beginning in the early 2000s was raging (e.g., Gordon, 2015; Fernald, 2015). Given the important policy implications of this debate we also added John Fernald’s measure of total factor productivity growth (henceforth, TFP) to the data on which the model was estimated. In order to give the DSGE a chance to capture secular shifts in productivity growth we modeled TFP as the sum of two components: a trend-stationary one (as in Smets and Wouters, 2007) and a non-stationary component whose growth rates follow an autoregressive process. As the autocorrelation coefficient approaches one, the latter component can in principle capture very persistent shifts in TFP growth. Furthermore, we also added the 10-Year Treasury Yield to the set of observables in order to capture changes in financial conditions stemming from quantitative easing operations as well as forward guidance. Finally, in 2016 we included GDI as an additional measure of output, following the work of Aruoba et al. (2016). We refer to this most recent model as Model SWFF<sup>++</sup>.<sup>6</sup>

Starting in [September 2014](#), the NY Fed DSGE model forecasts have been made public on the [Liberty Street Economics Blog](#) twice a year, and by the beginning of 2017, forecasts were being published four times a year (specifically made available in [May](#) and [December 2015](#),

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<sup>4</sup>SWFF is estimated on the same observables as Smets and Wouters (2007) (namely the growth rates in GDP, consumption, investment, and wages, all expressed in real terms, the level of hours, GDP deflator inflation, and the federal funds rate), plus spreads and long-run inflation expectations obtained from the SPF. The latter are included because Del Negro and Schorfheide (2013) found that they improve the model’s accuracy in forecasting inflation even when the prior on the steady-state inflation parameter is relaxed substantially relative to Smets and Wouters (2007)’s paper.

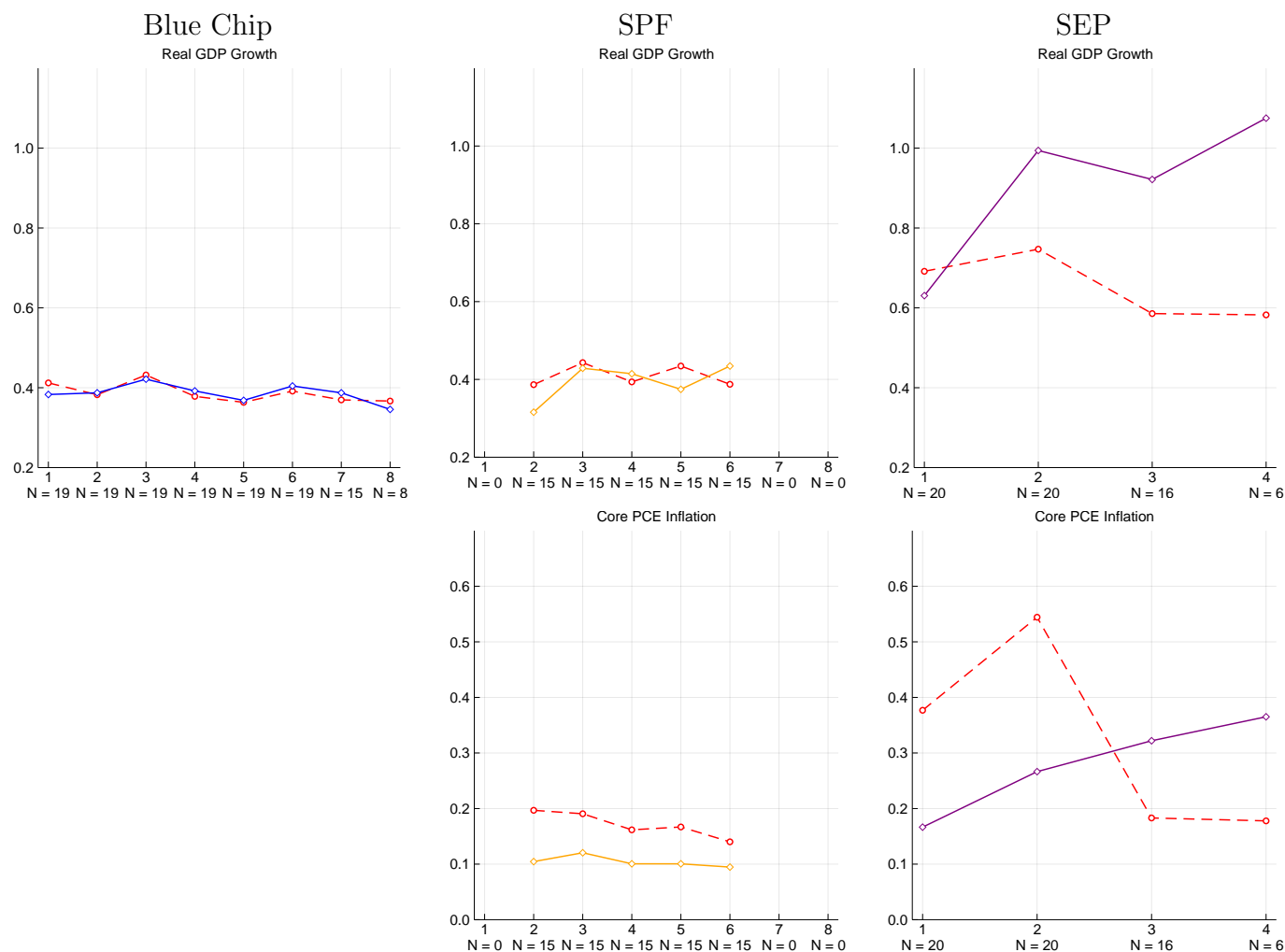
<sup>5</sup>This choice was inspired by the work of Boivin and Giannoni (2006) and Justiniano et al. (2013).

<sup>6</sup>The Appendix provides all the equilibrium conditions, the prior specification, and data definitions for models SWFF, SWFF<sup>+</sup> and SWFF<sup>++</sup>. As mentioned earlier, Del Negro et al. (2013) contains this information for the early financial friction model.

May and November 2016, and in February, May, August and November 2017). The current model specification is also available [online](#), as is the Matlab code for the early financial friction model and SWFF<sup>+</sup>, and the Julia code for SWFF<sup>++</sup>.<sup>7</sup>

## 2.2 NY Fed DSGE Forecasts

Figure 1: Historic RMSEs for NY Fed DSGE Model Forecasts



*Note:* These panels compare the RMSEs for NY Fed DSGE model forecasts (red circles) of real GDP growth and core PCE inflation from March 2011 to March 2016 to those of the Blue Chip Economic Indicators survey (blue diamonds, left), the Survey of Professional Forecasters (SPF) (yellow diamonds, center), and the Summary of Economic Projections (SEP) (purple diamonds, right). The Blue Chip and SPF forecasts are in terms of Q/Q percent rates and the SEP forecasts are expressed in Q4/Q4 average rates. When computing RMSEs, each external forecast is matched to the nearest preceding DSGE forecast in order to ensure comparability of results. Below each horizon we indicate the number of observations.

In this section, we examine the performance of NY Fed DSGE forecasts of real GDP

<sup>7</sup>The code for the three models is available at <https://github.com/FRBNY-DSGE> in the [DSGE-2014-Sep](#), [DSGE-2015-Apr](#), and [DSGE.jl](#) repositories, respectively.



growth and core PCE inflation, focusing on forecasts made for each FOMC cycle from 2011Q1 to 2016Q1. First, we consider the RMSEs of the DSGE model’s real output growth and core PCE inflation forecasts relative to the output forecasts of the Blue Chip Economic Indicators (henceforth, BCEI) monthly survey and the output and inflation forecasts of the SPF and the FOMC’s SEP.<sup>8</sup> We do not show the federal funds rate projections because during this period the NY Fed DSGE forecasts were conditional on external forecasts of this variable in order to take the ZLB and forward guidance into account, as discussed previously. Second, we examine the evolution of the NY Fed DSGE model’s forecasts for output and inflation and compare them to contemporaneous SEP forecasts and realized data in order to explain some of the differences in forecast accuracy. The NY Fed DSGE forecasts considered in this comparison range from March 2011 to March 2016.

We compute RMSEs by creating a sample of comparable NY Fed DSGE forecasts for each survey forecast. For a given survey forecast, we search for the nearest *preceding* DSGE model forecast with the same first forecast quarter (in the case of the SEP, we use the NY Fed DSGE forecast produced for the same FOMC meeting). If we cannot find such a forecast, then we drop that observation from the sample.<sup>9</sup> This matching scheme ensures that the DSGE forecasts are not given an informational advantage.

The BCEI forecasts are reported in quarter-to-quarter (henceforth, Q/Q) percent change and are released monthly. We consider the April, July, October and January forecasts, as these are the last ones that are released prior to the release of the Q1, Q2, Q3, and Q4 GDP measurements. Under our matching scheme, these forecasts are typically paired with the forecasts produced for the March, June, September, and December FOMC meetings, respectively, whenever available (Table A-2 in the Online Appendix contains the list of all forecast vintages used in the BCEI, SPF, and SEP RMSE comparisons). The Blue Chip survey asks respondents to forecast from the current quarter until the end of the next calendar year, which sets the forecast horizon to range from 9 quarters in January (beginning in Q4 of the previous year) to 6 quarters in October. We follow the literature and compare the NY Fed DSGE forecast with the average BCEI projection, which is often referred to as the Consensus Blue Chip forecast.

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<sup>8</sup>We cannot compare historic DSGE forecasts of inflation to BCEI forecasts as the latter reports GDP deflator inflation instead of core PCE inflation.

<sup>9</sup>Although we historically ran DSGE forecasts at least one to two times each quarter, the times they were run within the quarter were not always consistent. For this reason, sometimes there is not a suitable DSGE forecast preceding a survey forecast.

The SPF survey is conducted by the Philadelphia Fed’s Real-Time Data Research Center, and is released at the beginning of the second month of each quarter. It is therefore matched with DSGE forecasts from the January, April, July, and October FOMC meetings, whenever possible. Note that this alignment implies that the SPF forecasters have an informational advantage relative to the DSGE, as they have one additional quarter of NIPA data (the preliminary NIPA releases take place at the very end of January, April, July, and October). The SPF forecasts for core PCE inflation and real GDP growth are also reported in Q/Q percent change. Its forecast horizon is consistently five quarters. We compare the NY Fed DSGE forecast with the median SPF projection.<sup>10</sup>

Lastly, the SEP is released every other FOMC meeting beginning with the March meeting (the January meeting until 2013). SEP participants project Q4/Q4 (that is, the growth rate over the four quarters of the year being forecast) real GDP growth rates and core PCE inflation rates for the current year and up to three subsequent years. We compare the DSGE forecast with the median SEP projection.<sup>11</sup> Since DSGE forecasts are also produced in anticipation of each FOMC meeting, the corresponding DSGE forecasts are a natural match for the SEP projections. Note that while both Blue Chip and SPF surveys produce “fixed horizon” projections (that is, they are always released at a fixed interval before the quarter being forecast), the SEP are “fixed target”: in each year, there are four SEP releases which share the same first forecast year, but were made using different information sets.

The three sets of RMSE comparisons shown in Figure 1 illustrate that over the 2011-2016 period the NY Fed DSGE projections are broadly competitive with survey forecasts in terms of accuracy. The left panel of Figure 1 shows that the NY Fed DSGE and BCEI RMSEs for output growth are virtually the same throughout the forecast horizon.<sup>12</sup> The DSGE model’s forecasts for output growth are also comparable in terms of accuracy to the SPF forecasts (middle panels; note that we show RMSEs from period 2 onward, given that the SPF has a one-quarter informational advantage relative to the DSGE). The DSGE core PCE inflation forecasts are somewhat worse than the SPF forecasts, confirming Faust and

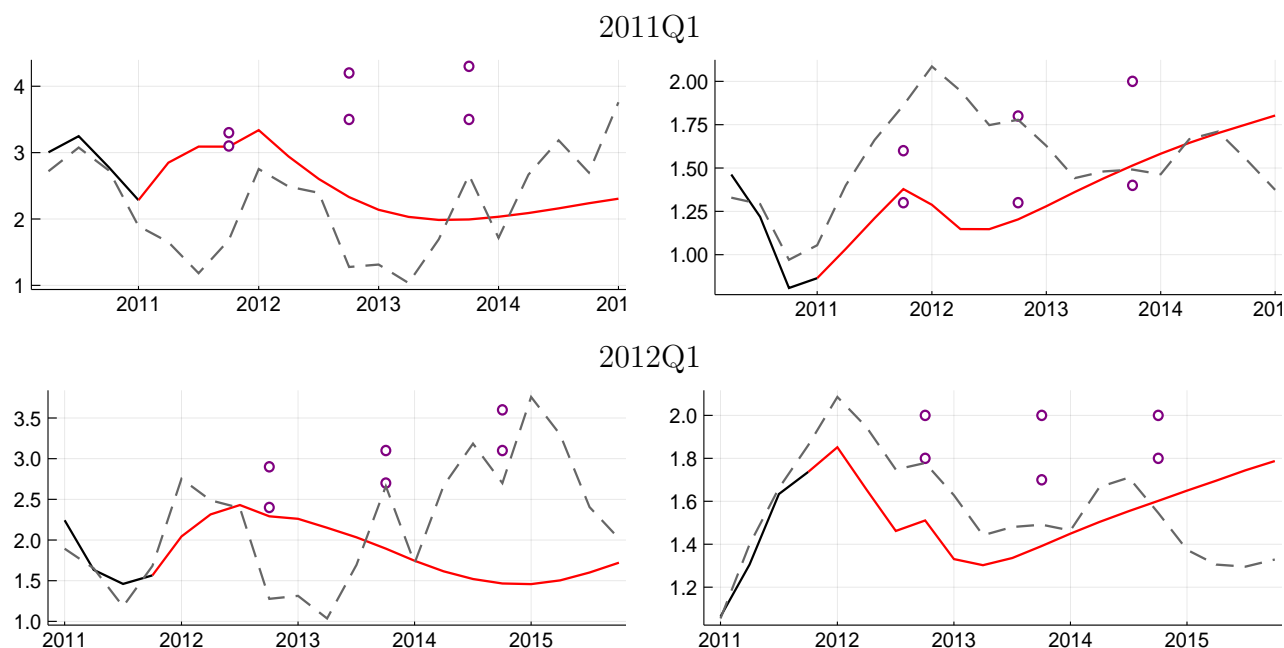
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<sup>10</sup>The median, rather than the mean, is used as the headline number on the [Philadelphia Fed’s website](#).

<sup>11</sup>When the median is not available, we use the average of the upper and lower limits of the SEP central tendency, a range which excludes the three highest and three lowest forecasts of each variable in each year.

<sup>12</sup>It may be surprising that the first quarter ahead DSGE forecasts (that is, the nowcasts) are as accurate as the BCEI’s, given the latter’s informational advantage. This result is driven by the fact that the NY Fed DSGE model conditions its projections on judgmental nowcasts from the staff in order to improve the short-run accuracy of its forecasts (see Del Negro and Schorfheide, 2013). Section 3.4 elaborates on this issue.

Figure 2: Evolution of NY Fed DSGE Model Forecasts  
 Output Growth                      Core PCE Inflation



*Note:* These panels show NY Fed DSGE model forecasts of four quarter average real GDP growth (left column, red lines) and core PCE inflation (right column, red lines) produced for the April 2011 and April 2012 FOMC meetings. In addition, these plots show the realized data as of the forecast date (solid black lines), the revised series as of November 1, 2017 (dashed black lines), and the upper and lower bounds of the central tendency of the Summary of Economic Projections (SEP) forecasts (purple circles) for the April 2011 and April 2012 FOMC meetings. The April SEP projections are still considered “Q1” as the Q1 NIPA data were still not available at the time the forecasts were made.

