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Abstract

This paper surveys the challenges for macroeconomics and their monetary policy implications by tracing the evolution of DSGE models before, during, and after the crisis. The survey primarily focuses on the issues relevant to the financial crises: financial frictions, unemployment and monetary policy. The survey ends by providing the challenges for future DSGE models.

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1 Introduction

The seminal work by Kydland and Prescott (1982) marked the pinnacle of a sea change in the way empirical macroeconomists conduct their research on business cycles. Their Real Business Cycle (RBC) revolution provided the reference framework, that is, the Dynamic Stochastic General Equilibrium (DSGE) models, for investigation of economic fluctuations, and thus became the core of the subsequent macroeconomic analysis. The triumph of the DSGE approach culminated in development of the New Keynesian monetary framework, which keeps widening the scope and the use of vintages of models by constantly addressing the criticisms raised against it. To date, many of the medium-scale versions of that model are developed and used by central banks and policy institutions throughout the world. Arguably, the New Keynesian paradigm constitutes the framework of reference for understanding fluctuations in economic activity and their key relation to both monetary and fiscal policies.

Yet, the Great Recession that began in the Great Financial Crisis in 2008 struck the economy and DSGE modelers like an earthquake. In the aftermath, the New Keynesian models were highly

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criticized for their failure to predict the crisis.　This failure is often attributed to lack of financial block in the workhorse DSGE model to account for the key factor behind the crisis, the nature behind which requires workings of financial factors. Also at the heart of criticism include the absence of unemployment, and the conspicuous interaction between financial turmoils and unemployment fluctuations were left unanswered.　Failing to predict the crisis and the recession of considerable severity, DSGE modelers have been struggling to understand the causes and impact of the nature of financial crises and the long-lasting Great Recession.

This paper surveys the challenges for macroeconomics and their monetary policy implications by tracing the evolution of DSGE models before, during, and after the crisis.　The survey primarily focuses on the issues relevant to the financial crises: financial frictions, unemployment and monetary policy.

This paper is organized into two main parts.　We first begin our brief description on how modern dynamic stochastic general equilibrium models have evolved to form what is called as the *New Keynesian* DSGE models and the medium-scale versions of the latter.　To build some intuition on the reference framework of the current DSGE program, the basic New Keynesian framework is also presented.

The second part consists of post-crisis issues and challenges of DSGE models.　It provides partial assessments on the causes and natures of the recent financial crisis and the Great Recession characterized by its slow recovery.　It then discusses why workhorse DSGE models abstract from financial factors and unemployment.　The rest of the post-crisis review continue discussing the issue pertaining to these two important areas of research. Some key approaches to modeling unemployment include development of search and matching mechanisms in tradition of Mortensen and Pissarides (1994), or the new and growing framework of involuntary unemployment pioneered by Galí (2011).　Financial frictions are typically incorporated by embedding either the collateral constraints of Kiyotaki and Moore (1997), or the external finance premium by Bernanke, Gertler and Gilchrist (1999).　This last part ends by providing discussion and directions for future research.

The contributions of this review are three folds.　First, it provides an introduction to the basic New Keynesian framework in the context of pre- and post- crises developments of DSGE models.

Second, this review is unique because it unifies two steams of literature on financial frictions and unemployment.　Given their significant impact on economic fluctuations and welfare, it is surprising that the existing literature does not thoroughly assess how financial factors affect unemployment variations and inefficient labor market developments, and vice versa.　To our knowledge, out paper is the first to provide that unified literature.

Third, the review focuses on a growing literature on involuntary unemployment pioneered, theoretically, by Galí (1996), Galí (2010), Galí (2011), and, empirically by Galí, Smets and Wouters (2012). Until now, there is no literature review primarily dedicated to developments and issues in this unemployment model. This paper contributes to provide a long-awaited review on this emerging framework distinct from the traditional search and matching literature.

The rest of the paper is structured as follows. Section 2 describes how DSGE models are developed before the crisis. Section 3 discusses the 2008 financial crisis and the Great Recession, why DSGE models did not predict their coming, and why DSGE models lack financial factors and unemployment. Section 4 lays out post-crisis developments of DSGE models of financial frictions and unemployment, followed by their issues and discussions in Section 5. Section 6 provides avenues for future research.

2 Before the Crisis

In this section, we describe development of DSGE models prior to the crisis. The discussion below primarily focuses on the characteristic of the New Keynesian framework and illustration of its canonical form, followed by their extensions known as the state-of-the-art medium-scale DSGE models.

2.1 The New Keynesian Models

The New Keynesian monetary framework is built upon the chassis of the DSGE methodologies pioneered by RBC theory to allow for some of the hallmarks of the traditional Keynesian assumptions, that is, nominal rigidities, tracing back to *General Theory* by Keynes (1936).

