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System DSGE Project Documentation

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Executive Summary

This memo serves as background material for the June 21 FOMC presentation on dynamic stochastic general equilibrium (DSGE) models and is intended to familiarize the Committee with DSGE models and the benefits that they can provide to policymakers. The first section, “Project Statement,” briefly outlines the uses and underlying characteristics of the DSGE models being developed in the System. The second section, “A Primer on DSGE Models”, informs the Committee about key aspects of the DSGE methodology. In the third section, “Explaining the Great Recession”, the models are applied to identify the key economic factors that contributed to the Great Recession and how various economic disturbances produced the severe downturn in economic activity. The final section, “Forecasts”, summarizes the economic forecasts of the four models that currently make up the project. More detailed discussions and in-depth descriptions of the models are contained in the Research Directors Drafts and the model Appendices.

Project Statement

The Federal Reserve's project on dynamic stochastic general equilibrium (DSGE) models seeks to promote the use of these models to support policymakers' analyses and policy decisions. The project can be viewed as part of an ongoing research effort at central banks around the world, as well as in academia, to develop, refine, and employ macroeconomic models grounded in optimizing behavior, a consistent treatment of expectations about the future, and adherence to budget constraints. The models have been employed to analyze and quantify the forces impacting the economy, to assess the effects of alternative policy choices, and to provide forecasts. On the latter dimension, the models have been shown to have good forecasting abilities, roughly on par with the leading alternative models. The participants in the Federal Reserve's DSGE project believe that regular presentations of forecasts and policy analyses from the System DSGE models would enable the Committee to better formulate its policy decisions.

A Primer on DSGE Models

What are DSGE models?

DSGE models have four distinguishing features. First, they provide explicit "micro foundations" for how households, firms, and policymakers behave and interact in the economy. The objectives and constraints facing households, firms, and policymakers are explicitly specified; moreover, these agents are aware of them. Households and firms solve their optimization problems and form forward-looking expectations. The use of optimizing behavior places restrictions on the models and the validity of these restrictions can be formally tested.

Second, an important lesson from modern macroeconomics is that expectations about the future affect current behavior, and that these expectations are endogenous, which implies that they are affected by policy decisions. This rigorous and consistent treatment of expectations is embedded in DSGE models (in most cases expectations are assumed rational, but the modeling strategy is not restricted to rational expectations). Third, the models are general equilibrium in that economy-wide prices, such as wages and interest rates, must ultimately adjust so that economy-wide budget constraints are met.

Finally, the driving forces underlying these models are "shocks" to productivity, aggregate demand, household behavior, and monetary and fiscal policy. The shocks capture the inherent unpredictability of macroeconomic data. These shocks can be identified via the restrictions imposed on the model's economic structure. The use of an explicit optimizing model makes the output of DSGE models -- whether that output is an economic forecast, the results of a policy experiment, or the analysis of sources of economic fluctuations -- readily interpretable in terms of economic theory. Thus, DSGE models paint a coherent picture with respect to a host of issues that are of interest to policy makers.

Like other types of models, DSGE models can be used to assess the relative importance of the shocks that are responsible for where the economy currently stands, to conduct analysis of the effects of alternative policies or of alternative economic scenarios, and to provide forecasts of the future evolution of the economy. Compared to these other types of models, DSGE models are able to provide more consistent explanations for how and why the shocks have affected GDP and inflation, for how an error in the assessment of potential output by policy makers would play out, and for how and why the forecast calls for improving GDP growth, for example. In particular, as mentioned above, DSGE models highlight the important role played by expectations and how they evolve in response to new information about the economy and about monetary and fiscal policy.

The parameters of DSGE models are typically estimated using Bayesian statistical techniques. A key feature of Bayesian methods is the use of prior beliefs that embody information from data sets not otherwise included in the estimation. For example, micro data on price adjustment may be employed to help pin down the frequency of price adjustment through the use of a prior. The statistical methodology also allows the user to characterize the uncertainty surrounding parameter estimates and economic forecasts, as well as the uncertainty surrounding the results of alternative policy experiments.

The Basic Structure Common to the Models in our Project

The basic structure of DSGE models is displayed in Figure 1. Firms employ workers and rent capital in order to produce goods, and production is subject to productivity shocks. Firms have pricing power and price setting is staggered, which means that each firm's price can be adjusted only occasionally. These price rigidities are an important feature of the models and are an important element in aligning the models with the data. The pricing mechanism generates a Phillips curve relating inflation to a measure of real activity. Along with a productivity shock, firms' decisions are influenced by shocks to the desired markup of price over marginal cost.

Households own the firms and the capital stock either directly or indirectly through their investments with financial intermediaries. They choose how much to consume and save, as well as how much labor to supply. Their period utility function involves current and past consumption. The influence of past consumption patterns on current decisions (also called "habit formation") turns out to be a relatively important ingredient for the model's ability to generate persistent GDP growth. As for the labor supply decision, households are viewed as monopolistically competitive suppliers of labor: they set wages in a fashion similar to the way firms set prices and then supply all the labor demanded by firms at that wage. Because many of the models do not explicitly incorporate financial frictions, the transformation of household savings into business investment formally appears as part of the household's problem. However, a useful interpretation of the capital accumulation process is that it requires some form of financial intermediation. The accumulation of capital is also subject to adjustment costs. These costs are stochastic and affect the marginal efficiency of investment (how much capital is produced by an additional unit of investment). Thus, this shock can quite naturally be given a financial interpretation (see Justiniano, Primiceri, and Tambalotti (2011)). A number of disturbances influence households' decisions: shocks to the rate of time discount (how impatient the household is), and shocks to labor supply (e.g., changes in the value of leisure). Shocks to the rate of time discount can be important in generating differential growth patterns in consumption and investment, and shocks to labor supply are intended to capture labor market frictions beyond those involving wage rigidity.

Most models also involve nonproductive consumption by the government, but that is generally the extent to which fiscal policy is incorporated in the model. Shocks to government spending are basically disturbances to the economies' overall resource constraint and can, therefore, also be interpreted as shocks to net exports or non-modeled shocks to private consumption and investment. Monetary policy is modeled as a generalized Taylor rule, with interest rates responding to inflation relative to target and some measure of economic activity. The Taylor rule is inertial and, monetary policy shocks capture deviations of the interest rate from this rule.