Wright (2013)’s finding that private survey forecasts are hard to beat for inflation. However, the results in Section 3.4 indicate that SPF’s informational advantage may be playing an important role for inflation forecasts. The NY Fed DSGE model performs notably better than the SEP’s output forecasts over horizons from two to four years ahead (note that we have only six four-year ahead observations), while performing only marginally worse in the first year horizon. In terms of inflation, the median SEP is more accurate for one to two years ahead, but slightly less accurate than the DSGE for three to four years ahead.

We should stress that we are comparing the predictions of a single model—the NY Fed model—to those of forecast *combinations* such as the Consensus Blue Chip. It is well known that forecast combinations, or pools, are often more accurate than their individual components (e.g., Timmermann, 2006), so the fact that a single model performs as well as these pools is worth noting.

Next, Figure 2 shows NY Fed DSGE forecasts of four-quarter average real GDP growth and core PCE inflation made in the first quarters of each year from 2011 to 2016, and provide some context for the RMSEs discussed previously. For comparison, we also include



Recession would be relatively quick, with growth rates above four percent. The NY Fed DSGE model instead projects a very slow recovery from the financial crisis, a finding that echoes the results of Reinhart and Rogoff (2009), although it is obtained in a completely different setting. As we now know, the more pessimistic forecasts of the NY Fed DSGE model were much closer to the realized growth rates through 2013. As discussed at length in Section 3.2, the model’s financial frictions play a key role in these projections. The DSGE model’s inflation projections are also very subdued. For this reason, they miss the spike in inflation associated with the so-called Arab Spring in late 2011-2012. However, they are quite in line with the low inflation experienced after 2013.

In the latter half of the sample, that is, from 2014 onward, the DSGE model’s forecasts are less accurate over the short run but still reasonably accurate over the medium and long term. It is worth noting that by 2015, the SEP and DSGE output growth forecasts have largely aligned. For inflation, the DSGE model’s forecasts are often more downbeat than the SEP, predicting only a gradual return of inflation to the FOMC’s long-run goal of two percent. Especially in later years, the DSGE tends to systematically under-predict inflation, while the SEP tends to over-predict it, as it always projects inflation to return to two percent inflation within a couple of years.

### 3 Pseudo Real-Time Forecasts

This section uses the results of a *pseudo* real-time forecasting exercise to understand what model features and observables explain the performance of the NY Fed DSGE model. While in a *real* real-time environment, we only have the forecasts from the specific model used at that time, a pseudo real-time setting offers the possibility of running counterfactual experiments, such as: What forecasts would we have obtained if we had stripped financial frictions from the model (Section 3.2)? What if we did not condition the forecast on external expectations for the policy rate (Section 3.3)? What if we did not condition on the nowcast (Section 3.4)? The remaining sections expand the forecast accuracy comparison both in terms of models under consideration and sample size. Section 3.5 compares the accuracy of the DSGE projections to those of simple univariate models and other standard benchmarks. While the forecasts discussed in Section 2 only pertain to the post-2011 years, which implies that the evaluation sample is quite short, in a pseudo-real time setting we can investigate the models’ performance from 1992 onward (this is the beginning of the sample used in Edge and Gürkaynak, 2010a, and Del Negro and Schorfheide, 2013). This is done in Section 3.6.

Last, we ask whether the addition of model features and data series in the current version of the NY Fed model, SWFF<sup>++</sup>, helped or hindered forecasting performance relative to the baseline SWFF model used in Del Negro and Schorfheide (2013), Del Negro et al. (2015), and Del Negro et al. (2016) (Section 3.7). The next section provides some details regarding the construction of the real-time dataset and of the DSGE model forecasts.

### 3.1 Real-Time Dataset and DSGE Forecasts Setup

The models used in this section are the prototypical Smets and Wouters (2007) model (henceforth, SW), which does not have financial frictions; the SWFF model; and the two “descendants” of SWFF mentioned in Section 2.1, SWFF<sup>+</sup> and SWFF<sup>++</sup>. In this section, we first discuss the data series used for these models (shown below in Table 1) and the process of constructing a real-time dataset. Next, we discuss the construction of the Blue Chip forecasts dataset – our benchmark for evaluating the accuracy of the DSGE forecasts. In the construction of both the real-time and the Blue Chip forecasts dataset we follow the approach of Del Negro and Schorfheide (2013, section 4.1) and Edge and Gürkaynak (2010a). Last, we discuss the DSGE forecast setup.

Table 1: Data series used in each model

Variable	SW	SWFF	SWFF <sup>+</sup>	SWFF <sup>++</sup>
GDP growth	X	X	X	X
Consumption growth	X	X	X	X
Investment growth	X	X	X	X
Real wage growth	X	X	X	X
Hours worked	X	X	X	X
GDP deflator inflation	X	X	X	X
Federal funds rate	X	X	X	X
10y inflation expectations		X	X	X
Spread		X	X	X
Core PCE inflation			X	X
10y bond yield			X	X
TFP growth			X	X
GDI growth				X

### 3.1.1 Data Series

Data on nominal GDP (GDP), nominal GDI (GDI), the GDP deflator (GDPDEF), core PCE inflation (JCXFE), nominal personal consumption expenditures (PCEC), and nominal fixed private investment (FPI) are produced at a quarterly frequency by the Bureau of Economic Analysis, and are included in the National Income and Product Accounts (NIPA). Average weekly hours of production and nonsupervisory employees for total private industries (AWHNONAG), civilian employment (CE16OV), and the civilian non-institutional population (CNP16OV) are produced by the Bureau of Labor Statistics (BLS) at a monthly frequency. The first of these series is obtained from the Establishment Survey, and the remaining from the Household Survey. Both surveys are released in the BLS Employment Situation Summary. Since our models are estimated on quarterly data, we take averages of the monthly data. Compensation per hour for the non-farm business sector (COMPFB) is obtained from the Labor Productivity and Costs release, and produced by the BLS at a quarterly frequency.

The federal funds rate (in the remainder of the paper we will sometimes use the acronym FFR) is obtained from the Federal Reserve Board’s H.15 release at a business day frequency. Long-run inflation expectations (average CPI inflation over the next 10 years) are available from the SPF from 1991Q4 onward. Prior to 1991Q4, we use the 10-year expectations data from the Blue Chip survey to construct a long time series that begins in 1979Q4.<sup>13</sup> Since the BCEI and the SPF measure inflation expectations in terms of the average CPI inflation and we instead use the GDP deflator and/or core PCE inflation as observables for inflation, as in Del Negro and Schorfheide (2013) we subtract 0.5 from the survey measures, which is roughly the average difference between CPI and GDP deflator inflation across the whole sample. We measure interest-rate spreads as the difference between the annualized Moody’s Seasoned Baa Corporate Bond Yield and the 10-Year Treasury Note Yield at constant maturity. Both series are available from the Federal Reserve Board’s H.15 release.

Lastly, TFP growth is measured using John Fernald’s TFP growth series, unadjusted for changes in utilization. We use his estimate of  $(1 - \alpha)$  to convert it into labor-augmenting terms. The details of the data transformations are given in Section A.6 of the appendix.

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<sup>13</sup>Since the Blue Chip survey reports long-run inflation expectations only twice a year, we treat these expectations in the remaining quarters as missing observations and adjust the measurement equation of the Kalman filter accordingly.

### 3.1.2 Blue Chip Forecasts

We primarily compare our pseudo real-time forecasts to contemporaneous ones from the BCEI and the Blue Chip Financial Forecasts (BCFF) survey. The latter contains business economists' projections for financial variables, while the BCEI mainly focuses on macroeconomic variables. In this paper, we are interested in forecasts of real GDP growth and (GDP deflator) inflation from the BCEI and forecasts of the federal funds rate from the BCFF. In the RMSE comparisons below, we compare our DSGE model forecasts to the mean BCEI GDP growth and inflation forecasts and the median BCFF federal funds rate forecast. The BCEI survey is published on the 10th of each month, using data that were available at the beginning of the month; the BCFF survey is published on the 1st of each month. Though both surveys are released on a monthly basis, we restrict our attention to the January, April, July, and October forecasts. These are the months in which the last forecast for each quarter is made.

For example, the BEA publishes the first estimate of fourth-quarter GDP at the end of January, and the first estimate of first-quarter GDP at the end of April. Hence the Blue Chip surveys released in February, March, and April contain forecasts in which the first forecasted quarter is Q1. The April Blue Chip survey is the last one to forecast Q1, and choosing it gives the Blue Chip forecasters the greatest informational advantage as they have access to all of the information released during Q1, and can potentially incorporate higher-frequency financial and other data into their forecasts.

The sample we consider contains the Blue Chip forecasts from January 1991 to April 2016 (this is the same sample of Section 2). Within this sample, we construct real-time datasets using data vintages available on the 10th of January, April, July, and October of each year. We use the St.Louis Fed's ALFRED database as our primary source of vintaged data. Hourly wage vintages are only available on ALFRED beginning in 1997; we use pre-1997 vintages from Edge and Gürkaynak (2010a). The GDP, GDP deflator, PCE, investment, hours, and employment series have vintages available for the entire sample. The earliest available vintages for the core PCE index and GDI are July 29th, 1999 and December 20th, 2012 respectively. Before these dates, we use the earliest available vintage of each series. John Fernald's capital share and TFP growth series are not available on ALFRED. Though there do seem to be revisions, particularly to the TFP growth estimates, we treat these two series as unrevised, using the February 28th, 2017 vintage.<sup>14</sup> The financial variables and the

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<sup>14</sup>Note that model SWFF does not use core PCE, GDI, or TFP as observables, so the lack of real-time



population series are not revised. For each real-time vintage, we use the Hodrick-Prescott filter on the population data observations available as of the forecast date.

When we compare the RMSEs of the DSGE model and Blue Chip forecasts below, we only use as many DSGE forecast horizons as are available in the corresponding Blue Chip release. As mentioned in Section 2.2, BCEI respondents submit quarterly forecasts through the end of the next calendar year, so that they forecast 9 quarters in January (beginning with Q4 of the previous year) but only 6 quarters in October. For the majority of our sample (beginning in April 1997), BCFF respondents submit forecasts for 6 quarters in the months of January, April, July, and October and for 5 quarters in all other months.<sup>15</sup> The RMSEs are computed using data downloaded on November 1st, 2017.

### 3.1.3 DSGE Forecast Setup

In our baseline setup, we condition on external interest rate forecasts following Section 5.4 of Del Negro and Schorfheide (2013) because this was the approach taken in generating the NY Fed DSGE model forecasts. We augment the measurement equation to add

$$R_{t+k|t}^e = R_* + \mathbb{E}_t R_{t+k}, \quad k = 1, \dots, K$$

where we use the median  $k$ -period ahead forecast from the BCFF for the observed series  $R_{t+k|t}^e$ ,  $\mathbb{E}_t R_{t+k}$  is the model-implied  $k$ -period ahead interest rate expectation, and  $R_*$  is the steady-state interest rate. (See Section A in the Appendix for additional details.) In order to provide the model with the ability to accommodate federal funds rate expectations, the policy rule in the model was augmented with anticipated policy shocks, as discussed in section 2.1. We take the number of anticipated shocks  $K$  to be 6, which is the maximum number of BCFF forecast quarters (excluding the observed quarterly average that we impute in the first forecast period).

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data for these variables is an issue for SWFF<sup>+</sup> and SWFF<sup>++</sup> only.

<sup>15</sup>Before April 1997, BCFF submit forecasts for 5 quarters in January, April, July, and October and for 4 quarters in all other months. Unlike the macroeconomic variables forecasted in the BCEI, which are released on a lag, the quarterly averages for the financial variables in the BCFF are immediately observed at the end of each quarter. To maintain consistency with the output growth and inflation forecasts, we impose that the first forecasted period for the interest rate is the previous quarter, which is perfectly forecasted to be the observed quarterly average. This gives us a total FFR forecast horizon of 7 quarters.

Specifically, in a given quarter  $t$ , the interest rate expectations observables  $R_{t+1|t}^e, \dots, R_{t+K|t}^e$  come from the BCFF forecast released in the first month of quarter  $t + 1$ .<sup>16</sup> For example, for  $t = 2008Q4$ , we use the January 2009 BCFF forecasts of interest rates. We first use interest rate expectations data beginning in 2008Q4 and continue their use through liftoff, reflecting the post-financial crisis era of central bank forward guidance. Unlike in Del Negro and Schorfheide (2013), after 2008Q4, we use the expanded dataset containing interest rate forecasts in both estimation and forecasting — again, because this was the approach taken in forecasting with the NY Fed DSGE. However, rather than estimating a separate standard deviation  $\sigma_{r^m,k}$  for each of the  $K$  anticipated shocks, we impose the restriction  $\sigma_{r^m,k}^2 = \frac{\sigma_{r^m}^2}{K}$ , which implies that the sum of the variances of the anticipated shocks equals the variance of the contemporaneous shock  $\sigma_{r^m}^2$ . We do so because at the beginning of the ZLB period, we have too few observations to estimate these variances independently.<sup>17</sup>

Table 2: Summary of  $T + 1$  conditioning information

Variable	Source
GDP growth $_{T+1}$	BCEI forecast of $T + 1$ GDP growth
GDP deflator inflation $_{T+1}$	BCEI forecast of $T + 1$ GDP deflator inflation
Spread	Observed Data
$R_{T+1}$	Observed Data
$R_{T+2 T+1}$	$R_{T+2 T+1}^e$
$\vdots$	$\vdots$
$R_{T+K+1 T+1}$	$R_{T+K+1 T+1}^e$

We furthermore follow section 5.3 of Del Negro and Schorfheide (2013) in conditioning on nowcasts — forecasts of the current quarter — of GDP growth, GDP deflator inflation, and financial variables. We accomplish this by appending an additional period of partially observed data for period  $T + 1$  (the current quarter, given our timing convention).<sup>18</sup> Specifically, for each real-time forecast vintage, we condition on the corresponding BCEI release’s

<sup>16</sup>Since the BCFF survey is released during the first few days of the month, the information set of BCFF forecasters is effectively  $t$  — that is, they have no information about quarter  $t + 1$ .

<sup>17</sup>This restriction was also imposed when producing the NY Fed DSGE projections.

<sup>18</sup>Unlike in Del Negro and Schorfheide (2013), we treat the nowcast for  $T + 1$  as a perfect signal of  $y_{T+1}$ , a specialization of both of the *Noise* and *News* assumptions in that paper in which we set  $\eta_{T+1} = 0$ . This is also what we do in the production of the NY Fed DSGE forecasts, although we usually rely on the staff’s nowcast rather than the BCEI’s.

mean forecasts of GDP growth and GDP deflator inflation in period  $T + 1$ . Our choice of forecast origin months means that the entire first forecast quarter has already elapsed by the time the forecast is made, so quarterly averages of financial variables have been observed in their entirety. Finally, we use the BCFF interest rate forecast  $R_{T+2:T+K+1|T+1}^e$  as observed expectations of future interest rates in quarter  $T + 1$ . Table 2 summarizes the  $T + 1$  conditioning information. Note that we do not use any of this  $T + 1$  information in estimating the model parameters. The models are estimated only using time  $T$  information. In fact, in the pseudo real-time forecasting exercise, we do not reestimate the DSGE model in every quarter, but only once a year using the January vintage.