Theoretically, monetary non-neutralities result form the presence of nominal rigidities. For example, if prices are not flexible to adjust in proportion to changes in the money supply, this results in changes in real balances. Or, if one-for-one relation between expected inflation and the nominal interest rate does not hold, this leads to a change in the real interest rate, paving the way for monetary policy to affect the subsequent equilibrium levels of output and employment. To replicate these nominal-to-real channels by monetary policy, DSGE modelers seek to incorporate some forms of nominal rigidities into otherwise frictionless RBC apparatus. The resulting framework is called the New Keynesian DSGE models.

2.1.1 What is the New Keynesian model?

The following key elements and properties of the resulting framework emerge as the New Keynesian features that are distinct from those of RBC theory:

Monopolistic competition. Aggregate prices, and in instances wages as well, are set by private economic agents (firms) in order to maximize their objective functions, as opposed to being given in an environment characterized by perfect competition in which private agents can not exert their powers to change prices/wages. This results in the economy where the responses of any macro variables to exogenous disturbances are inefficient in terms of welfare.

Nominal rigidities. Monopolistically competitive firms are not free to determine their prices. They are subject to constraints on the frequency with which they can adjust the prices of the good they sell. The same kind of friction in labor market—staggered wages—can also be imposed on workers who have market power in determining their wages.

Non-neutrality of monetary factors and monetary policy. The presence of nominal rigidities, as a result, breaks the one-for-one between changes in expected inflation and changes in short-term nominal interest rates, thus paving the way to variations in real interest rates. The latter bring about changes in consumption and investment, and since it is optimal for price-resetting firms adjust their good supply to the newly-set demand, aggregate output and employment are affected eventually. The same chain of events hold true for wage-resetting workers as well. But, prices and wages will adjust in the long run, and the economy reverts to the flexible prices and wages equilibrium. This implies that, in the short run, monetary policy can intervene to the economy to enhance social welfare by minimizing the distortions resulting from nominal rigidities. In short, and in contrast to the prediction by RBC theory, the New Keynesian models imply that *real variables respond to monetary policy shocks in the short run.*

2.1.2 The Basic New Keynesian Model: An Illustration

To see how the introduction of nominal rigidities breaks down the monetary policy neutrality, a simple version of that framework, called the basic New Keynesian model, is to be presented below.

This small-scale version of the latter assumes sticky prices as nominal rigidity (that is, wages are still flexible), following the conventional textbook treatment.[1] The log-linearization of the fist order conditions of households and firms with market clearing conditions augmented with a monetary policy rule forms the canonical representation of the model's equilibrium in three equations—a dynamic IS equation, the New Keynesian Phillips curve, and the Taylor rule. Below, all hatted variables are log-linearized around their steady state.

The *dynamic IS equation* determines the current output gap as sum of expected output gap and the term in proportion to the real rate gap—a gap between the real interest rate and the natural rate of interest:

$$\widehat{ygap}_t = E_t\left\{\widehat{ygap}_{t+1}\right\} - \frac{1}{\sigma}\left(\hat{i}_t - E_t\left\{\hat{\pi}^p_{t+1}\right\} - \hat{r}^n_t\right),$$

where $\widehat{ygap}_t \equiv \hat{y}_t - \hat{y}^n_t$ is the output gap, in words, the difference between log output $\hat{y}_t$ and log natural output $\hat{y}^n_t$, $\hat{i}_t$ is the nominal rate, $\hat{\pi}_t$ denotes inflation, and $\hat{r}^n_t$ is the natural rate of interest. The real interest is given by the Fisher relation, $\hat{r}_t = \hat{i}_t - E_t\left\{\hat{\pi}^p_{t+1}\right\}$. The parameter σ is the reciprocal of the

1) The reference textbooks include Woodford (2011), Galí (2015), and Walsh (2017).

intertemporal substitution elasticity that measures strength of the wealth effect of labor supply. This forward looking relation is named after the celebrated IS-LM model.

The *New Keynesian Phillips curve* determines the current inflation depending on expected inflation and the current output gap:

$$\hat{\pi}_t^p = \beta E_t\{\hat{\pi}_{t+1}^p\} + \kappa \widehat{ygap_t},$$

where β is the discount factor, the parameter κ is composed of a set of complex functions of structural parameters, including the one that governs Calvo (1983) probability of unchanged prices θ. Note that NKPC also shows a forward looking relation as in the case of DIS, in contrast to the original and static supply curve relation by Phillips (1958). It is also easy to show that in NKPC, if $\theta \rightarrow 0$, that is, if prices become fully flexible, then NKPC becomes vertical and the output gap is not dependent on inflation.