Model development is ongoing, and although the models employed by the various Reserve Banks and the Board share most of the above features, they do differ in terms of their underlying economic structure as well as the data used to estimate the parameters, identify the shocks, and generate forecasts. The structure of the Prism model is closest to the one described here. The FRBNY model incorporates a specific financial sector along the lines of Bernanke, Gertler, and Gilchrist (1999). The Board EDO model has multiple sectors and exogenously incorporates risk premia into the pricing of bonds. Finally, the Chicago model includes neutral and capital embodied technical progress, uses an interest rate risk spread to identify the shock to the marginal efficiency of investment, and exploits the information in multiple inflation indicators.

Consequently, we have a rich set of DSGE models that, unsurprisingly, gives rise to differing interpretations of economic events.

We view this heterogeneity as a strength of our project. By using a number of different DSGE models we can, to some degree, ascertain the extent of model uncertainty as well as the uncertainty that characterizes each particular model. Examining model uncertainty is an important part of analyzing the output of DSGE exercises since economists are in general more uncertain about their models' basic structure than they are about the parameter values of any particular model.

Using the Models for Forecasting and Evaluating Policy Alternatives

The models are estimated using Bayesian methods in order to incorporate prior restrictions on the parameters. The priors allow one to incorporate information not well captured by aggregate data, such as the frequency of price adjustment observed at the micro level.

Once the models are estimated, they can be used for a variety of exercises. First, the models can be used to forecast the variables that are part of the model structure. The use of "bridge" models makes forecasting additional non-modeled variables possible as well (see Schorfheide, Sill, and Kryshko (2010)). The latter methodology has been used in conjunction with Philadelphia's Prism model. Bayesian methods allow uncertainty around forecasts, due to both parameter and shock uncertainty, to be taken into account. DSGE model forecasts are generally of a quality similar to that of reduced form forecasts and forecasts that are more judgmental in nature (see Gurkaynak and Edge (2010) and Smets and Wouters (2007)). DSGE models are also amenable to "nowcasting" exercises, which incorporate more timely information, as is commonly done in FRBNY and Chicago forecasting exercises. It remains the case, though, that forecasts from less tightly parameterized, hybrid models, which relax the restrictions embedded in DSGEs, generally outperform those from DSGE models (see Del Negro and Schorfheide (2004)). At present, a deficiency of our forecasting exercise is that we have yet to examine the out-of-sample forecasting accuracy of our models (with the exception of the Board's EDO).

A key benefit of DSGE models is that they allow one to identify the disturbances that are driving economic fluctuations and forecasts. The strength of the DSGE framework is shown in the analysis of the Great Recession that we conducted for this project. Many of the models in our project identify the shocks responsible for the recent recession as those that are most closely linked with financial market behavior. The estimated DSGE models allow one to back out the "history" of these implied shocks, which, in turn, provide information that can be checked with other sources.

Finally, DSGE models allow for an exploration of the effects of alternative policies. The estimation of DSGE models focuses on parameters that are assumed to be invariant to policy changes – parameters pertaining to preferences and technology; hence, one can properly ask questions about the effect of alternative policies. For example, one can analyze the effects of alternative interest rate paths, either as simple deviations from the model's forecasted path or as paths that would result from entirely different ways of conducting monetary policy, such as adopting a price level targeting regime.

Potential Pitfalls of the Models

Our overview would be incomplete if we did not point out some of the inherent weaknesses of the DSGE approach. One weakness is that the models are not particularly large scale; they explain the behavior of a relatively small set of variables; typically they have 10-30 equations with 7 or 8 potential driving forces. As a result they suffer from model misspecification. Furthermore, some of the restrictions imposed by the models are at odds with the data. For example, some of the great ratios, such as the ratio of consumption to output, exhibit a trend. The models treat these ratios as stationary. This type of misspecification can lead to poorly estimated structural disturbances. Also, in their present state, all of the models ignore open economy aspects, firms' and agents' heterogeneity, and several other features that are potentially important for the transmission mechanism of the various shocks. One outgrowth of model misspecification is that many of the stochastic disturbances are long-lived, and the behavior of some of the endogenous variables in DSGE models is very closely aligned with the behavior of a particular disturbance. However, the importance of the misspecification can be tested by comparing the fit of the DSGE model with that of less tightly parameterized models (see Del Negro and Schorfheide (2004)). Another factor to consider is that some of the behavioral relationships embedded in the model are still not fully structural. The price setting mechanism, for example (known as "Calvo" price setting), is not derived from the optimizing decision of firms, and so, the estimated parameters of that mechanism are probably not invariant to alternative policies. This suggests that when analyzing alternative policies, one should have more confidence in the model's prediction the closer the alternative is to actual policy. Finally, the models often lack important sectors, such as a sophisticated financial sector, and the modeling of fiscal policy could be more sophisticated, as well. We note that alternative models, such as vector autoregressions (VARs) and big macroeconometric models, such as FRBUS, also suffer from misspecification, and suffer at least as much if not more from a lack of structural behavioral relationships.