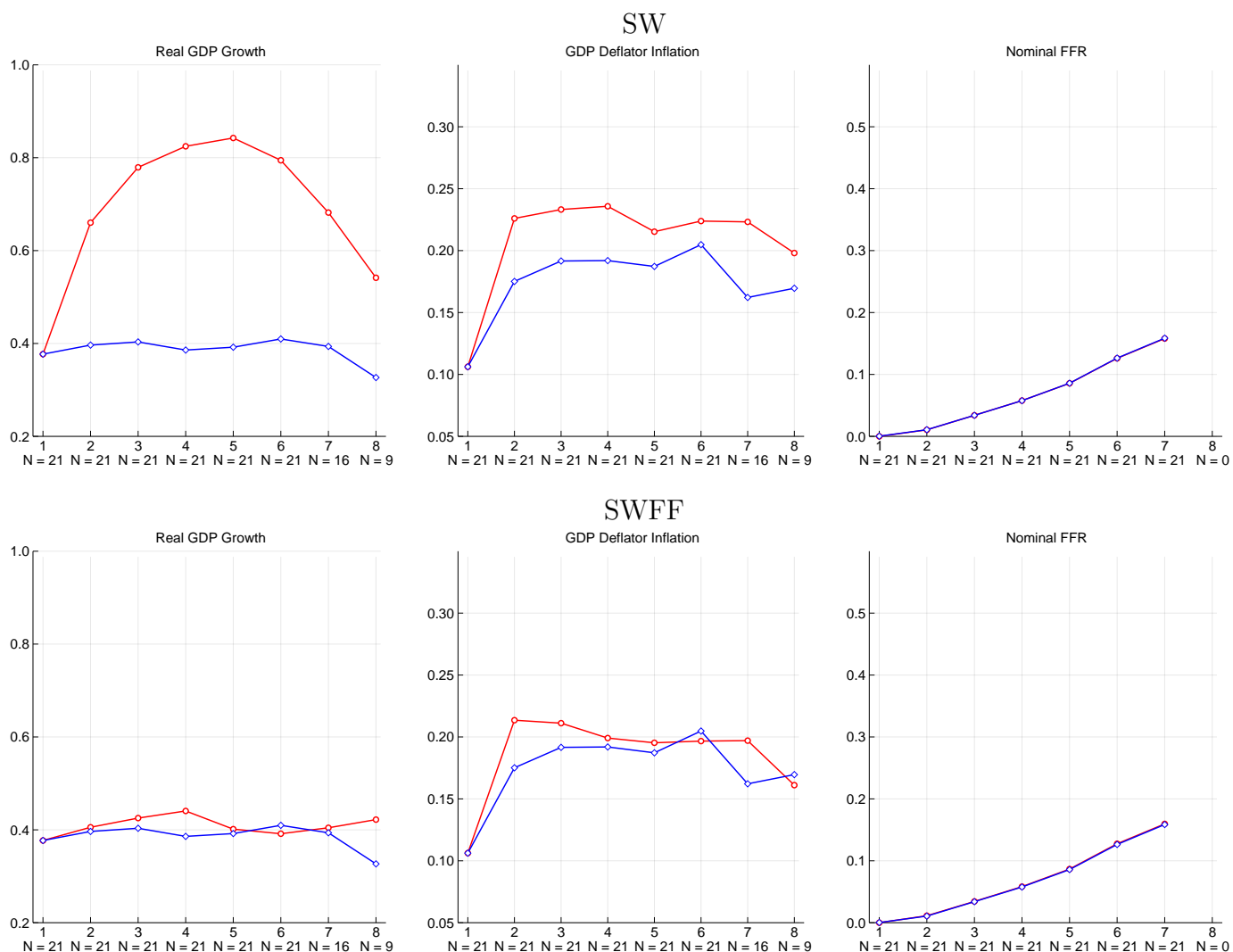
### 3.2 The Importance of Financial Frictions

This section investigates the importance of financial frictions for the DSGE models' forecasting performance during the recovery. It does so by comparing the forecasting performance of the prototypical SW model with that of SWFF, a version of that model augmented with financial frictions.

The top and bottom panels of Figure 3 compare the RMSEs for SW (top row, red circles) and SWFF (bottom row, red circles) with the Blue Chip (blue diamonds) for output growth, inflation, and interest rates projections one through eight quarters ahead, computed from April 2011 to April 2016. For both models, the forecasts are conditional on the BCFF forecasts for the federal funds rate and the BCEI nowcasts for output growth and inflation. (We do so because conditioning on external forecasts for the policy instrument and nowcasts was the standard procedure for the NY Fed DSGE projections during this period, as discussed above.)

Figure 3 shows that the accuracy of the SWFF projections for output growth and inflation is comparable to that of the BCEI median forecasts. In fact, the output growth RMSEs for SWFF (lower left panel) are also very similar to those of the NY Fed DSGE model shown in Figure 1. The accuracy of the forecasts from the SW model is considerably worse however, especially for output. SWFF differs from SW because of both the addition of financial frictions (and spreads as observables) and the use of long run inflation expectations (and a time-varying inflation target). Figure A-1 in the Appendix shows that the key difference between the two models in terms of forecasting performance is the financial frictions: the SW model with long run inflation expectations —called  $SW\pi$  in Del Negro and Schorfheide

Figure 3: RMSEs for SW and SWFF models

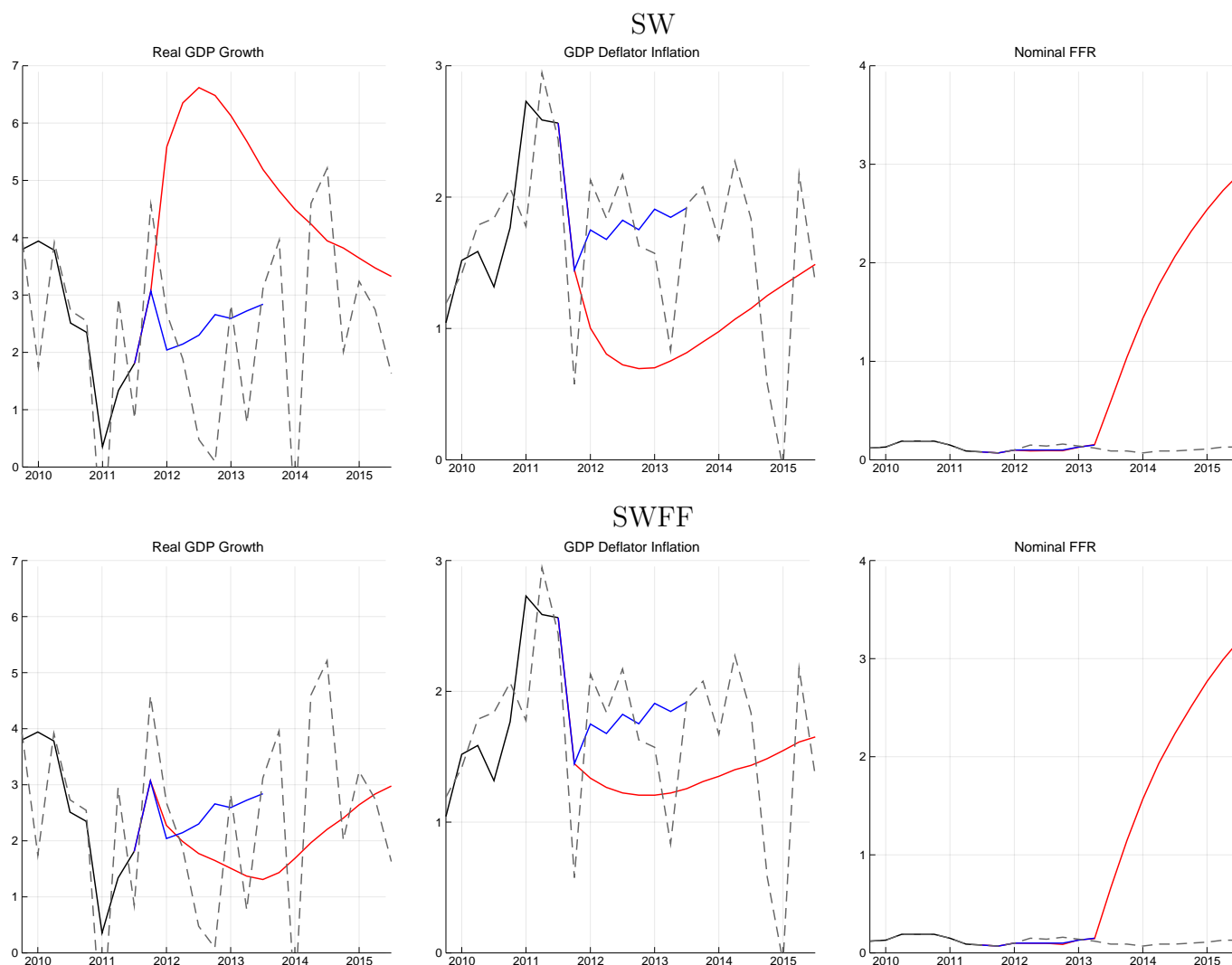


*Note:* The top and bottom panels compare the RMSEs for the SW (top row, red circles) and SWFF (bottom row, red circles) DSGE models with the Blue Chip (blue diamonds) for one through eight quarters ahead for output growth, inflation, and interest rates. Output growth and inflation are expressed in Q/Q percent terms, whereas interest rates are in quarterly percentage points. The  $N = n$  labels under each  $x$ -axis tick indicate the number of observations available for both the BCEI and DSGE forecasts at that horizon. The forecasts included in these calculations are from April 2011 to April 2016. The DSGE forecasts are conditional on the BCFE forecasts for the federal funds rate, and the BCEI nowcasts for output growth and inflation. Section 3.2 provides the details of the forecast comparison exercise.

(2013)— performs as poorly as SW for output during this period (although it does perform slightly better for inflation, consistent with the findings in Del Negro and Schorfheide, 2013).

In order to understand why the SWFF model's forecasts are so much more accurate than SW's, Figure 4 shows the two models' forecasts computed using the January 2012 vintage. The top and bottom rows show the forecast for the SW and SWFF model, respectively. Specifically, the figure shows the DSGE model forecast (red solid line); the January 2012 Blue Chip forecast (blue solid line); real-time data (black solid); and revised final data from

Figure 4: SW and SWFF forecasts using January 2012 data

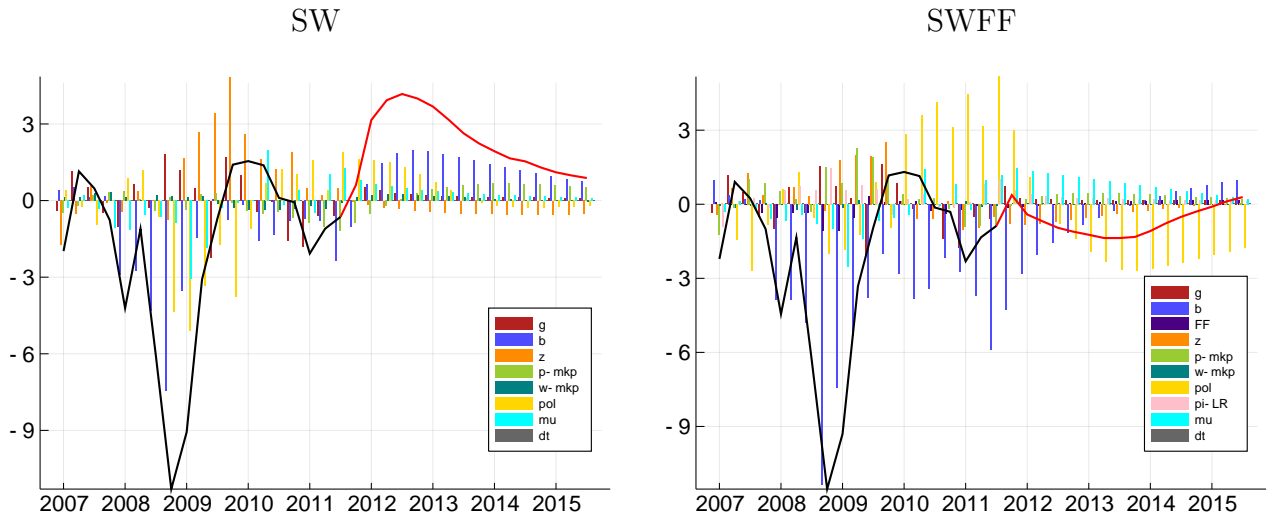


*Note:* The panels show the DSGE forecasts (red solid) obtained using data available as of January 2012, the January 2012 Blue Chip forecast (blue solid); real-time data (black solid); and revised final data from November 1st, 2017 (gray dashed) of output, inflation, and the interest rate. The DSGE forecasts are conditional on the BCFF forecasts for the federal funds rate, and the BCEI nowcasts for output growth and inflation. The top and bottom rows show the forecast for the SW and SWFF model, respectively. Output growth and inflation are expressed in Q/Q percent annualized terms, whereas interest rates are in quarterly annualized percentage points.

November 1st, 2017 (gray dashed) of output, inflation, and the interest rate. Similar to the SEP forecasts shown in Figure 2, the SW model forecasts a fast recovery after the Great Recession. Like the NY Fed DSGE model, the SWFF model instead projects a slow recovery – its forecasts are even more subdued than the BCEI projections. The January 2012 inflation projections from SW are also further off the mark than those from SWFF.<sup>19</sup>

<sup>19</sup>This is partly explained by the fact that the degree of nominal rigidities is lower in SW than in SWFF, as documented in Table A-1. Hence, inflation depends more on current marginal costs and less on future marginal costs (see the discussion in Del Negro et al., 2015). Since in terms of levels, the output gap is also still open in 2012 for the SW model, current marginal costs are still low and inflation projections are lower.

Figure 5: Shock Decompositions of GDP Growth

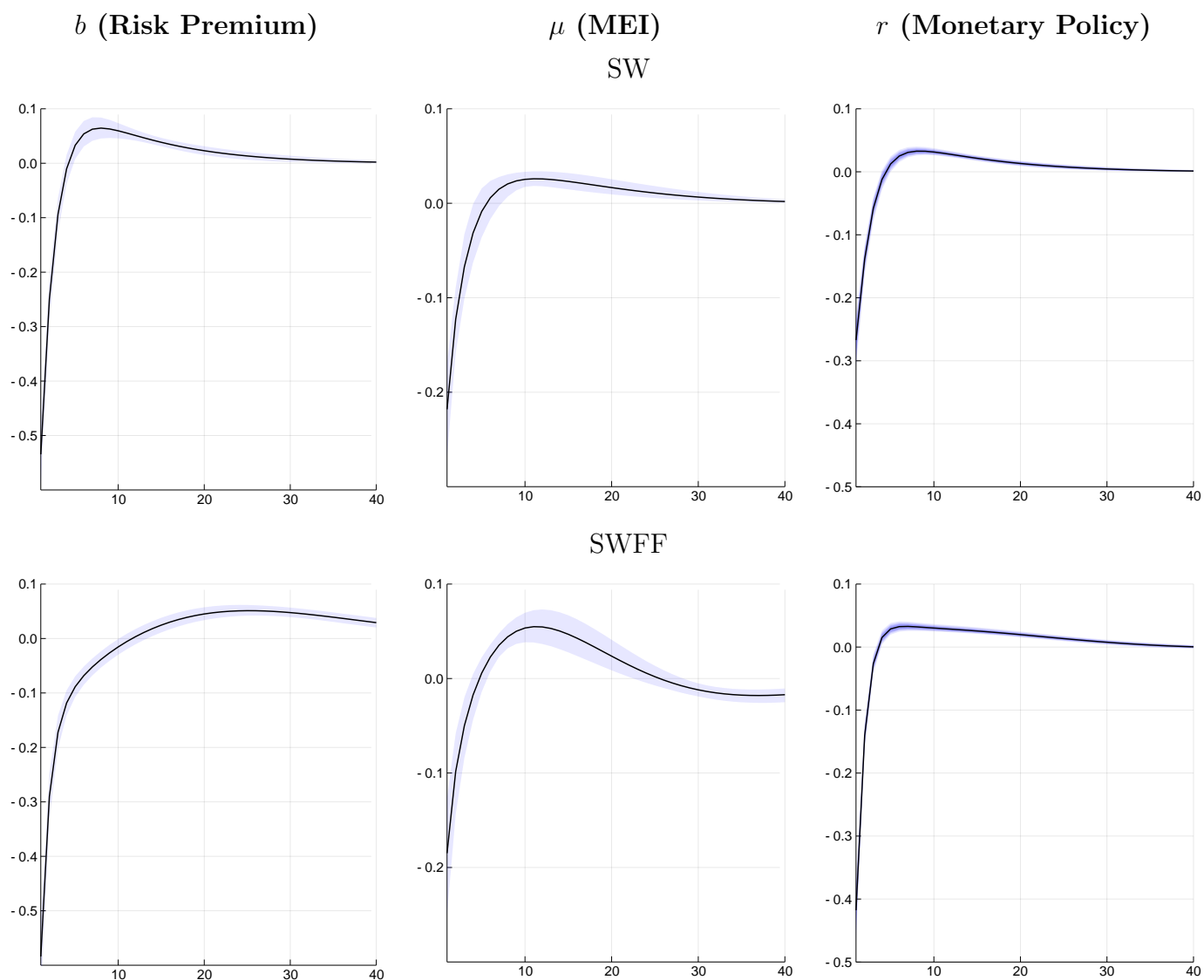


*Note:* The panels show the SW (left) and SWFF (right) models' shock decompositions of real GDP growth from the January 2012 forecast origin. The solid line (black for realized data, red for mean forecast) shows output growth in deviation from steady state in Q/Q percent annualized terms. The bars represent the contribution of each shock to the deviation from steady state, computed as the counterfactual values obtained when all other shocks are zero. Some of the shocks have been aggregated in this decomposition. In order, the SWFF shocks are categorized into aggregate demand, discount factor, financial frictions, productivity, price markup, wage markup, monetary policy, inflation target, and marginal efficiency of investment. The gray bars represent the deterministic trend, the counterfactual values obtained from iterating the initial state vector forward without any shocks. The shock categories for the SW model are a strict subset of the SWFF shock categories.