The *Taylor rule* (Taylor (1993)) describes an interest rate rule for a monetary authority to determine the nominal rate of interest in reaction to conditions of economy summarized by the current inflation and the current output gap:

$$\hat{i}_t = \phi_\pi \hat{\pi}_t^p + \phi_y \widehat{ygap_t} + \hat{\varepsilon}_t^i,$$

where $\hat{\varepsilon}_t^i$ represents the exogenous monetary policy shocks, with the sensitivity parameters for inflation and the output gap given by ϕ_π and ϕ_y, respectively. The condition of $\phi_\pi > 1$ is often referred to as the *Taylor principle*, playing an important role in anchoring the inflation to avoid sunspot equilibriums. This policy reaction function implies that monetary policy can be tighter or looser than the historical pattern by capturing the stance of monetary policy conducts in a given period of time as (unpredicted) shocks summarized in $\hat{\varepsilon}_t^i$.

Natural output and the natural rate of interest are the values that output and real interest rate would take in equilibrium if prices were assumed to be fully flexible:

$$\hat{y}_t^n \equiv \psi_{ya} \hat{\varepsilon}_t^a$$
$$\hat{r}_t^n \equiv (1-\rho_a)\psi_{ya}\hat{\varepsilon}_t^a + (1-\rho_b)\hat{\varepsilon}_t^b,$$

where $\hat{\varepsilon}_t^a$ is the exogenous technology shocks, whereas the $\hat{\varepsilon}_t^b$ can be interpreted as the shocks to the households' discount factor. The composite parmeter $\psi_{ya} \equiv \dfrac{1+\varphi}{\sigma(1-\alpha)+\varphi+\alpha}$ represents how those natural variables react to the variations in the technology shocks, with φ being the Frisch labor elasticity and α representing the capital share in a typical Cobb-Douglas-type production function.

Finally, the three structural shocks mentioned above are typically assumed to follow autoregressive process of the form:

$$\hat{\varepsilon}_t^x = \rho_x \hat{\varepsilon}_{t-1}^x + \eta_t^x,$$

where $x \in (a, b, i)$ with the term η_t^x typically being assumed to be i.i.d. Gaussian.

Figure 1 facilitates some intuition on the equilibrium of the 3-equation New Keynesian model represented as the dynamic AD and the dynamic AS diagram in inflation-output gap space. The dynamic AD (aggregate demand) schedule gives an inverse relation between inflation and the output gap (for any given expectations) The curve is obtained by combining the dynamic IS equation and the Tylor rule to eliminate the nominal rate. On the other hand, NKPC, given inflation expectations, solely represents the dynamic AS (aggregate supply) schedule—a positive relation between the same two variables. The intersection of the dynamic AD-AS curves (point E_0) determines the equilibrium of the economy.

2.1.3 How has the New Keynesian model evolved?

How did the DSGE modelers finally form the canonical New Keynesian framework described above? This section briefly trace the development of this monetary enterprise.

Some initial attempts to construct a monetary model that firmly establishes the microfoundation for nominal rigidities include Akerlof and Yellen (1985), Mankiw (1985), Blanchard and Kiyotaki (1987), and Ball and Romer (1990). These early developments contribute to provide monopolistic competition and staggered prices models, although the scope of these models are still confined to largely static and/or reduced-form (and partial) equilibrium settings. Taylor (1980) seeks to rectify the absence of nominal rigidities in the context of dynamic optimization by introducing sticky prices the duration of which are fixed and predetermined. That initial Taylor model is augmented with Chari, Kehoe and

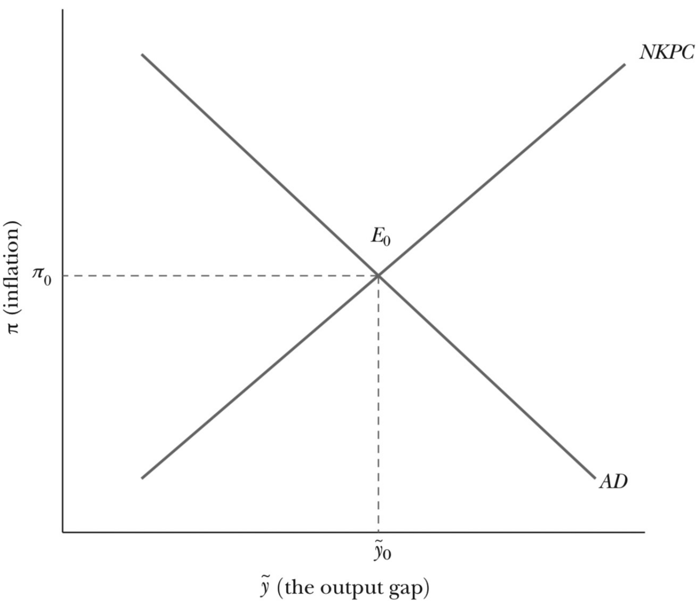

FIG. 1. THE BASIC NEW KEYNESIAN MODEL

SOURCE: GALÍ (2018)

McGrattan (2000). Rotemberg (1982) provides another form of a staggered-price setting by assuming a quadratic cost function for firms price adjustment. Roberts (1995) shows that the resulting inflation dynamics and equation of Rotemberg (1982) has the form identical to the canonical New Keynesian Phillips curve described above.