Going Forward

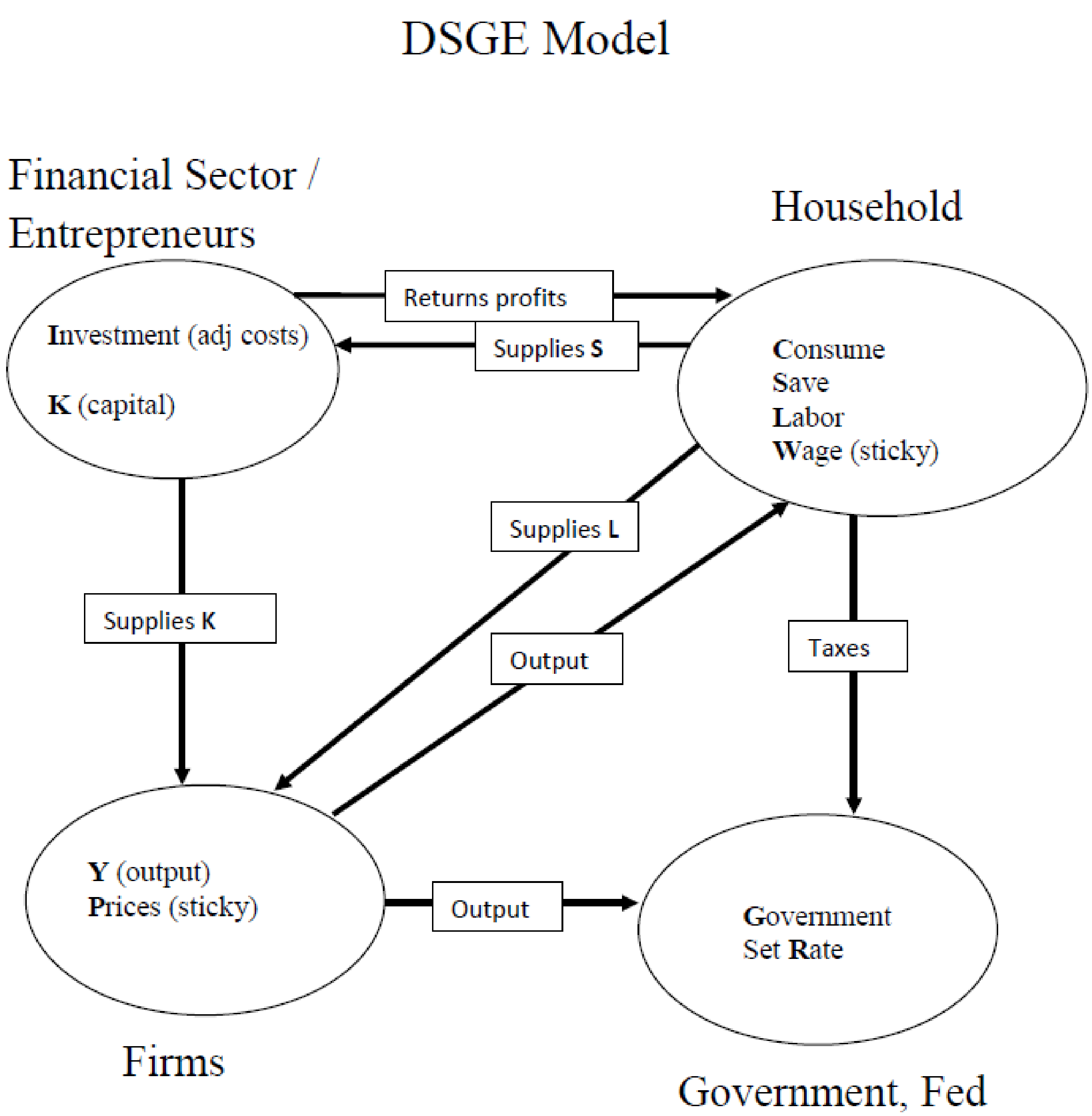
We believe the weaknesses are more than offset by the strengths of the DSGE framework, and these models should be an important element of the policymaker's toolkit. The analyses and forecasts from DSGE models can be used as a complement to other model-based analyses and forecasts, as well as other information and views that policymakers bring to the table. Specifically, we believe there are three ways in which DSGE models can be useful to the committee:

1. They can be used to identify particular types of shocks that are driving the economy as is done in the current forecast and the exploration of the causes of the Great Recession. Such exercises potentially provide useful information to policymakers. For example, the appropriate policy response to a decline in GDP induced by a productivity shock may well differ from the response to a decline in GDP induced by a shock to aggregate demand.
2. They can be used to analyze alternative policies and alternative economic scenarios, and to deliver a coherent and consistent explanation for how the policies and scenarios would affect the economy. For example, they could be used to analyze the differences between anticipated and unanticipated changes to policy, or to compare economic behavior under different monetary policy regimes (for example, price level targeting versus inflation targeting), or to explore the consequences of alternative fiscal policies. In some cases, DSGE models are the only tool that can be used to analyze these scenarios. This should

inform policymakers about the merits and costs of different policy actions, as well as of the potential consequences if particular scenarios play out.

3. They can be used to provide forecasts to the Committee. This would have two benefits. First, the models would provide a coherent and internally consistent explanation for the driving forces underlying the forecast, and for how these forces are transmitted to the economy. Second, the accuracy of the forecasts can be assessed over time via formal comparison with the performance of other models.

Figure 1.



References

Bernanke, Ben, Mark Gertler, and Simon Gilchrist. “The Financial Accelerator in a Quantitative Business Cycle Framework,” in J.B. Taylor and M. Woodford, eds., Handbook of Macroeconomics, vol. 1C, Amsterdam: North Holland, 1999.

Del Negro, Marco and Frank Schorfheide. “Priors from General Equilibrium Models for VARs,” International Economic Review, 45(2), 2004, pp. 643-673.

Edge, Rochelle and Refet S.Gurkaynak. “How Useful Are Estimated DSGE Model Forecasts for Central Bankers?” Brookings Papers on Economic Activity, Fall 2010.

Justiniano, Alejandro, Giorgio Primiceri, and Andrea Tambalotti. “Investment Shocks and the Relative Price of Investment,” Review of Economic Dynamics, (14), 2011, pp 102-121.

Smets, Frank and Ralphael Wouters. “Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach,” American Economic Review, 97(3), 2007, pp. 586-606.

Schorfheide, Frank, Keith Sill, and Maxim Kryshko. “DSGE Forecasting of Non-modeled Variables,” International Journal of Forecasting, 26(2), 2010, pp. 348-373.

Explaining the Great Recession

The Great Recession provides an important episode to be understood by our models – both because of the severity of the recession and because the recession and the early recovery are central to understanding the current outlook. Explaining the recession is especially challenging for our project because only two of the models explicitly incorporate financial variables and only the FRBNY model does so endogenously. This makes the recession an interesting testing ground for the plausibility of the models' interpretation of recent events. Nevertheless, the models reach some similar conclusions.

Figure 2 displays some of the key variables whose behavior we hope to understand. Real GDP in the second quarter of 2009 was more than 4 percent below its level of a year earlier, the sharpest four-quarter decline since the Great Depression. The decline in business fixed investment was even more severe, falling nearly 21 percent over the same period. Commensurately, hours worked in the nonfarm business sector fell 8 percent and payroll employment fell by more than 4.7 percent. Core inflation fell during the recession, but the decline was not dramatic. Also, real wages grew over the latter part of the recession but were fairly flat in the early stages of the recovery. Notably, the huge run-up in interest rate spreads provides evidence of severe financial distress.