The differences in the forecasts between SW and SWFF are not surprising if we consider the different explanations these two models have for the Great Recession. Figure 5 decomposes the history of real GDP growth, as of 2012, into the various disturbances affecting the economy in the two models. The SWFF model (right panel) attributes the Great Recession almost exclusively to financial shocks, mostly the so-called “risk premium” shocks. (These are the shocks labeled  $b$  in Figure 5, represented by blue bars.) The impulse responses in Figure 6 (bottom panel) show that these risk premium shocks have a very persistent effect on the economy: they have a negative effect on *growth rates* for almost 12 quarters, implying that the *level* of GDP begins to recover only after three years.

The SW model also attributes the Great Recession in part to risk premium shocks. (See the left panel of Figure 5.) However, the role of these shocks is not as important as in SWFF, partly because the SW model does not use spreads as observables. Moreover, because the SW model lacks financial frictions, the impulse responses to these shocks are far less persistent (top panel of Figure 6), with growth rebounding only a few quarters after the shock. In that model, the Great Recession is driven in large part by policy shocks (which capture the ZLB constraint; yellow bars in left panel of Figure 5) and by marginal efficiency of investment shocks (these are the so-called MEI shocks emphasized in Justiniano et al., 2010; they are

Figure 6: Impulse Responses of Real GDP Growth



*Note:* The panels compare the SW (top panels) and SWFF (bottom panels) DSGE models' impulse response functions of real GDP growth to a one-standard-deviation innovation in the discount factor (left), the marginal efficiency of investment (center), and (contemporaneous) monetary policy (right). Parameters estimated using the baseline January 2012 dataset are used.

labeled  $\mu$  in Figure 5 and are represented by light blue bars). Figure 6 shows that both of these shocks have much less persistent effects on GDP growth than risk premium shocks in SWFF.

In conclusion, the SW model attributes the Great Recession to disturbances whose effects on the economy are relatively transitory, in contrast to the SWFF model in which financial shocks have a much more persistent effect on output growth. This implies that the SW model expects a faster return of the economy to steady state, and therefore high growth rates of the economy. In addition, when these high growth rates do not materialize in the aftermath

of the recession, the model attributes these forecast misses to *additional* temporary negative shocks, that are followed by a quick recovery. As the effect of these shocks compounds, SW ends up predicting very high growth rates for the economy, as shown in Figure 4.

Figure 7: SWFF Forecast of the 1982 Recession



*Note:* The figure shows the SWFF forecast for real GDP growth beginning in 1982Q1 (red solid); real-time data (black solid); and revised final data from November 1st, 2017 (gray dashed) of real GDP growth. The forecast was generated using April 1982 data, using the parameters from the January 2016 estimation.

Does SWFF predict a slow recovery after *every* recession? Figure 7 reveals that this is not the case. The figure shows the real GDP growth projections using the April 1982 data vintage — that is, at the trough of the 1982 recession.<sup>20</sup> The SWFF model predicts a very fast recovery after the 1982 recession, and its predictions are broadly in line with *ex-post* outcomes. This is the case because the model attributes the recession to disturbances, such as monetary policy shocks, whose effect on the economy is more transient than that of financial shocks.

### 3.3 Conditioning on FFR Expectations

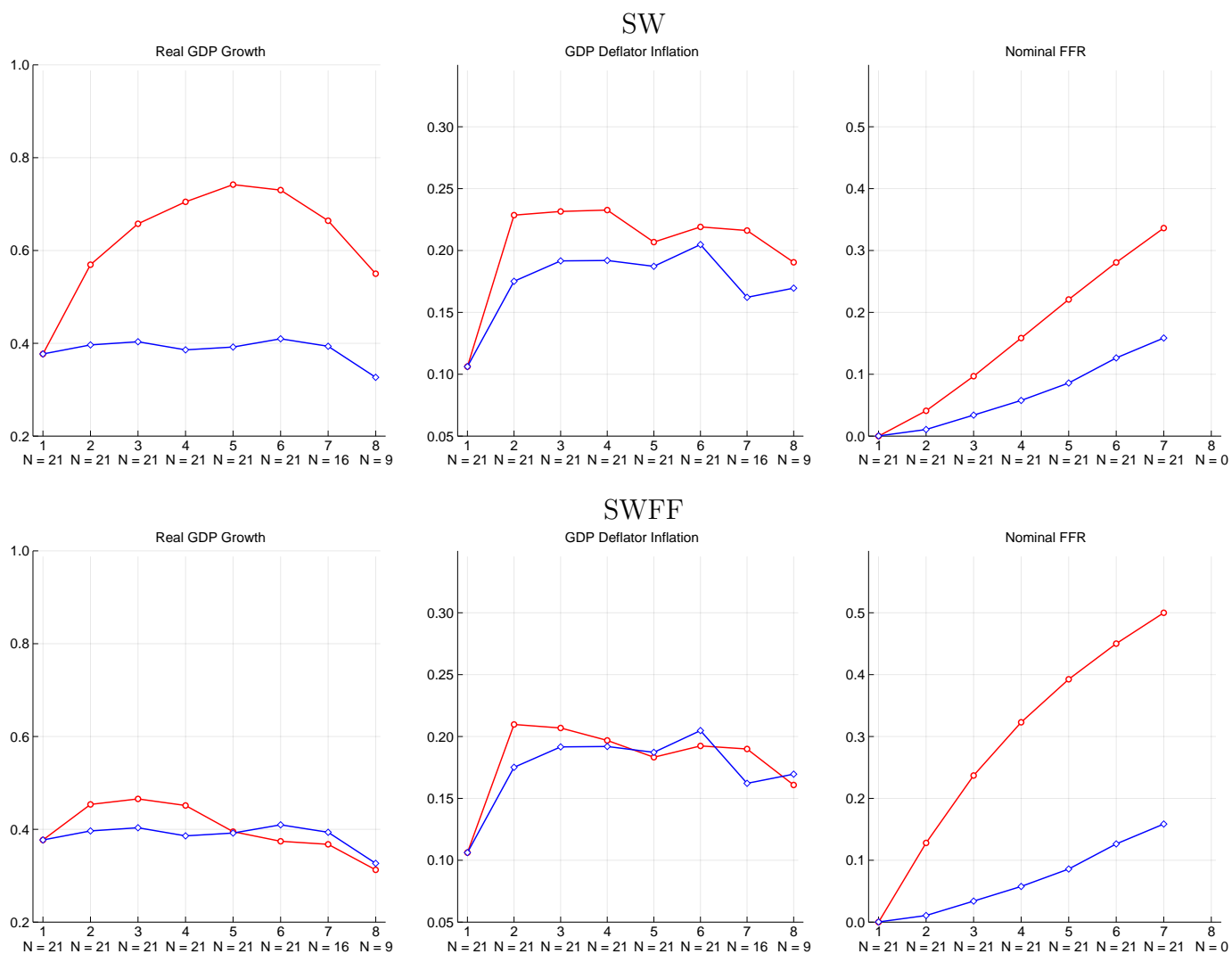
As discussed before, in our baseline analysis, we condition on interest rate forecasts from the BCFF in both the estimation and forecast steps in order to incorporate additional information available in the era of central bank forward guidance. This section investigates the impact of that choice. Figure 8 shows the RMSEs of the SW and SWFF models when we do not use BCFF interest rate forecasts.<sup>21</sup> The sample is the same as Figure 3 —April 2011

<sup>20</sup>We use the end-of-sample parameter estimates, but otherwise the forecast is out-of-sample.

<sup>21</sup>For the results in Figure 8 we continue to use the parameter estimates obtained from the estimation *with* the FFR expectations data. However, Figure A-2 in the Appendix for RMSEs shows that we obtain very



Figure 8: RMSEs for SW and SWFF vs. Blue Chip, without conditioning on FFR expectations

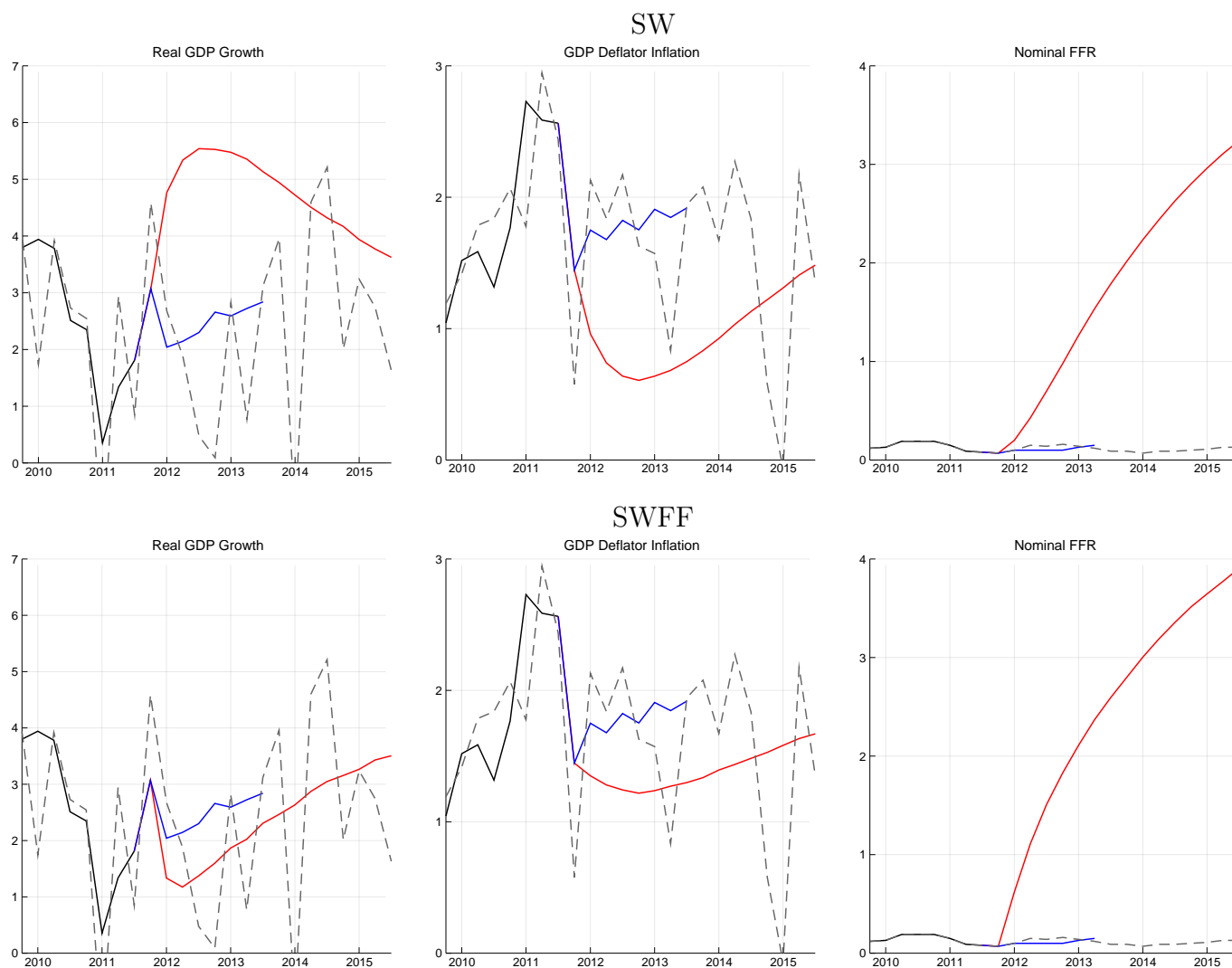


*Note:* The top and bottom panels compare the RMSEs for the SW (top row, red circles) and SWFF (bottom row, red circles) DSGE models that do not condition on FFR expectations, with the RMSEs for the Blue Chip forecasts (blue diamonds) for one through eight quarters ahead for output growth, inflation, and interest rates. Output growth and inflation are expressed in Q/Q percent terms, whereas interest rates are in quarterly percentage points. The  $N = n$  labels under each  $x$ -axis tick indicate the number of observations available for both the BCEI and DSGE forecasts at that horizon. The forecasts included in these calculations are from April 2011 to April 2016. The DSGE forecasts are conditional on the BCEI nowcasts for output growth and inflation. Section 3.3 provides the details of the forecast comparison exercise.

to April 2016— and we continue to condition on the BCEI nowcasts of output growth and inflation, as well as on the observed quarterly average interest rate in the first period.

similar results when we do not use FFR expectations data at all, including in the estimation. Even when we do not condition on the expected policy path, the projections for the federal funds rate still respect the ZLB as we follow the algorithm described in Section 6.2 of Del Negro and Schorfheide (2013). Specifically, for each path where the ZLB is violated, we use unanticipated policy shocks to bring the federal funds rate up the ZLB.

Figure 9: SW and SWFF forecasts using January 2012 data, without conditioning on FFR expectations



*Note:* The panels show the DSGE forecasts obtained using data available as of January 2012 (red solid); the January 2012 Blue Chip forecast (blue solid line); real-time data (black solid); and revised final data from November 1st, 2017 (gray dashed) of output, inflation, and the interest rate. The DSGE forecasts are conditional on the BCEI nowcasts for output growth and inflation. The top and bottom rows show the forecasts for the SW and SWFF models, respectively. Output growth and inflation are expressed in Q/Q percent annualized terms, whereas interest rates are in quarterly annualized percentage points.

The main takeaway of Figure 8 is that, in the absence of interest rate expectations data, the RMSEs for output growth and inflation in the SWFF model are very similar to those computed in Figure 3, even though the RMSEs for the federal funds rate deteriorate substantially. Regarding the SW model, the RMSEs for output growth improve somewhat in the absence of interest rate expectations data, but remain sensibly above those of the SWFF model. On the basis of these results one may conclude that policy transmission is weak in SWFF (forecasts for the policy rate are very different, but forecasts for output growth and

inflation are not) and less weak for SW. This would be the wrong conclusion (in Del Negro et al. (2015), we show that the policy transmission in SWFF is quite important). Rather, the explanation for this result can be found in the different ways that SWFF and SW interpret the conditioning on federal funds rate expectations. The remainder of the section elaborates on this point.

In order to understand the effect of conditioning on FFR expectations on the two models, we again focus on a specific set of forecasts — those computed using the January 2012 vintage. Figure 9 is analogous to Figure 4, except that the DSGE projections are computed without using FFR expectations. Clearly, both DSGE models predict an earlier liftoff of the federal funds rate relative to both the BCFF projections and ex-post outcomes. This is not surprising: Blue Chip forecasters are aware of the Federal Reserve’s forward guidance while the DSGE econometrician, without conditioning on either market or survey expectations, is not (which is why in the NY Fed DSGE model we condition on federal funds rate expectations). We also note that SWFF projects a faster liftoff of the policy rate than SW. This is not surprising in light of the fact that SW projects inflation to be (counterfactually) lower than SWFF, and that the estimated policy reaction function, which is the basis of the FFR projections for the DSGE models, depends positively on inflation. This observation explains why the RMSEs for the federal funds rate shown in Figure 9 are worse for SWFF than for SW.

The differences in the DSGE forecasts for output growth and inflation between Figures 4 and 9 illustrate the effect of conditioning on FFR expectations. From the perspective of the DSGE econometrician, forward guidance can be interpreted in two different ways, as either “Odyssean” or “Delphic” (see Campbell et al., 2012). The Odyssean interpretation amounts to anticipated future monetary policy accommodation — the policy “news” shocks discussed in Section 2.1. The Delphic interpretation instead leads the econometrician to revise her assessment of the state of the economy, which is of course latent in DSGE models: the lower FFR projections are then interpreted as an indication that the state of the economy is worse than previously estimated.<sup>22</sup>

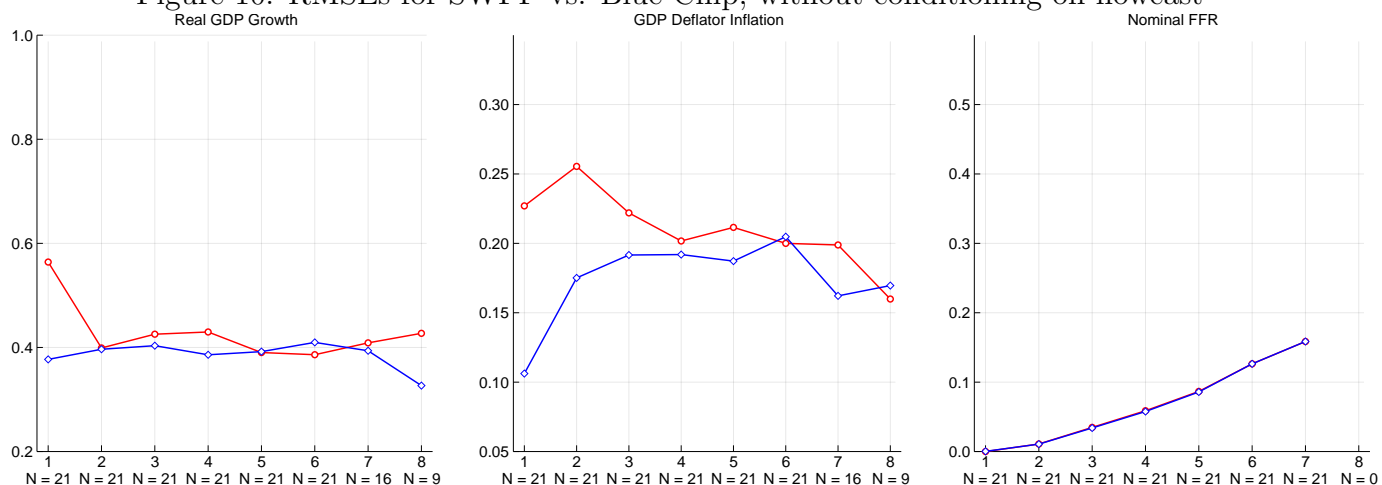
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<sup>22</sup>Some readers may find it confusing that we discuss Delphic forward guidance, even though there are no information asymmetries in the model. However, recall that the state of the economy is latent from the perspective of the DSGE econometrician. Therefore, from the perspective of the econometrician there are informational asymmetries: She/he does not see the policy shocks (unlike the agents in the DSGE model, who have perfect information on all the shocks), but needs to make inference on them on the basis of available information (all the observables, including the expected policy path).

Both effects are at play in the DSGE projections. However, the comparison of Figures 4 and 9 indicates that the Odyssean effect is very strong particularly for the SW model: In Figure 9 the SW projections for output growth are still overly optimistic relative to ex-post outcomes, but much less so than in Figure 4. The comparison of Figures 4 and 9 therefore reveals that the SW model suffers from what Del Negro et al. (2012) called the “forward guidance puzzle”: incorporating the accommodation from forward guidance results in overly optimistic projections for the economy. This also explains why the SW RMSEs for real GDP growth shown in Figure 8 are smaller than those in Figure 3. For the SWFF model, the differences in both forecasts and RMSEs with and without conditioning on FFR expectations are much more muted than for the SW model. This is partly because SWFF interprets forward guidance as a combination of Odyssean and Delphic signals, which cancel each other out in terms of output growth and inflation projections. In addition, SWFF is less affected by the “forward guidance puzzle” than SW.<sup>23</sup>

### 3.4 Conditioning on Nowcasts

Figure 10: RMSEs for SWFF vs. Blue Chip, without conditioning on nowcast



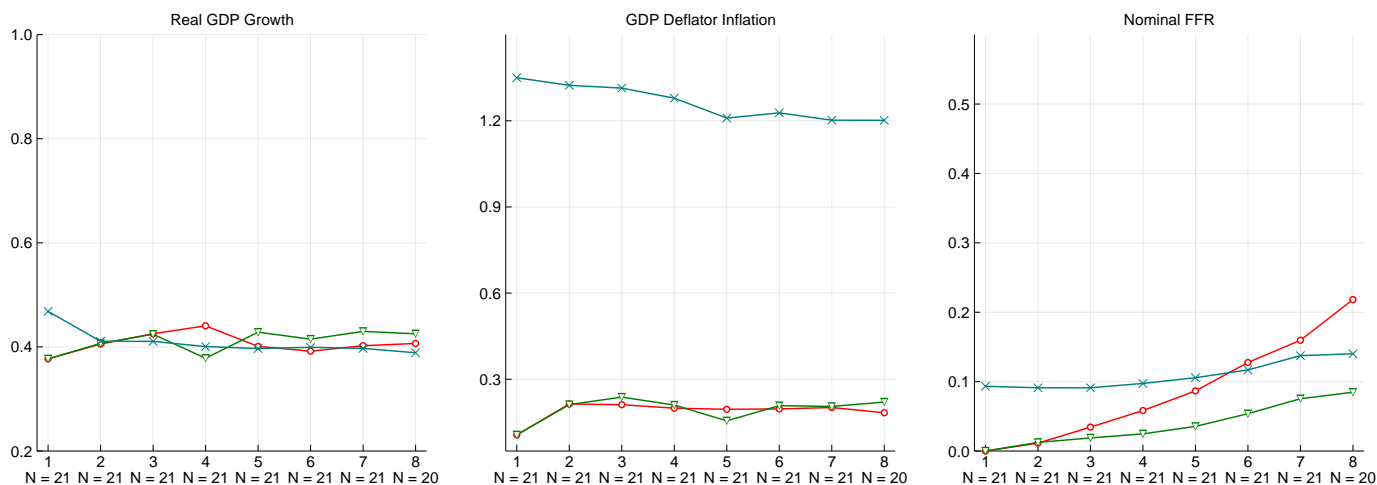
*Note:* The panels compare the RMSEs for SWFF (red circles) with the Blue Chip (blue diamonds) for one through eight quarters ahead for output growth, inflation, and interest rates. Output growth and inflation are expressed in Q/Q percent terms, whereas interest rates are in quarterly percentage points. The  $N = n$  labels under each  $x$ -axis tick indicate the number of observations available for both the BCEI and DSGE forecasts at that horizon. Forecast origins from April 2011 to April 2016 only are included in these calculations. Section 3.4 provides the details of the forecast comparison exercise.

<sup>23</sup>This is because the SWFF model has higher nominal rigidities than the SW model, among other factors (See Del Negro et al., 2015, and the parameter estimates shown in Table A-1 of the Appendix.) We should note that it is not straightforward to assess the relative importance of Odyssean and Delphic effects, or to attribute the different responses across models to forward guidance shocks to specific model features. We leave these questions to future research.

Del Negro and Schorfheide (2013) discuss the challenges facing the DSGE econometrician. One well-understood challenge is model misspecification (e.g., see Del Negro and Schorfheide, 2004; Del Negro et al., 2007). Another challenge arises from the limitations of the econometrician’s information set—that is the set of observables used in estimating the model and generating forecasts. Augmenting the set of observables with spreads, for instance, as the SWFF model does, provides valuable information to the econometrician regarding financial conditions. Similarly, conditioning on FFR expectations informs the econometrician about the degree of future policy accommodation. A third challenge is given by the timeliness of the econometrician’s information set: the majority of the data series — both “hard” (monthly releases of inflation and consumption) and “soft” (e.g., from surveys, such as the Institute for Supply Management survey, or ISM) — used in the estimation of our model become available at a quarterly frequency and therefore do not include all the information available at a higher frequency. Blue Chip forecasters use this information to produce nowcasts for output and inflation. For this reason, the DSGE model current-quarter forecasts stand to benefit from conditioning on the nowcasts obtained from the Blue Chip survey. Similarly, the NY Fed forecasts discussed in Section 2 incorporate the nowcast from in-house forecasters.

How much does incorporating the nowcast improve the DSGE forecasts? Figure 10 depicts RMSEs for SWFF and the Blue Chip forecasts for output growth, inflation, and the nominal federal funds rate without conditioning on nowcasts. The sample is the same as Figure 3 —April 2011 to April 2016— and we continue to condition on the BCFF FFR expectations. Not surprisingly, the Blue Chip nowcasts are much more accurate than the DSGE’s for both output growth and inflation. However, for output growth the RMSEs are quite similar to those in Figure 3 from horizon 2 onward, while for inflation the improvement associated with including nowcasts persists for about 4 quarters. Therefore, we confirm the results in Del Negro and Schorfheide (2013) that the positive effect of conditioning on the nowcast on inflation is much more persistent than the corresponding effect on GDP, which is not surprising in light of the different persistence in the two series.<sup>24</sup>

Figure 11: RMSEs for SWFF, AR(2), and a naive forecast



*Note:* The panels compare the RMSEs for the SWFF (red circles) DSGE model with an AR(2) (green triangles) and a set of naive forecasts (teal crosses) for one through eight quarters ahead for output growth, inflation, and interest rates. The naive forecast for Real GDP Growth is the sample mean of the data until the first forecast horizon. The naive forecasts for GDP deflator and the nominal rate are random walks averaged over 4 quarters. All variables are expressed in terms of Q/Q percent terms. Forecast origins from April 2011 to April 2016 only are included in these calculations.

### 3.5 Comparison with Naive Forecasts/AR Models

Edge and Gürkaynak (2010b) show that naive predictions obtained using the sample mean for output growth and inflation and the random walk for interest rates perform about as well in their sample as the forecasts from Smets and Wouters' DSGE model. Gürkaynak et al. (2013) find that simple models, such as univariate autoregressive (henceforth, AR( $p$ ) denotes an autoregressive model with  $p$  lags and the constant) or small vector autoregressive models, perform as well if not better than Smets and Wouters' model. In general, the literature has found that either naive or simple AR forecasts are hard to beat for both output (e.g. Chauvet and Potter, 2013) and inflation (e.g. Atkeson et al., 2001). In light of this, we thought it would be useful to compare the accuracy of the SWFF forecasts to those of naive and AR(2) forecasts (the results for AR(1) forecasts are nearly identical) for the sample we are interested in. We use the same naive forecasts as Edge and Gürkaynak (2010b) for output growth and interest rates, but for inflation we use the random walk forecasts based on a four-quarter moving average of past data, which in the literature is usually considered as a standard benchmark for this variable (see Surico et al., 2006).<sup>25</sup>

<sup>24</sup>As noted in Section 3.1, the nowcast is treated simply as  $T + 1$  data, as opposed to a noisy measurement of the forecasted variables at time  $T + 1$  as in Del Negro and Schorfheide (2013). We do so because this is the approach taken in producing the NY Fed DSGE forecasts.

<sup>25</sup>Edge and Gürkaynak (2010b) seem to use the *ex-post* sample mean over the forecast evaluation period as

Figure 11 compares the RMSEs from the SWFF model (the same red circles shown in Figure 3) to those obtained from the AR(2) (green triangles) and naive forecasts (teal crosses). The accuracy of the AR(2) model is very similar to that of SW for both output and inflation (and more accurate for the interest rate forecasts, but those are really the Blue Chip’s forecasts since the DSGE projections are conditional on the expected policy path). The naive forecasts are also as accurate as the DSGE’s for output, but far less accurate for inflation (and somewhat less accurate for the interest rate, at least up to five quarters).

Except for inflation, where Atkeson et al. (2001)’s benchmark performs very poorly, these results confirm the findings in the literature.<sup>26</sup> In light of these results a skeptic could ask: What is the point of forecasting with the DSGE models if they cannot improve upon simple ARs and naive forecasts (nor can the Blue Chip, by the way)? At least to us, the answer is pretty obvious: try to do policy analysis or to understand the forces driving the economy with an AR model if you can! We view forecasting as mainly a test for DSGEs, as opposed to their main goal. We will elaborate further on this point in the conclusions.

### 3.6 Whole Sample vs. Post-Great Recession

The results so far, and in much of the paper, focus on forecasting during the recovery from the Great Recession, because this is the period of interest and the one for which we have forecasts from the NY Fed DSGE model. This section turns to the question of how the DSGE models fared across our entire available sample of 1992-2017, for the sake of comparison with the previous literature on the accuracy of DSGE model forecasts for the U.S. As in the previous sections, we condition on time  $T + 1$  BCEI forecasts of output and inflation. Interest rate expectations are incorporated starting in 2008Q4, to match the beginning of the ZLB period.

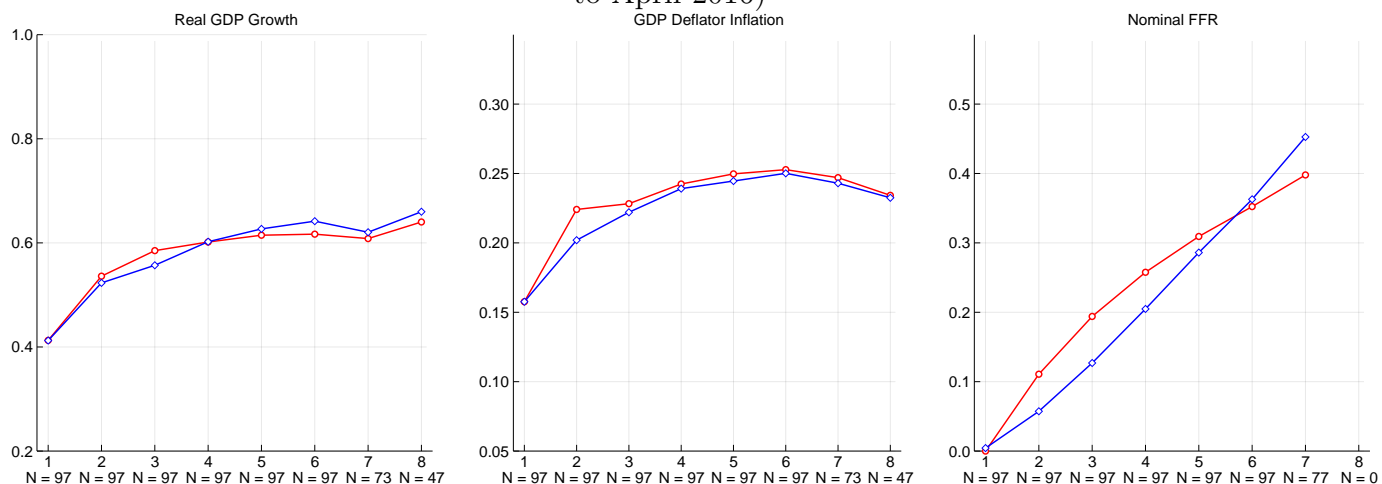
Figure 12 shows that the SWFF model’s performance is remarkably similar to that of the Blue Chip forecasts across all horizons and variables. As far as output and inflation are concerned, this finding is in line with that of Del Negro and Schorfheide (2013). Interest rate

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their benchmark, which of course is not available ex-ante. We use instead the sample mean using real-time data for GDP growth, which is what the literature generally uses as a benchmark (again, see Surico et al., 2006). We also considered a random walk forecast based on the last quarterly observation for both output growth and inflation, and obtained not surprisingly very poor results which we do not report. Finally, note also that since the SWFF model takes advantage of the nowcast, we let the AR(2) model do that as well and treat it as an observable.