In understanding which economic factors contributed to the Great Recession, a model's treatment of a financial sector and financial variables is of prime importance. Of the four models, the EDO and FRBNY models explicitly incorporate aspects of financial intermediation that allow them to capture the effects of financial distress. In the EDO model, various "risk" premia over the risk-free rate enter as exogenous factors. The EDO model identifies shocks to risk premia as key drivers of the downturn in activity, although the model is not estimated using risk spreads. A positive shock to aggregate risk premia in the model reduces aggregate demand, while disturbances to sector-specific risk premia act in a more targeted manner. Thus, identification of multiple risk premia shocks helps the model capture the collapse in aggregate demand and in particular the spending on intermediated purchases, primarily investment-type expenditures. In the FRBNY model, financial frictions a la Bernanke, Gertler, and Gilchrist (1999) generate a wedge between the interest rate paid by investors and that paid by the government. A widening of this wedge due to an increase in the riskiness of borrowers, which in the model is labeled as a "spread" shock, is the key driver of the recession. The spread shock reduces investment and leads to a decline in output and inflation, which are amplified by the presence of nominal rigidities.

Neither the Chicago nor the Prism models include any explicit financial intermediation. Interestingly, however, the shocks that contribute the most to the explanation of the recession are those closely tied to intertemporal decisions. In particular, negative shocks to the efficiency of investment are important contributors to the fall in investment and output. A negative shock to the efficiency of investment literally implies that a unit of investment produces less capital than it normally would, making investing less desirable. More broadly, this shock can be interpreted as capturing the efficiency with which savings are turned into future capital and thus serves as a proxy for the efficiency of financial intermediation. The FRBNY model also indicates that as financial markets recovered in the latter stage of the recession, this shock contributed to weak output growth and falling inflation. It is also the case that a decline in the value of consumption in the present versus consumption in the future—a shock to consumers' discount rate— reduced output and inflation in the Chicago and Prism models. Both shocks imply a decrease in inflation because they reduce aggregate demand and marginal costs.

That said, marginal efficiency of investment shocks and discount factor shocks have some counterfactual implications: realizations that are adverse for macroeconomic activity tend to boost the market value of firms (e.g., equity prices) in DSGE models, in contrast to the sharp decline in asset values seen during the recession. The more explicit modeling of financial factors in the FRBNY and EDO models is instead consistent with substantial declines in asset values in response to increases in risk premia, suggesting that these mechanisms may deserve further explicit treatment in subsequent modeling efforts.

Detailed Model-by-Model Descriptions

<u>The EDO model</u>

EDO identifies the lead up to and the early stages of the recession as associated with increasingly tight terms on financing residential investment, driven by an increase in the risk premium on such investment. However, as the economic weakness broadened to include overall consumer spending and business investment, the primary driver of the weakness centered on an increase in the economy-wide risk premium.

Within the model's interpretation of events, these shifts in fundamentals brought about the weakness in economic activity through several channels. The increase in the risk premium associated with residential investment directly depressed residential spending and real estate prices by raising the cost of capital for such spending, but the overall macroeconomic impact would have been fairly limited, according to EDO, if economy-wide risk premia had not risen as well. In this regard, future work may wish to investigate the mechanisms that could link the weakness in housing to the more general macroeconomic fallout that followed the decline in house prices, perhaps through a more sophisticated modeling of financial intermediation.

That said, the sharp increase in the economy-wide risk premia estimated for the second half of 2008 through the middle of 2009 depressed consumer spending, residential investment, and business investment through a range of channels. First, this increase directly raised the cost of capital for residential and business investment and consumer durable outlays. In addition, higher risk premia lowered household wealth (including equity claims on firms and the value of residential real estate), depressing consumption of nondurables and services. These declines in spending were further exacerbated by the weakening in labor income. It is worth reiterating that the EDO model identifies increases in various risk premia as the main contributors to the recession, even though the model is not estimated using measures of risk premia.

All else equal, EDO would have expected a fairly strong recovery to have commenced after the first half of 2009, as risk premia were projected to fall, and monetary policy would have been expected to provide continuous support to the recovery in normal times. However, three conditions contributed to a more moderate recovery. First, the zero lower bound limited the degree to which monetary policy could support the recovery. Second, risk premia are estimated to have fallen more slowly than expected, restraining the recovery in demand. Finally, the persistently slow recovery led to a modest downward adjustment in the model's estimate of the economy's productive potential.

Regarding inflation, the weakness in the labor market and household wealth, as well as the decline in unit labor costs that stemmed from weak wages and strong labor productivity, contributed to lower inflation through the drag these factors placed on marginal costs of production. However, most of the movements in inflation, especially the sharp swings seen in late 2008 and early 2009, are estimated to have stemmed from markup shocks.

The FRBNY model

The New York model has an explicit financial sector that allocates savings to investment projects. The model allows for several types of disturbances, namely, shocks to the riskiness of investment projects (or "spread shocks"), the marginal efficiency of investment, productivity, monetary policy, government spending, labor supply, and the price markup. These shocks are identified by matching the behavior of U.S. data on real GDP growth, core PCE inflation, the labor share, aggregate hours, the effective federal funds rate, and the spread between Baa corporate bonds and 10-year Treasury yields.

As discussed, the Great Recession was characterized by a severe financial crisis that impaired the flow of credit, depressing aggregate demand and employment. The presence of credit intermediation frictions enables the FRBNY model to capture the majority of the Great Recession as triggered by one shock, called the "spread" shock. Credit frictions imply that the rate of interest at which investors can borrow is generally higher than the riskless rate, since borrowers can default, and financial intermediaries need to be compensated for such default risk. Spread shocks capture changes in the perceived riskiness of borrowers – or, more broadly, changes in financial conditions. The model identifies such shocks using the spread of the Baa corporate bond rate over the rate for 10-year Treasuries. Nominal rigidities in prices and wages play an important role in the transmission of spread shocks: in the absence of nominal rigidities the increase in spreads would lead to a drop in investment but would have little effect on output, which would remain close to potential. Instead, nominal rigidities lead to a drop in economic activity and the opening of an output gap. In turn, this leads to a prolonged decline in real marginal costs and inflation, while policymakers respond by cutting the federal funds rate.

Other shocks also contributed to the Great Recession. Productivity shocks played some role in the decline in output, particularly in 2008. Productivity shocks cannot fully account for the

Great Recession, however, as a drop in productivity leads to an increase in inflation, rather than the decline that was observed. The marginal efficiency of investment shock plays a role in the latter part of the recession, especially in the second half of 2009. This shock helps to account for the continued decline in output and inflation despite the financial markets' recovery during this period.