<sup>26</sup>The RMSEs obtained using the sample mean of inflation as a naive benchmark—which we do not report—are all above .5%, which is considerably worse than those of the DSGE model.

Figure 12: RMSEs for SWFF vs. Blue Chip, computed from whole sample (January 1992 to April 2016)



*Note:* The panels compare the RMSEs for SWFF (red circles) with the Blue Chip (blue diamonds) for one through eight quarters ahead for output growth, inflation, and interest rates. Output growth and inflation are expressed in Q/Q percent terms, whereas interest rates are in quarterly percentage points. The  $N = n$  labels under each  $x$ -axis tick indicate the number of observations available for both the BCEI and DSGE forecasts at that horizon. The forecasts included in these calculations are from January 1991 to April 2016. The DSGE forecasts are conditional on the BCFE forecasts for the federal funds rate, and the BCEI nowcasts for output growth and inflation. Section 3.6 provides the details of the forecast comparison exercise.

projections are moderately worse in the short to medium run, but overall are comparable in performance. This last point is notable given the lack of interest rate expectations from 1992-2008Q3, and indicates that the model is capable of producing reasonable interest rate forecasts away from the zero lower bound.

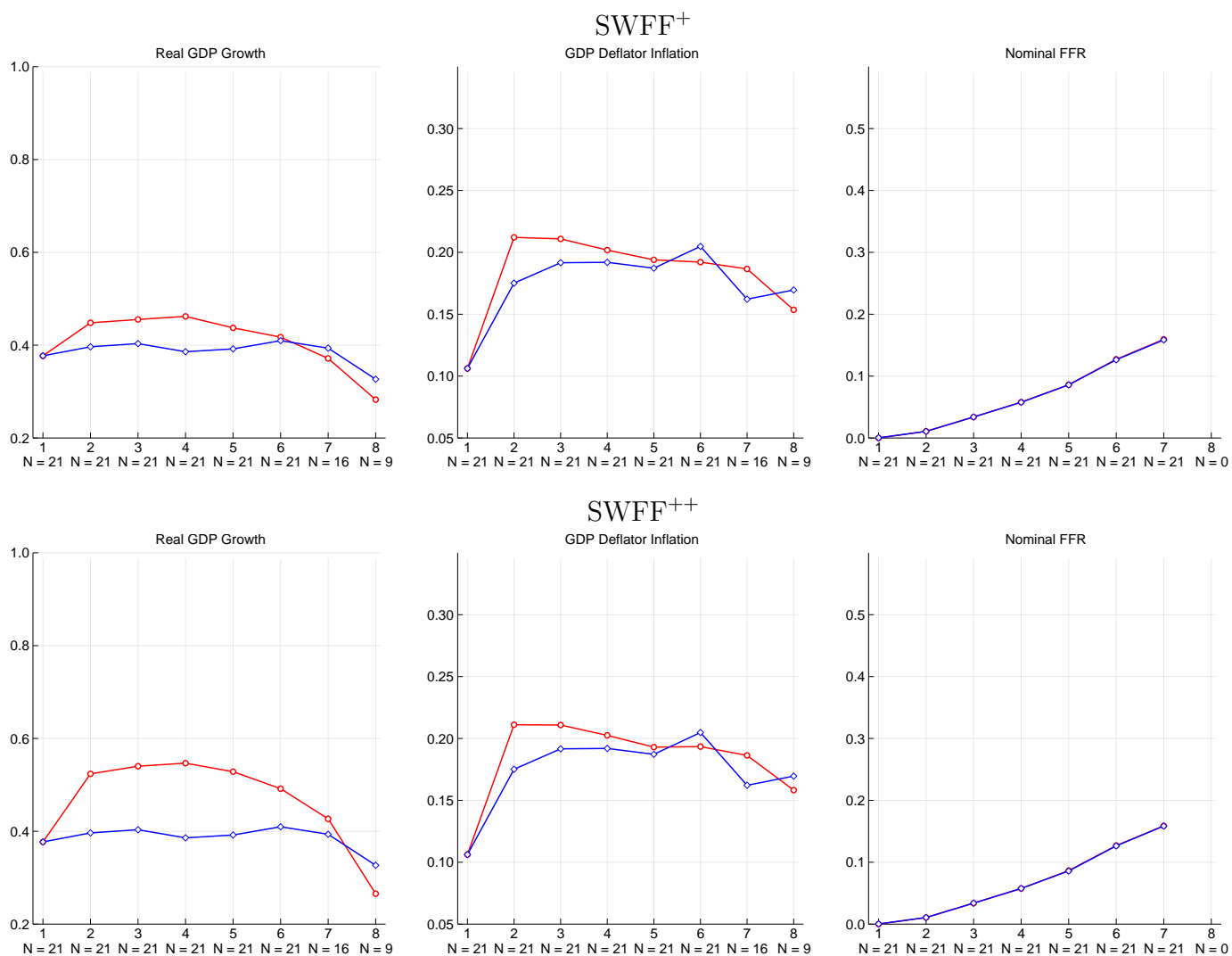
Edge and Gürkaynak (2010a)'s results showed that the accuracy of DSGE models' forecasts is comparable to those of private forecasters. One could dismiss those findings on the ground that they applied to the Great Moderation period, an easy period to forecast.<sup>27</sup> These results shown here are notable because they document that the accuracy of DSGE models' forecasts is comparable to that of private forecasters even though almost half of the sample includes periods that are particularly difficult for DSGE models, such as the Great Recession and its aftermath.

### 3.7 SWFF vs. Its Descendants

As described in Section 2.1, the main models used in producing the various internal policy materials and forecasts were built on top of SWFF, mainly by adding more observables

<sup>27</sup>Del Negro and Schorfheide (2013)'s showed that this is still true if the sample is extended to 2011. Edge and Gürkaynak (2010a) also find all the forecast methods to be inaccurate in an  $R^2$  sense, in that there were few forecastable fluctuations in the Great Moderation period.



Figure 13: RMSEs for SWFF<sup>+</sup> and SWFF<sup>++</sup> vs. Blue Chip

*Note:* The top and bottom panels compare the RMSEs for the SWFF<sup>+</sup> (top row, red circles) and SWFF<sup>++</sup> (bottom row, red circles) DSGE models with the Blue Chip (blue diamonds) for one through eight quarters ahead for output growth, inflation, and interest rates. Output growth and inflation are expressed in Q/Q percent terms, whereas interest rates are in quarterly percentage points. The  $N = n$  labels under each  $x$ -axis tick indicate the number of observations available for both the BCEI and DSGE forecasts at that horizon. The forecasts included in these calculations are from April 2011 to April 2016. The DSGE forecasts are conditional on the BCFF forecasts for the federal funds rate, and the BCEI nowcasts for output growth and inflation. Section 3.7 provides the details of the forecast comparison exercise.

(and more features to accommodate these observables).<sup>28</sup> In this section, we ask to what extent these choices changed the DSGE's forecasting accuracy. Comparing the RMSEs from SWFF in Figure 3 to the RMSEs shown below in Figure 13, we see that the near-term and medium-term output growth forecast performance slightly declined from SWFF to SWFF<sup>+</sup>

<sup>28</sup>The technical details of the additional features included in these models, SWFF<sup>+</sup> and SWFF<sup>++</sup>, are in sections A.4 and A.5 of the appendix respectively.

and from SWFF<sup>+</sup> to SWFF<sup>++</sup>, whereas long-term forecasting performance improved a bit from horizons 7 and beyond, even outperforming the Blue Chip forecast at that horizon. Near-term and medium-term forecasts of inflation remained largely on par between SWFF and its descendants, but in a similar fashion to the output growth forecasts, long-term performance from horizon 6 and beyond improved.

## 4 Conclusions

The paper documents the accuracy of the projections of the NY Fed DSGE model during the recovery from the financial crisis. We find that in the short and medium run—from one through eight quarters ahead—our DSGE model’s RMSEs are comparable to those obtained from the mean and median forecasts of the Blue Chip and SPF surveys, respectively. Relative to the median of the FOMC’s Summary of Economic Projections, however, the NY Fed DSGE model performed much better in terms of the accuracy of its output growth forecasts, especially at longer horizons. For inflation, the DSGE performed worse than the median SEP up to a two year horizon, but better at a three year horizon. The paper then uses a pseudo real-time forecasting exercise to assess which model features explain the results. It finds that financial frictions play a major role, especially in terms of the projections for economic activity, as they imply a slow recovery from financial crises.

The work of Schorfheide (2000), Otrok (2001), and Smets and Wouters (2003, 2007) more than ten years ago contained an implicit promise: namely, that the macroeconomic profession could count on theory-based models that are flexible enough to fit the data, not only in sample but also *out of sample*. This paper shows that medium-scale DSGE models kept some of their promises as far as out-of-sample forecasting accuracy is concerned. In order to do so DSGE models had to change and incorporate financial frictions. Our prediction is that they will have to change again in the near future, both to keep up with the frontier of research in macroeconomics (e.g., heterogeneous agents models as in Kaplan et al., 2018, or non-linear models as in Brunnermeier and Sannikov, 2014), and to maintain and perhaps even improve their forecasting performance.

In closing, we should stress that in our view forecasting is not the primary objective of DSGE models, even though it is the focus of this paper. Out-of-sample forecasting accuracy is not important per se, but only as an indirect test of model misspecification. DSGEs are used in many central banks for quantitative policy analysis. While good forecasting

performance is no guarantee that the model's answers are correct, one can at least say that bad forecasting performance is an indication that something is wrong with the model. Its users should then at the very least be aware of it.

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# Online Appendix for “DSGE Forecasts of the Lost Recovery”

## A DSGE Model Descriptions

This section of the appendix contains the model specifications for SW, SW $\pi$ , SWFF, SW $^+$ , and SW $^{++}$ , along with a description of how we construct our data, and a table with the priors on the parameters of the various models.

### A.1 SW

We include a brief description of the log-linearized equilibrium conditions of the Smets and Wouters (2007) model to establish the foundation for explaining the later models. We deviate from the original Smets-Wouters specification by detrending the non-stationary model variables by a stochastic rather than a deterministic trend. This is done in order to express the equilibrium conditions in a flexible manner that accommodates both trend-stationary and unit-root technology processes. The model presented below is the model referred to in the paper as the SW model.

Let  $\tilde{z}_t$  be the linearly detrended log productivity process, defined here as:

$$\tilde{z}_t = \rho_z \tilde{z}_{t-1} + \sigma_z \epsilon_{z,t}, \quad \epsilon_{z,t} \sim N(0, 1) \quad (\text{A-1})$$

All non-stationary variables are detrended by  $Z_t = e^{\gamma t + \frac{1}{1-\alpha} \tilde{z}_t}$ , where  $\gamma$  is the steady-state growth rate of the economy. The growth rate of  $Z_t$  in deviations from  $\gamma$ , which is denoted by  $z_t$ , follows the process:

$$z_t = \ln(Z_t/Z_{t-1}) - \gamma = \frac{1}{1-\alpha}(\rho_z - 1)\tilde{z}_{t-1} + \frac{1}{1-\alpha}\sigma_z\epsilon_{z,t} \quad (\text{A-2})$$

All of the variables defined below will be given in log deviations from their non-stochastic steady state, where the steady state values will be denoted by \*-subscripts.

### A.1.1 Equilibrium Conditions

The *optimal allocation of consumption* satisfies the following Euler equation:

$$c_t = -\frac{(1 - he^{-\gamma})}{\sigma_c(1 + he^{-\gamma})} (R_t - \mathbb{E}_t[\pi_{t+1}] + b_t) + \frac{he^{-\gamma}}{(1 + he^{-\gamma})} (c_{t-1} - z_t) + \frac{1}{(1 + he^{-\gamma})} \mathbb{E}_t [c_{t+1} + z_{t+1}] + \frac{(\sigma_c - 1)}{\sigma_c(1 + he^{-\gamma})} \frac{w_* L_*}{c_*} (L_t - \mathbb{E}_t[L_{t+1}]). \quad (\text{A-3})$$

where  $c_t$  is consumption,  $L_t$  denotes hours worked,  $R_t$  is the nominal interest rate, and  $\pi_t$  is inflation. The exogenous process  $b_t$  drives a wedge between the intertemporal ratio of the marginal utility of consumption and the riskless real return,  $R_t - \mathbb{E}_t[\pi_{t+1}]$ , and follows an AR(1) process with parameters  $\rho_b$  and  $\sigma_b$ . The parameters  $\sigma_c$  and  $h$  capture the relative degree of risk aversion and the degree of habit persistence in the utility function, respectively.

The *optimal investment decision* comes from the optimality condition for capital producers and satisfies the following relationship between the level of investment  $i_t$  and the value of capital,  $q_t^k$ , both measured in terms of consumption:

$$q_t^k = S'' e^{2\gamma} (1 + \beta e^{(1-\sigma_c)\gamma}) \left( i_t - \frac{1}{1 + \beta e^{(1-\sigma_c)\gamma}} (i_{t-1} - z_t) - \frac{\beta e^{(1-\sigma_c)\gamma}}{1 + \beta e^{(1-\sigma_c)\gamma}} \mathbb{E}_t [i_{t+1} + z_{t+1}] - \mu_t \right) \quad (\text{A-4})$$

This relationship is affected by investment adjustment costs ( $S''$  is the second derivative of the adjustment cost function) and by the marginal efficiency of investment  $\mu_t$ , an exogenous process which follows an AR(1) with parameters  $\rho_\mu$  and  $\sigma_\mu$ , and that affects the rate of transformation between consumption and installed capital (see Greenwood et al. (1998)).

The *installed capital*, which we also refer to as the capital stock, evolves as:

$$\bar{k}_t = \left( 1 - \frac{i_*}{\bar{k}_*} \right) (\bar{k}_{t-1} - z_t) + \frac{i_*}{\bar{k}_*} i_t + \frac{i_*}{\bar{k}_*} S'' e^{2\gamma} (1 + \beta e^{(1-\sigma_c)\gamma}) \mu_t \quad (\text{A-5})$$

where  $\frac{i_*}{\bar{k}_*}$  is the steady-state ratio of investment to capital. The parameter  $\beta$  captures the intertemporal discount rate in the utility function of the households.

The *arbitrage condition between the return to capital and the riskless rate* is:

$$\frac{r_*^k}{r_*^k + (1 - \delta)} \mathbb{E}_t [r_{t+1}^k] + \frac{1 - \delta}{r_*^k + (1 - \delta)} \mathbb{E}_t [q_{t+1}^k] - q_t^k = R_t + b_t - \mathbb{E}_t [\pi_{t+1}] \quad (\text{A-6})$$



where  $r_t^k$  is the rental rate of capital,  $r_*^k$  its steady-state value, and  $\delta$  the depreciation rate. The relationship between  $\bar{k}_t$  and the *effective capital* rented out to firms  $k_t$  is given by:

$$k_t = u_t - z_t + \bar{k}_{t-1}. \quad (\text{A-7})$$

where capital is subject to variable capacity utilization,  $u_t$ .

The optimality condition determining the *rate of capital utilization* is given by:

$$\frac{1 - \psi}{\psi} r_t^k = u_t. \quad (\text{A-8})$$

where  $\psi$  captures the utilization costs in terms of foregone consumption.