The Prism model

The Prism model is estimated using data on real per capita consumption, real per capita output, real per capita investment, hours worked, nominal wage growth, core PCE inflation, and the average effective federal funds rate. The recession was marked by a severe impairment to financial intermediation that adversely affected both firms' and consumers' ability to borrow. This led to a rapid decline in both investment and consumption, which was accompanied by a large drop in employment. Without a financial sector that interacts with the rest of the model, the model is forced to find other ways of reducing consumption, investment, and hours worked.

To match the weakness in desired consumption, the model identifies a shock to the parameter that governs desired consumption growth. Thus, the model identifies an increase in the consumer's rate of time preference, causing current consumption growth to be weak relative to future consumption growth. To account for the weakness in investment, the model identifies a negative shock to the efficiency of investment. In particular, a unit of investment produces less capital than it normally would, making investing less desirable. As mentioned, an interpretation of this shock is that it reflects the efficiency with which saving is turned into future capital. Inefficiency in this transformation leads to a less productive economy and lower desired investment. Also, the extreme fall in employment cannot be accounted for by the discount factor shock and the negative shock to the efficiency of investment, although both shocks work in the right direction. It also requires that individuals desire more leisure. This is a somewhat unattractive feature of the model, and it is fair to say that additional research needs to be done regarding the way that labor markets are modeled. Finally, in order for the model to generate sufficient economic weakness, the model must attach a high probability to a negative shock to productivity.

The marginal efficiency of investment shock and the discount factor shock are the shocks in the model most closely aligned with the financial crisis. The discount factor shock is directly related to asset prices, and the efficiency of the investment shock in part is due to inefficiencies in the investment process brought about by financial distress. That said, asset price movements during the recession were essentially the opposite of that predicted by the Prism model (which would have expected rising asset prices following an increase in the discount factor and a decline in the marginal efficiency of investment).

Inflation during the recession did not fall precipitously. Factors that contributed to declining inflation were the two shocks most responsible for weak growth in aggregate demand: the discount factor shock and the marginal efficiency of investment shock. The negative discount factor shock also results in declining wages and marginal cost, which tend to reduce inflation pressures. Further, negative shocks to firm markups contributed to the fall in inflation in late 2008 and early 2009. Offsetting the effects of these shocks was a decline in households' willingness to supply labor, which raised wages, marginal cost, and hence inflation as well. Because inflation is the most important variable in the model's estimated policy reaction function, these are the same shocks that are the primary drivers of the funds rate path.

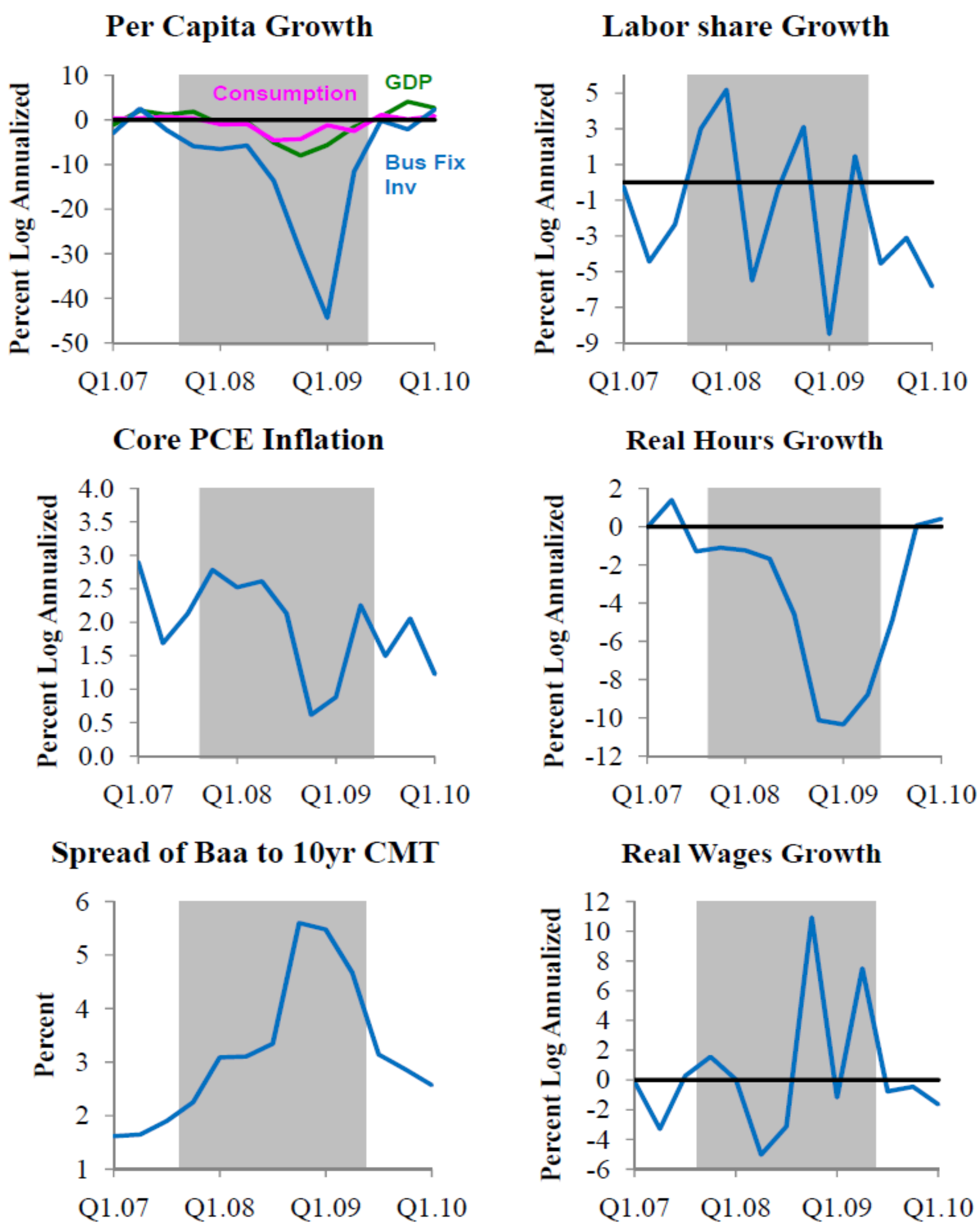
The Chicago model

In the Chicago model, the fall in GDP in the early stages of the recession is primarily driven by demand shocks – an increase in households' desire to postpone consumption and especially a fall in the marginal efficiency of investment. The latter shocks have a substantial negative correlation with the high yield-AAA corporate bond spread, which corroborates their interpretation as reflecting financial market stress. Subsequently, relatively tight monetary policy, arising from the binding zero lower bound on the funds rate, contributed to the prolonged slump in economic activity.