From the optimality conditions of goods producers it follows that all firms have the same *capital-labor ratio*:

$$k_t = w_t - r_t^k + L_t. \quad (\text{A-9})$$

*Real marginal costs* for firms are given by:

$$mc_t = (1 - \alpha) w_t + \alpha r_t^k. \quad (\text{A-10})$$

where  $\alpha$  is the income share of capital (after paying markups and fixed costs) in the production function.

All of the equations mentioned above have the same form regardless of whether or not technology has a unit root or is trend-stationary. A few small differences arise for the following two equilibrium conditions.

The *production function* under trend stationarity is:

$$y_t = \Phi_p (\alpha k_t + (1 - \alpha) L_t) + \mathcal{I}\{\rho_z < 1\} (\Phi_p - 1) \frac{1}{1 - \alpha} \tilde{z}_t. \quad (\text{A-11})$$

The last term  $(\Phi_p - 1) \frac{1}{1 - \alpha} \tilde{z}_t$  drops out if technology has a stochastic trend because then one must assume that the fixed costs are proportional to the trend.

The *resource constraint* is:

$$y_t = g_t + \frac{c_*}{y_*} c_t + \frac{i_*}{y_*} i_t + \frac{r_*^k k_*}{y_*} u_t - \mathcal{I}\{\rho_z < 1\} \frac{1}{1 - \alpha} \tilde{z}_t, \quad (\text{A-12})$$

The term  $-\frac{1}{1 - \alpha} \tilde{z}_t$  disappears if technology follows a unit root process.

Government spending,  $g_t$ , is assumed to follow the exogenous process:

$$g_t = \rho_g g_{t-1} + \sigma_g \epsilon_{g,t} + \eta_{gz} \sigma_z \epsilon_{z,t} \quad (\text{A-13})$$

The *price and wage Phillips curves* respectively are:

$$\begin{aligned} \pi_t = & \frac{(1 - \zeta_p \beta e^{(1-\sigma_c)\gamma})(1 - \zeta_p)}{(1 + \iota_p \beta e^{(1-\sigma_c)\gamma}) \zeta_p ((\Phi_p - 1) \epsilon_p + 1)} m c_t \\ & + \frac{\iota_p}{1 + \iota_p \beta e^{(1-\sigma_c)\gamma}} \pi_{t-1} + \frac{\beta e^{(1-\sigma_c)\gamma}}{1 + \iota_p \beta e^{(1-\sigma_c)\gamma}} \mathbb{E}_t[\pi_{t+1}] + \lambda_{f,t} \end{aligned} \quad (\text{A-14})$$

$$\begin{aligned} w_t = & \frac{(1 - \zeta_w \beta e^{(1-\sigma_c)\gamma})(1 - \zeta_w)}{(1 + \beta e^{(1-\sigma_c)\gamma}) \zeta_w ((\lambda_w - 1) \epsilon_w + 1)} (w_t^h - w_t) \\ & - \frac{1 + \iota_w \beta e^{(1-\sigma_c)\gamma}}{1 + \beta e^{(1-\sigma_c)\gamma}} \pi_t + \frac{1}{1 + \beta e^{(1-\sigma_c)\gamma}} (w_{t-1} - z_t - \iota_w \pi_{t-1}) \\ & + \frac{\beta e^{(1-\sigma_c)\gamma}}{1 + \beta e^{(1-\sigma_c)\gamma}} \mathbb{E}_t[w_{t+1} + z_{t+1} + \pi_{t+1}] + \lambda_{w,t} \end{aligned} \quad (\text{A-15})$$

where  $\zeta_p$ ,  $\iota_p$ , and  $\epsilon_p$  are the Calvo parameter, the degree of indexation, and the curvature parameters in the Kimball aggregator for prices, with the equivalent parameters with subscript  $w$  corresponding to wages.

The variable  $w_t^h$  corresponds to the *household's marginal rate of substitution between consumption and labor* and is given by:

$$\frac{1}{1 - h e^{-z_t^*}} (c_t - h e^{-z_{t-1}^*} c_{t-1} + h e^{-z_t^*} z_t) + \nu_l L_t = w_t^h. \quad (\text{A-16})$$

where  $\eta_l$  is the curvature of the disutility of labor (equal to the inverse of the Frisch elasticity in the absence of wage rigidities).

The mark-ups  $\lambda_{f,t}$  and  $\lambda_{w,t}$  follow exogenous ARMA(1, 1) processes:

$$\lambda_{f,t} = \rho_{\lambda_f} \lambda_{f,t-1} + \sigma_{\lambda_f} \epsilon_{\lambda_f,t} + \eta_{\lambda_f} \sigma_{\lambda_f} \epsilon_{\lambda_f,t-1} \quad (\text{A-17})$$

$$\lambda_{w,t} = \rho_{\lambda_w} \lambda_{w,t-1} + \sigma_{\lambda_w} \epsilon_{\lambda_w,t} + \eta_{\lambda_w} \sigma_{\lambda_w} \epsilon_{\lambda_w,t-1} \quad (\text{A-18})$$

Lastly, the monetary authority follows a *policy feedback rule*:

$$R_t = \rho_R R_{t-1} + (1 - \rho_R) (\psi_1 \pi_t + \psi_2 (y_t - y_t^f)) + \psi_3 ((y_t - y_t^f) - (y_{t-1} - y_{t-1}^f)) + r_t^m \quad (\text{A-19})$$

where the flexible price/wage output  $y_t^f$  is obtained from solving the version of the model absent nominal rigidities (without equations (3)-(12) and (15)), and the residual  $r_t^m$  follows an AR(1) process with parameters  $\rho_{r^m}$  and  $\sigma_{r^m}$ .

The exogenous component of the policy rule  $r_t^m$  evolves according to the following process:

$$r_t^m = \rho_{r^m} r_{t-1}^m + \epsilon_t^R + \sum_{k=1}^K \epsilon_{k,t-k}^R \quad (\text{A-20})$$

where  $\epsilon_t^R$  is the usual contemporaneous policy shock and  $\epsilon_{k,t-k}^R$  is a policy shock that is known to agents at time  $t - k$ , but affects the policy rule  $k$  periods later — that is, at time  $t$ . As outlined in Laseen and Svensson (2011), these *anticipated policy shocks* allow us to capture the effects of the zero lower bound on nominal interest rates, as well as the effects of forward guidance in monetary policy.

### A.1.2 Measurement Equations

The SW model is estimated using seven quarterly macroeconomic time series, whose measurement equations are given below:

$$\begin{aligned} \text{Output growth} &= \gamma + 100(y_t - y_{t-1} + z_t) \\ \text{Consumption growth} &= \gamma + 100(c_t - c_{t-1} + z_t) \\ \text{Investment growth} &= \gamma + 100(i_t - i_{t-1} + z_t) \\ \text{Real Wage growth} &= \gamma + 100(w_t - w_{t-1} + z_t) \\ \text{Hours} &= \bar{l} + 100l_t \\ \text{Inflation} &= \pi_* + 100\pi_t \\ \text{FFR} &= R_* + 100R_t \\ \text{FFR}_{t,t+j}^e &= R_* + \mathbb{E}_t[R_{t+j}], j = 1, \dots, 6 \end{aligned} \quad (\text{A-21})$$

where all variables are measured in percent,  $\pi_*$  and  $R_*$  measure the steady-state levels of net inflation and short term nominal interest rates, respectively, and  $\bar{l}$  represents the mean of the hours (this variable is measured as an index).

The priors for the DSGE model parameters are the same as in Smets and Wouters (2007) and are summarized in Panel I of the priors table listed in the SW<sup>++</sup> section.

## A.2 SW $\pi$

The SW $\pi$  model builds on SW by allowing the inflation target to be time-varying. The time-varying inflation target,  $\pi_t^*$ , allows us to capture the dynamics of inflation and interest rates in the estimation sample.

The time-varying *inflation target* evolves according to

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \sigma_{\pi^*} \epsilon_{\pi^*,t} \quad (\text{A-22})$$

where  $0 < \rho_{\pi^*} < 1$  and  $\epsilon_{\pi^*,t}$  is an i.i.d. shock.  $\pi_t^*$  is a stationary process, although the prior on  $\rho_{\pi^*}$  forces this process to be highly persistent.

### A.2.1 Measurement Equations

As in Aruoba and Schorfheide (2008) and Del Negro and Eusepi (2011), we use data on long-run inflation expectations in the estimation of SW $\pi$ . This allows us to pin down the target inflation rate to the extent that long-run inflation expectations contain information about the central bank's objective.

Thus there is an additional measurement equation for 10 year inflation expectations that augments (A-21), given by

$$10y \text{ Infl. Expectations} = \pi_* + \mathbb{E}_t \left[ \frac{1}{40} \sum_{j=0}^{39} \pi_{t+j} \right] \quad (\text{A-23})$$

## A.3 SWFF

Financial frictions are incorporated into the SW model following the work of Bernanke et al. (1999) and Christiano et al. (2009).

### A.3.1 Equilibrium Conditions

SWFF replaces (A-6) with the following equation for the *excess return on capital* — that is, the spread between the expected return on capital and the riskless rate — and the definition of the *return on capital*,  $\tilde{R}_t^k$ , respectively:

$$\mathbb{E}_t \left[ \tilde{R}_{t+1}^k - R_t \right] = -b_t + \zeta_{sp,b}(q_t^k - \bar{k}_t - n_t) + \tilde{\sigma}_{\omega,t} \quad (\text{A-24})$$

and

$$\tilde{R}_t^k - \pi_t = \frac{r_*^k}{r_*^k + (1 - \delta)} r_t^k + \frac{(1 - \delta)}{r_*^k + (1 - \delta)} q_t^k - q_{t-1}^k \quad (\text{A-25})$$

where  $\tilde{R}_t^k$  is the gross nominal return on capital for entrepreneurs,  $n_t$  is entrepreneurial equity, and  $\tilde{\sigma}_{\omega,t}$  captures mean-preserving changes in the cross-sectional dispersion of ability across entrepreneurs (see Christiano et al. (2009)) and follows an AR(1) process with parameters  $\rho_{\sigma_\omega}$  and  $\sigma_{\sigma_\omega}$ .

The following equation outlines the *evolution of entrepreneurial net worth*:

$$\hat{n}_t = \zeta_{n,\tilde{R}_t^k} \left( \tilde{R}_t^k - \pi_t \right) - \zeta_{n,\tilde{R}_t^k} (R_{t-1} - \pi_t) + \zeta_{n,qK} (q_{t-1}^k + \bar{k}_{t-1}) + \zeta_{n,n} n_{t-1} - \frac{\zeta_{n,\sigma_\omega}}{\zeta_{sp,\sigma_\omega}} \tilde{\sigma}_{\omega,t-1} \quad (\text{A-26})$$

### A.3.2 Measurement Equations

SWFF's additional measurement equation for the spread (given below) augments the standard set of SW measurement equations (A-21) along with (A-23).

$$Spread = SP_* + 100 \mathbb{E}_t \left[ \tilde{R}_{t+1}^k - R_t \right] \quad (\text{A-27})$$

where  $SP_*$  measures the steady-state spread. Priors are specified for the parameters  $SP_*$ ,  $\zeta_{sp,b}$ ,  $\rho_{\sigma_\omega}$ ,  $\sigma_{\sigma_\omega}$ , and the parameters  $\bar{F}_*$  and  $\gamma_*$  (the steady-state default probability and the survival rate of entrepreneurs, respectively), are fixed.

## A.4 SWFF<sup>+</sup>

The SW<sup>+</sup> model augments the technology process,  $Z_t^*$ , with a long-run component,  $Z_t^p$ , such that  $Z_t^* = e^{\frac{1}{1-\alpha} \tilde{z}_t} Z_t^p e^{\gamma t}$ . Recall the previous specification of the growth rate of the technology process (A-2). Now with an additional term,  $z_t^p = \ln(Z_t^p/Z_{t-1}^p)$ , the growth rate of the technology process follows:

$$z_t = \ln(Z_t^*/Z_{t-1}^*) - \gamma = \frac{1}{1-\alpha} (\rho_z - 1) \tilde{z}_{t-1} + \frac{1}{1-\alpha} \sigma_z \epsilon_{z,t} + z_t^p \quad (\text{A-28})$$

where

$$z_t^p = \rho_{z^p} z_{t-1}^p + \sigma_{z^p} \epsilon_{z^p,t}, \quad \epsilon_{z^p,t} \sim N(0, 1) \quad (\text{A-29})$$

### A.4.1 Measurement Equations

SW<sup>+</sup> adds an additional set of measurement equations for core PCE, the 10 year nominal bond yield, and TFP.

$$\begin{aligned}
\text{Core PCE Inflation} &= \pi_* + \pi_t + e_t^{pce} \\
\text{10y Nominal Bond Yield} &= R_* + \mathbb{E}_t \left[ \frac{1}{40} \sum_{k=1}^{40} R_{t+k} \right] + e_t^{10y} \\
\text{TFP growth, demeaned} &= z_t + \frac{\alpha}{1-\alpha} (u_t - u_{t-1}) + e_t^{tfp}
\end{aligned} \tag{A-30}$$

All the  $e_t^*$  processes follow exogenous AR(1) specifications, and can be thought of either as measurement errors or some other unmodeled source of discrepancy between the model and the data (e.g., risk premia for the long term nominal rate).

## A.5 SWFF<sup>++</sup>

### A.5.1 Measurement Equations

SW<sup>++</sup> adds the additional measurement equation for GDI and modifies the equation for GDP given in Section A-21:

$$\begin{aligned}
\text{GDP growth} &= 100\gamma + (y_t - y_{t-1} + z_t) + e_t^{gdp} - \mathcal{C}_{me} e_{t-1}^{gdp} \\
\text{GDI growth} &= 100\gamma + (y_t - y_{t-1} + z_t) + e_t^{gdi} - \mathcal{C}_{me} e_{t-1}^{gdi}
\end{aligned} \tag{A-31}$$

The  $e_t^*$  terms follow exogenous AR(1) specifications as similarly described in Section A.4. Furthermore, we introduce correlation in the measurement errors for GDP and GDI, which evolve as follows:

$$\begin{aligned}
e_t^{gdp} &= \rho_{gdp} e_{t-1}^{gdp} + \sigma_{gdp} \epsilon_t^{gdp}, \quad \epsilon_t^{gdp} \sim i.i.d.N(0, 1) \\
e_t^{gdi} &= \rho_{gdi} e_{t-1}^{gdi} + \rho_{gdp} \sigma_{gdp} \epsilon_t^{gdp} + \sigma_{gdi} \epsilon_t^{gdi}, \quad \epsilon_t^{gdi} \sim i.i.d.N(0, 1)
\end{aligned}$$

We assume that  $\mathcal{C}_{me} = 1$ . The measurement errors for GDP and GDI are thus stationary in levels, and enter the observation equation in first differences (e.g.  $\epsilon_t^{gdp} - \epsilon_{t-1}^{gdp}$  and  $\epsilon_t^{gdi} - \epsilon_{t-1}^{gdi}$ ). GDP and GDI are also cointegrated as they are driven by a common stochastic trend.

## A.6 Data Transformation

The data are transformed following Smets and Wouters (2007), with the exception of the civilian population data, which are filtered using the Hodrick-Prescott filter to remove jumps around census dates. For each financial variable, we take quarterly averages of the annualized daily data and divide by four. Let  $\Delta$  denote the temporal difference operator. Then:

GDP growth	=	$100 * \Delta LN((GDP/GDPDEF)/CNP16OV)$
GDI growth	=	$100 * \Delta LN((GDI/GDPDEF)/CNP16OV)$
Consumption growth	=	$100 * \Delta LN((PCEC/GDPDEF)/CNP16OV)$
Investment growth	=	$100 * \Delta LN((FPI/GDPDEF)/CNP16OV)$
Real wage growth	=	$100 * \Delta LN(COMP NFB/GDPDEF)$
Hours worked	=	$100 * LN((AWHNONAG * CE16OV/100)/CNP16OV)$
GDP deflator inflation	=	$100 * \Delta LN(GDPDEF)$
Core PCE inflation	=	$100 * \Delta LN(JCXFE)$
FFR	=	$(1/4) * \text{FEDERAL FUNDS RATE}$
$FFR_{t+k t}^e$	=	$(1/4) * \text{BLUE CHIP } k\text{-QUARTERS AHEAD FFR FORECAST}$
10y inflation exp	=	$(10\text{-year average CPI inflation forecast} - 0.50)/4$
Spread	=	$(1/4) * (\text{Baa Corporate} - 10 \text{ year Treasury})$
10y bond yield	=	$(1/4) * (10 \text{ year Treasury})$
TFP growth, demeaned	=	$(1/4) * (\text{Fernald's TFP growth, unadjusted, demeaned})/(1 - \alpha)$

In the long-term inflation expectation transformation, 0.50 is the average difference between CPI and GDP annualized inflation from the beginning of the sample to 1992.

## A.7 Inference, Prior and Posterior Parameter Estimates

We estimate the model using Bayesian techniques. This requires the specification of a prior distribution for the model parameters. For most parameters common with Smets and Wouters (2007), we use the same marginal prior distributions. As an exception, we favor a looser prior than Smets and Wouters (2007) for the quarterly steady-state inflation rate  $\pi_*$ ; it is centered at 0.75% and has a standard deviation of 0.4%. Regarding the financial frictions, we specify priors for the parameters  $SP_*$ ,  $\zeta_{sp,b}$ ,  $\rho_{\sigma_\omega}$ , and  $\sigma_{\sigma_\omega}$ , while we fix the parameters corresponding to the steady-state default probability and the survival rate of entrepreneurs, respectively. In turn, these parameters imply values for the parameters of (A-26). Information on the priors and posterior mean is provided in Table A-1.

Table A-1: Parameter Estimates

Parameter	SWFF Prior			SWFF Posterior			SW Posterior		
	Type	Mean	SD	Mean	90.0% <sub>LB</sub>	90.0% <sub>UB</sub>	Mean	90.0% <sub>LB</sub>	90.0% <sub>UB</sub>
<i>Steady State</i>									
$100\gamma$	N	0.400	0.100	0.406	0.382	0.431	0.367	0.320	0.414
$\alpha$	N	0.300	0.050	0.142	0.112	0.172	0.143	0.115	0.171
$100(\beta^{-1} - 1)$	G	0.250	0.100	0.127	0.062	0.193	0.168	0.071	0.265
$\sigma_c$	N	1.500	0.370	0.776	0.614	0.937	1.063	0.854	1.270
$h$	B	0.700	0.100	0.521	0.428	0.615	0.611	0.531	0.690
$\nu_l$	N	2.000	0.750	2.574	1.741	3.410	2.161	1.278	3.005
$\delta$	-	0.025	0.000	0.025	0.025	0.025	0.025	0.025	0.025
$\Phi$	N	1.250	0.120	1.582	1.444	1.713	1.559	1.435	1.690
$S//$	N	4.000	1.500	3.325	1.813	4.717	6.590	4.927	8.197
$\psi$	B	0.500	0.150	0.684	0.562	0.821	0.759	0.626	0.896
$\bar{L}$	N	-45.000	5.000	-46.042	-48.189	-43.815	-45.106	-47.011	-43.251
$\lambda_w$	-	1.500	0.000	1.500	1.500	1.500	1.500	1.500	1.500
$\pi_*$	G	0.750	0.400	1.151	0.808	1.490	0.681	0.526	0.839
$g_*$	-	0.180	0.000	0.180	0.180	0.180	0.180	0.180	0.180
<i>Nominal Rigidities</i>									
$\zeta_p$	B	0.500	0.100	0.926	0.903	0.950	0.844	0.799	0.888
$\zeta_w$	B	0.500	0.100	0.923	0.905	0.942	0.856	0.811	0.904
$\iota_p$	B	0.500	0.150	0.294	0.139	0.443	0.223	0.092	0.345
$\iota_w$	B	0.500	0.150	0.445	0.256	0.633	0.484	0.279	0.687
$\varepsilon_p$	-	10.000	0.000	10.000	10.000	10.000	10.000	10.000	10.000
$\varepsilon_w$	-	10.000	0.000	10.000	10.000	10.000	10.000	10.000	10.000
<i>Policy</i>									
$\psi_1$	N	1.500	0.250	1.148	1.039	1.250	1.847	1.584	2.100
$\psi_2$	N	0.120	0.050	0.004	-0.005	0.013	0.110	0.064	0.156
$\psi_3$	N	0.120	0.050	0.193	0.160	0.225	0.207	0.171	0.241
$\rho$	B	0.750	0.100	0.724	0.693	0.754	0.868	0.840	0.897
$\rho_{rm}$	B	0.500	0.200	0.182	0.106	0.257	0.257	0.170	0.342
<i>Financial Frictions</i>									
$F(\omega)$	-	0.030	0.000	0.030	0.030	0.030	-	-	-

Note: N, B, G, and IG stand, respectively, for the normal, beta, gamma, and root inverse gamma distributions. Under the inverse gamma prior mean and SD, the mode  $\tau$  and degrees of freedom  $\nu$  are reported.



Table A-1: Parameter Estimates

Parameter	SWFF Prior			SWFF Posterior			SW Posterior		
	Type	Mean	SD	Mean	90.0% <sub>LB</sub>	90.0% <sub>UB</sub>	Mean	90.0% <sub>LB</sub>	90.0% <sub>UB</sub>
$spr_*$	G	2.000	0.100	1.914	1.775	2.054	-	-	-
$\zeta_{spb}$	B	0.050	0.005	0.052	0.045	0.059	-	-	-
$\gamma_*$	-	0.990	0.000	0.990	0.990	0.990	-	-	-
<i>Exogenous Processes</i>									
$\rho_g$	B	0.500	0.200	0.983	0.974	0.992	0.978	0.965	0.992
$\rho_\mu$	B	0.500	0.200	0.874	0.827	0.924	0.713	0.623	0.801
$\rho_z$	B	0.500	0.200	0.940	0.918	0.964	0.978	0.960	0.995
$\rho_{\lambda_f}$	B	0.500	0.200	0.725	0.594	0.862	0.858	0.794	0.924
$\rho_{\lambda_w}$	B	0.500	0.200	0.403	0.135	0.668	0.980	0.966	0.994
$\eta_{\lambda_f}$	B	0.500	0.200	0.637	0.461	0.816	0.731	0.596	0.866
$\eta_{\lambda_w}$	B	0.500	0.200	0.421	0.176	0.656	0.972	0.957	0.988
$\eta_{gz}$	B	0.500	0.200	0.796	0.622	0.974	0.796	0.635	0.974
$\sigma_g$	IG	0.100	2.000	2.919	2.677	3.147	2.891	2.660	3.118
$\sigma_\mu$	IG	0.100	2.000	0.401	0.320	0.474	0.365	0.301	0.431
$\sigma_z$	IG	0.100	2.000	0.509	0.465	0.554	0.517	0.473	0.563
$\sigma_{\lambda_f}$	IG	0.100	2.000	0.145	0.126	0.164	0.128	0.106	0.150
$\sigma_{\lambda_w}$	IG	0.100	2.000	0.381	0.336	0.425	0.356	0.326	0.386
$\rho_b$	B	0.500	0.200	0.950	0.944	0.957	0.888	0.857	0.920
$\sigma_b$	IG	0.100	2.000	0.035	0.029	0.040	0.094	0.078	0.108
$\rho_{\sigma_\omega}$	B	0.750	0.150	0.982	0.971	0.990	-	-	-
$\rho_{\pi^*}$	-	0.990	0.000	0.990	0.990	0.990	-	-	-
$\sigma_{\sigma_\omega}$	IG	0.050	4.000	0.067	0.060	0.074	-	-	-
$\sigma_{\pi^*}$	IG	0.030	6.000	0.018	0.014	0.022	-	-	-
$\sigma_{rm}$	IG	0.100	2.000	0.185	0.172	0.199	-	-	-

*Note:* N, B, G, and IG stand, respectively, for the normal, beta, gamma, and root inverse gamma distributions. Under the inverse gamma prior mean and SD, the mode  $\tau$  and degrees of freedom  $\nu$  are reported.

## B Vintages for Real Real-Time Forecast Comparison

Table A-2: Vintages for Real Real-Time Forecast Comparison

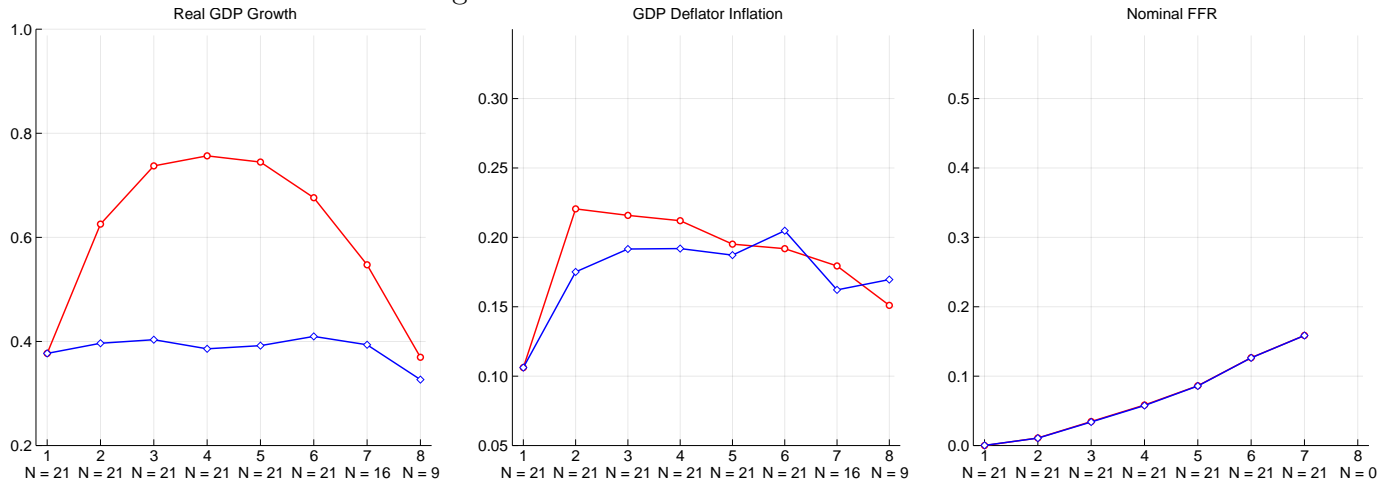
Quarter	Bluechip		SPF		SEP	
	Vintage	NYFed Vintage	Vintage	NYFed Vintage	Vintage	NYFed Vintage
2011-Q1	110410	110315			110426	110420
2011-Q2	110710	110615	110513	110311	110621	110615
2011-Q3					111101	111019
2011-Q4			111114	111019	120124	120111
2012-Q1	120410	120409	120210	120111	120424	120409
2012-Q2	120710	120605	120511	120409	120619	120605
2012-Q3	121010	120829			120912	120829
2012-Q4	130110	121113			121211	121113
2013-Q1	130410	130308	130215	130124	130319	130308
2013-Q2	130710	130613			130618	130613
2013-Q3	131010	130912	130816	130723	130917	130912
2013-Q4	140110	131212	131125	131023	131217	131212
2014-Q1	140410	140313			140318	140313
2014-Q2	140710	140610	140516	140423	140617	140610
2014-Q3	141010	140908	140815	140722	140916	140908
2014-Q4	150110	141209	141117	141021	141216	141209
2015-Q1	150410	150309	150213	150121	150317	150309
2015-Q2	150710	150610	150515	150421	150616	150610
2015-Q3	151010	150828	150814	150721	150916	150828
2015-Q4	160110	151204	151113	151014	151215	151204
2016-Q1	160410	160226	160212	160117	160315	160226

*Note:* The “Quarter” column corresponds to the first forecast quarter for the Bluechip and SEP forecast comparisons, and the second forecast quarter for the SPF forecast comparison. The “Vintage” and “NYFed Vintage” columns correspond to the release dates of the Bluechip, SPF, and SEP, and the NY Fed DSGE real real-time forecast vintage that they were matched with. The vintages are reported in YYMMDD format (year-month-day).

## C Additional Results

### C.1 Financial Frictions vs. Time-Varying $\pi^*$

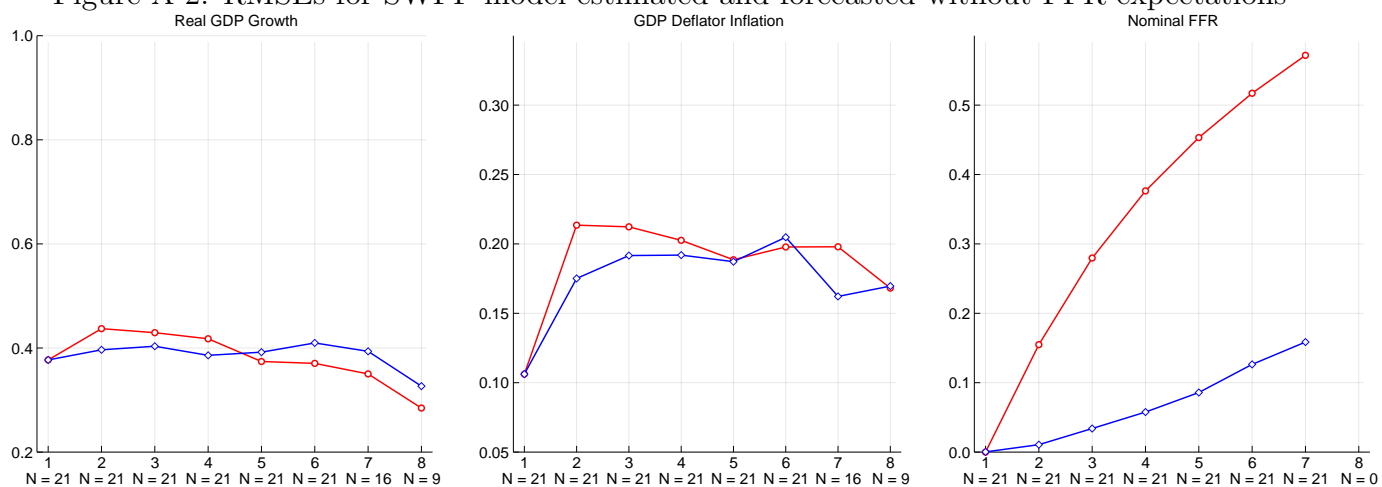
Figure A-1: RMSEs for SW $\pi$  model



*Note:* The panels compare the RMSEs for the SW $\pi$  DSGE model (red circles) with the Blue Chip (blue diamonds) for one through eight quarters ahead for real output growth, GDP deflator inflation, and interest rates. Output growth and inflation are expressed in Q/Q percent terms, whereas interest rates are in quarterly percentage points. The  $N = n$  labels under each  $x$ -axis tick indicate the number of observations available for both the BCEI and DSGE forecasts at that horizon. Forecast origins from January 2011 to January 2016 only are included in these calculations.

## C.2 Estimating and Forecasting without FFR Expectations

Figure A-2: RMSEs for SWFF model estimated and forecasted without FFR expectations



*Note:* The panels compare the RMSEs for the SWFF DSGE model (red circles) with the Blue Chip (blue diamonds) for one through eight quarters ahead for real output growth, GDP deflator inflation, and interest rates. Output growth and inflation are expressed in Q/Q percent terms, whereas interest rates are in quarterly percentage points. The  $N = n$  labels under each  $x$ -axis tick indicate the number of observations available for both the BCEI and DSGE forecasts at that horizon. Forecast origins from January 2011 to January 2016 only are included in these calculations. In this exercise, we re-estimated and forecasted the SWFF model without FFR expectations data. Compare to the RMSEs in Figure 8, which were computed from the baseline parameter draws (estimated using FFR expectations data).