Demand shocks are also responsible for weak consumption and investment in the early phase of the recovery, but their effect is offset by the accommodative stance of monetary policy. In particular, the forward guidance in 2010, which drove expectations of looser-than-average monetary policy in 2011, offset any remaining drag from the zero lower bound constraint and contributed substantially to lifting GDP growth.

The effects of the demand shocks on inflation and the federal funds rate are very persistent in the Chicago model due to their depressing effect on producers' marginal costs, which in turn reduce price pressures. Because negative demand shocks are simultaneously leading to falling inflation and output, they are also responsible for a persistent easing of monetary policy.

Figure 2.



Forecasts

Overview

This section summarizes forecasts for real GDP growth, core PCE inflation, and the funds rate provided by our four models. The forecasts are displayed in Table 1 and Figures 3-5. Because the models differ along a number of dimensions, their forecasts provide different lenses for viewing the economy.

Regarding output growth, all four models depict an economy in recovery, with an average forecasted growth rate between 3 percent and 4 percent in both 2011 and 2012. The four models differ markedly regarding the strength of the recovery, however. The Prism and Chicago models anticipate very robust recoveries; the Board model predicts real growth slightly above trend (about 2.7 percent), while the FRBNY model predicts growth slightly below trend. The main difference across the model forecasts can be traced to whether the shocks that generated the recession continue to hinder the return of output to potential, or whether they dissipate allowing a rapid rebound in economic activity. The Prism model, and to a lesser extent the Chicago and EDO models, represents the latter case: as the economy returns to its potential after the strain from "financial" shocks, these models forecast relatively sustained growth. The FRBNY model represents the other extreme: in that model the headwinds from the financial crisis have an adverse effect on economic activity for a very prolonged period, and hence the recovery is subdued.

The inflation forecasts display more agreement across models. For the most part, the models indicate downward pressure on core inflation in response to weak aggregate demand and a level of economic activity below potential through the end of the forecast horizon. Of the four models, only Prism projects that inflation will exceed a 2 percent threshold over the forecast horizon. The FRBNY model anticipates that inflation will reach approximately 1.5 percent by the end of 2013, while EDO and Chicago models expect inflation to be in the neighborhood of 1.0 percent in 2012 and 2013. Taken together, the models do not anticipate significant inflationary pressures over the forecast horizon. For the most part, the recent surge in inflation is viewed as transitory and hence does not have a large policy response in the forecasts. This is partly due to the fact that all models assume a Taylor-type interest rule with a strong response to persistent movements in inflation. This feature, together with the assumption of rational expectations, anchors inflation expectations in the models.

In terms of interest rate forecasts, the models imply different paths for monetary policy. This is not surprising given that the models differ in their forecasts for output and inflation. Also, the models' policy rule specifications differ from each other. Monetary policy reacts to the output gap in EDO and Prism and to the four-quarter growth in output in the other models. The FRBNY and Chicago models impose an "extended period" of zero interest rates until early 2012. Both project a modest tightening thereafter because they expect inflation to remain below target. This forecast is similar to the EDO model's forecast, which anticipates tightening to begin in late 2011. By the end of 2012, the funds rate is expected to reach 1.1 percent in the FRBNY model, 1.2 percent in the Chicago model, and 1.7 percent in EDO. Despite its forecast of a very robust recovery, Prism's monetary policy response to the output gap is very small. As a result, the model projects that policy tightening will begin in the second quarter of this year, but will proceed at a measured pace, with the funds rate expected to reach only 2 percent at the end of 2012.

Detailed Model-by-Model Descriptions

<u>The EDO model</u>

EDO projects that real GDP will advance at a pace modestly above trend -- about 3 percent, on average, over 2011-2013 -- as the aversion to risk-taking apparent in the elevated level of risk premia (and, implicitly, restrictions on credit availability) falls back to historically typical levels. The above-trend pace of growth is accompanied by inflation just above 1 percent per year, substantially below the target of 2 percent. This reflects the labor market slack apparent in the shortfall of output relative to its estimated long-run trend. Given these developments, the federal funds rate is projected to remain near zero until late in 2011 and rises only gradually thereafter.

The projected recovery is strongly influenced by the role that adverse shocks to financial conditions in 2008 and early 2009 played in shaping the recession. Specifically, the recovery in real GDP projected for 2011-13 is essentially entirely the result of the projected step-up in demand that should accompany projected lower risk premia. Indeed, the need to accommodate the adverse impact of the tightening in financial conditions beginning in 2008 is the most important factor holding the federal funds rate at a low level through the projection.

The FRBNY Model

Forecasts in the FRBNY model are mainly driven by the negative "headwinds" from the financial crisis. The model captures these headwinds via the marginal efficiency of investment (MEI) shock, which can be viewed as reflecting financial market imperfections that do not translate into higher spreads ("spread" shocks are the drivers of the recession in this model, but since spreads have returned to normal after 2009, the effect of these shocks on inflation and output has subsided). These headwinds contribute to keeping the output level below potential throughout the forecast horizon and, as a consequence, generate subdued inflation forecasts. The federal funds rate mainly responds to inflation in the estimated policy rule; hence, the renormalization of the interest rate is expected to be very gradual. Moreover, the FRBNY model constrains the expectations of the policy rate to be at the current low rate through 2012Q2 in order to match median expectations from the Dealers' survey. The effect of MEI shocks on output *growth* (as opposed to its level) is fairly small, and growth is forecasted to remain close to steady state (roughly 2.7 percent annualized) throughout the forecast horizon.

Other factors also play a role in the FRBNY forecasts. Accommodative monetary policy, which was instrumental in keeping inflation and output growth from falling any further during the recession, actually has a negative impact on output growth over the forecast horizon as its expansionary effect on the level of output fades. Positive productivity growth is a major contributor to the recovery in output in 2009 and 2010, but by 2011, its effects have largely disappeared. Finally, price mark-up shocks, which tend to capture transitory movements in inflation due to, for example, commodity price shocks, have a substantial impact on core inflation in the first half of 2011, but little effect thereafter.

The Prism Model

Prism forecasts a very robust recovery over the forecast horizon, with real output growth running well above its estimated 2.7 percent trend rate. Real output growth reaches 7 percent by the end of 2011, while core PCE inflation is forecasted to reach 2 percent by mid-2012. The response of the federal funds rate is somewhat subdued, though: policy tightening is forecast to begin in the 2011Q2, but the funds rate rises to only a shade above 3 percent by the end of 2013. The model explains the Great Recession largely with two shocks: a discount factor shock that alters the relative price of current versus future consumption and a marginal efficiency of investment shock that makes investment more or less effective in producing a unit of capital. While the model does not have an explicit financial sector, both of these shocks can be interpreted as financial shocks. The discount factor shock is key for explaining negative consumption growth during the recession, and the MEI shock is the primary driver in explaining the dramatic fall in investment growth. The model sees productivity growth as a key factor in the 2009 rebound period, but going forward, the forecast is largely driven by the model's financial shocks – both the discount factor shock and the MEI shock. The discount factor shock, which lowers the relative price of current consumption, pulls consumption from the future to the present and so supports strong consumption growth over the forecast horizon. Indeed, the model predicts that consumption growth will rise above 4 percent in 2011 and then decline gradually toward steady state over the next three years. The MEI shock accounts for very strong investment growth that peaks in 2012 and still remains above 10 percent at the end of 2013. While the two financial shocks work together to push output growth above trend, they have opposing effects on inflation – the discount factor shock tends to pull inflation down and the MEI shock tends to push inflation up. On balance, the discount factor shock dominates, and, for the most part, inflation remains below 2 percent until mid-2012.

The estimated monetary policy rule in Prism puts little weight on the output gap compared to inflation. Consequently, with inflation running at a subdued pace over the next three years, the federal funds rate is expected to increase at a modest pace. Not surprisingly, given the role that the discount factor shock plays in driving the inflation forecast, it is the most important shock that keeps the funds rate below its steady state over the next few years.

The Chicago model

Although GDP growth for 2010 was disappointing and the first two quarters of 2011 have also not looked strong, the Chicago model forecasts a prolonged period of above-trend GDP growth: 3.4 percent for 2011 and over 4 percent for the following three years. This reflects slow recovery dynamics in the model. Instead of a rapid one-year turnaround as seen in 1983, the model's recovery unfolds as several years of above-trend growth. The model interprets the relatively slow growth of 2010 as resulting from demand shocks that slowed but did not stop this recovery dynamic.

The Chicago model sees substantial remaining slack, so it associates the prolonged recovery with no demand-side price pressures. The forecast of year-on-year core PCE inflation for 2011 is only 1.4 percent. The model uses inflation measures based on the core PCE deflator, a deflator constructed to match the model's definition of nondurable consumption (nondurable goods plus nonhousing services), and the GDP deflator. Their annualized rates for the first quarter of 2011 were 1.4 percent, 5.0 percent, and 1.9 percent. Our estimation procedure views each of these as a noisy signal of an underlying inflation rate from the model. This allows our forecasting procedure to discount (appropriately) the energy price inflation that dominated the model-appropriate deflator's inflation. The inflation forecasts for the next few years embody the reduction of producers' marginal costs from strong investment spending driven by low interest rates. This capital-accumulation brings the forecast for core PCE inflation down to 0.7 percent in 2012, 0.3 percent in 2013, and 0.6 percent in 2014.

Table 1
Summary Table

Federal Reserve Bank	Output Growth (Q4/Q4)			Inflation (Q4/Q4)			Federal Funds Rate (Q4)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
Philadelphia	6.0 (3.6,8.7)	6.9 (3.5,10.4)	5.6 (2.2,9.1)	1.6 (0.8,2.4)	2.0 (0.7,3.3)	2.2 (0.7,3.5)	0.8 (-0.5,2.0)	2.0 (0.2,3.6)	3.2 (1.1,5.1)
New York	2.8 (-0.2,4.8)	2.1 (-1.3,5.0)	2.0 (-1.2,5.3)	0.8 (0.2,1.4)	1.2 (0.3,1.9)	1.5 (0.6,2.3)	0.2 (0.3,1.3)	1.1 (0.3,2.5)	1.9 (0.6,3.5)
Chicago	3.2 (.,.)	4.4 (.,.)	4.2 (.,.)	1.5 (.,.)	0.7 (.,.)	0.3 (.,.)	0.1 (.,.)	1.2 (.,.)	2.7 (.,.)
Board of Governors	3.1 (1.4,4.5)	3.0 (0.9,5.1)	2.7 (0.8,4.9)	1.1 (0.8,1.4)	1.1 (0.6,1.6)	1.1 (0.6,1.7)	0.5 (0.1,1.4)	1.7 (0.6,3.0)	2.4 (1.0,3.9)
Annual Average	3.2 (2.6,5.9)	3.7 (2.3,6.8)	3.5 (2.0,5.5)	1.3 (1.0,1.6)	1.1 (0.7,1.9)	1.3 (0.3,2.1)	0.3 (0.1,0.4)	0.9 (0.5,1.5)	2.2 (1.4,2.7)

*Annual Average shows the median annual average, with the minimum and maximum in parentheses.

Figure 3
Real GDP Growth

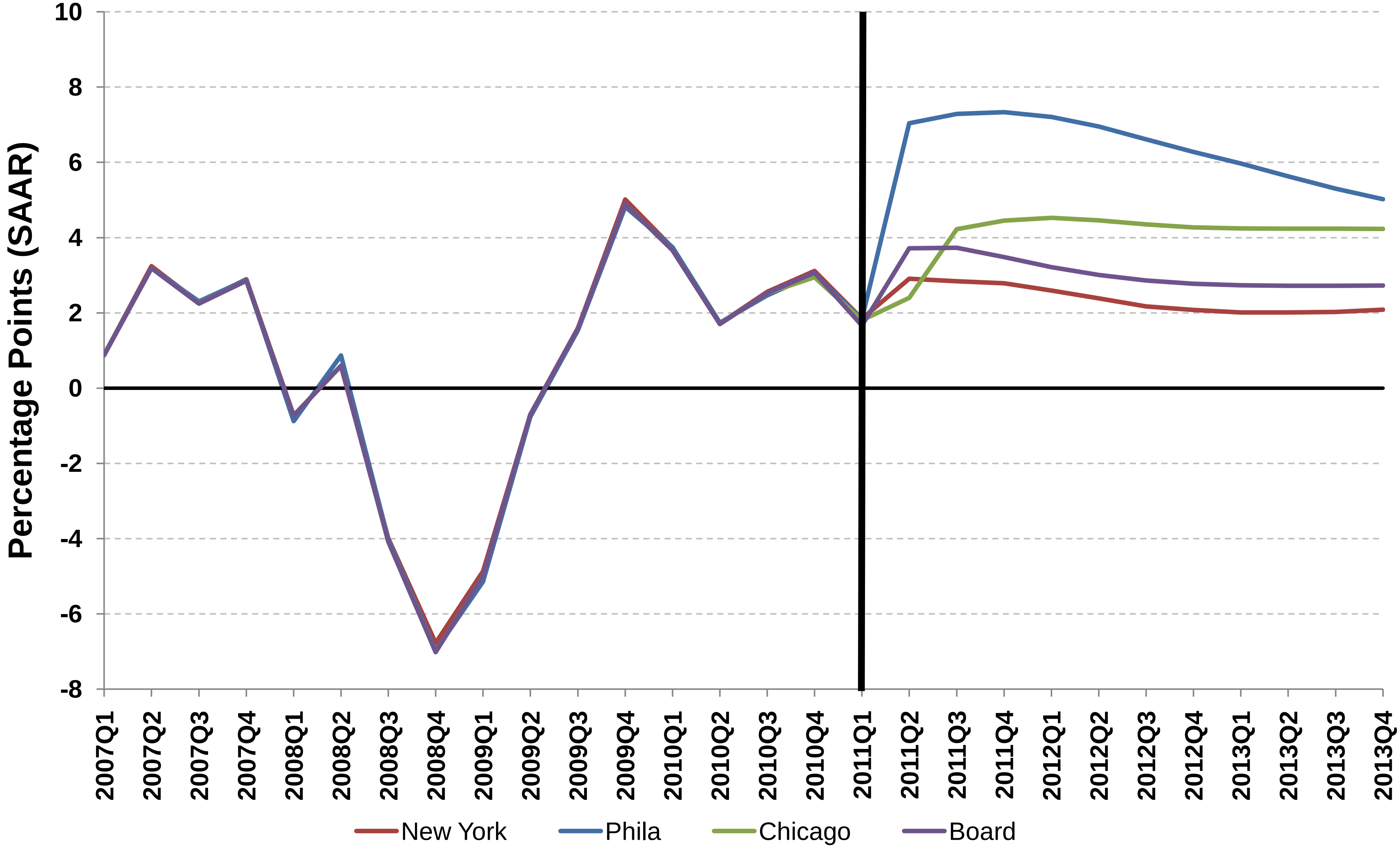


Figure 4
Core PCE Inflation

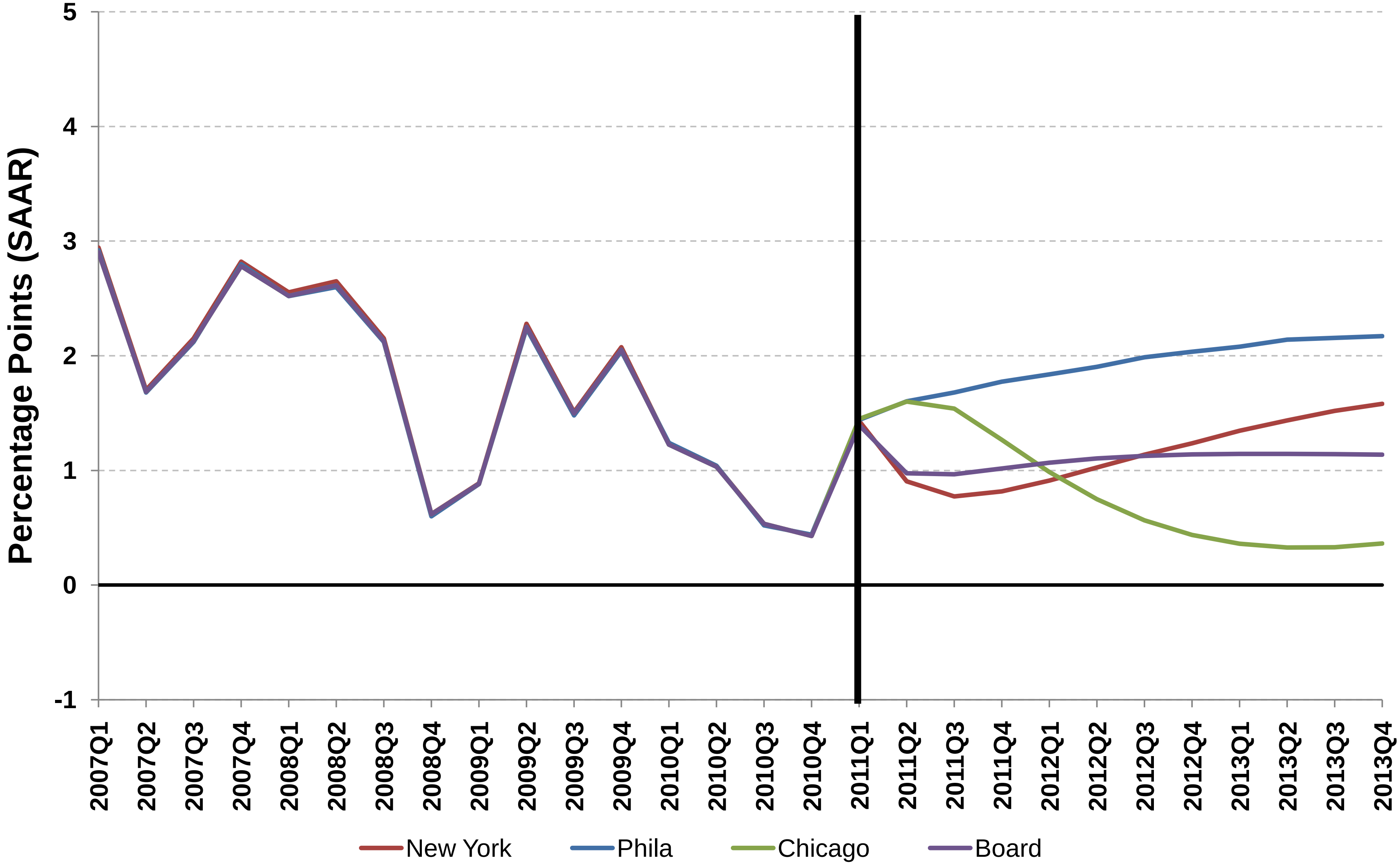


Figure 5
Federal Funds Rate