On top of the development of these staggered price models emerges the basic New Keynesian framework, with major contributions made by Calvo (1983) and Yun (1996). Calvo (1983) formalizes price stickiness by assuming that, in any given period of time, only a fraction of firms can randomly reset their prices to maximize their current and future profits. The probability for firms to change their prices is assumed to follow a Poisson process. This solves the complexities of tracking all the histories of price changes modeled by the early sticky price literature. Yun (1996) develops a discrete-time version of this elegant and easy formalism that can accommodate any degree of price stickiness in a tractable way, giving rise to a general equilibrium model with a dynamic inflation relation. That inflation equation is referred to as the New Keynesian Phillips curve, one of the core ingredients that form the canonical New Keynesian DSGE model.

The evidence in favor of the empirical performance of the New Keynesian Phillips curve include Galí, Jordi and Gertler, Mark (1999) (unobservability of the output gap), Sbordone (2002) (marginal costs), and Galí, Gertler and Lopez-Salido (2001) (European inflation dynamics). They typically describe inflation in proportion to marginal costs, and pinpoint some difficulties in estimating or testing that inflation relation due to the unobservability of the output gap.

The canonical New Keynesian framework is completed by introducing the policy block that describes the behavior of the nominal interest rate. In his seminal work, Taylor (1993) argues that a simple and properly calibrated interest rate rule to show systematic reaction to inflation and detrended output approximates the federal fund rates in the Greenspan era fairly well. Cross-country empirical evidence concerning the stability of the this rule includes Orphanides (2003), Clarida, Galí and Gertler (1998) and Clarida, Galí and Gertler (2000).

Identifying monetary policy shocks is not an easy task. The latter can reflect a variety of factors, and an considerable part of the movements of the monetary policy instrument—the short-term nominal rate—are highly likely to show endogeneity. The key challenge lies in identifying only the changes in policy that can be interpreted as exogenous against other variables. Sims (1986) argues that one should identify monetary policy shocks with disturbances to a monetary policy reaction function in which a short-term interest rate is use ad the relevant policy instrument. Bernanke and Blinder (1992) and Christiano, Eichenbaum and Evans (1999) follow Sims (1986) to identify monetary policy shocks by assuming that the latter have no contemporaneous impact on both inflation and output.

2.2 Medium-Scale DSGE Models

Seeing success of the New Keynesian program, a key challenge for academic researchers, central bankers and other policy makers alike is to develop an empirically plausible version of the New Keynesian model that could account quantitatively for the observed aggregate data.

A vast and growing literature is actively engaging in developing and estimating those quantitative and elaborated versions of the New Keynesian DSGE models often referred to as the *medium-scale* DSGE models. Because of their complexities arising from a rich array of modeling and statistical features, here we only touch upon some of the important modifications and extensions. The latter are often called as *shocks and frictions*. Shocks are structural (and orthogonal) disturbances interpreted as sources of business cycles fluctuations.
Frictions are the ingredients—both real and nominal—to improve performances of models.

Below, we briefly outline those shocks and frictions by referring to one of the highly influential paper that defines the discipline to the medium-scale DSGE models: the Wouters (2007), henceforce SW.

2.2.1 The Smets and Wouters Model

The SW model is based on work by Christiano, Eichenbaum and Evans (2005), who added various forms of frictions to a basic New Keynesian model in order to capture the dynamic response to a monetary policy shock as measure by a structural VAR of, for example, Christiano, Eichenbaum and Evans (1999). Smets and Wouters (2003) augments the Christiano, Eichenbaum and Evans (2005) model by additional exogenous structural shocks to capture the joint dynamics of Euro Area output, consumption, investment, hours worked, wages, inflation, and the nominal interest rate. The SW model is built on these two reference papers and tuned for investigation of the pre-crisis US economy.

2.2.2 Frictions

It is often convenient to explain shocks and frictions in terms of demand-side and supply-side of the aggregate economy, as previously sketched in the conventional AD-AS diagram.

The demand-side of the model is augmented with frictions that incorporate habit-formation, exogenous spending and investment, investment adjustment costs, and a generalized version of the Taylor rule.

Consumption habit. Consumption appears in the utility function relative to a time-varying external habit formation of Fuhrer (2010) to create the hump-shape response and empirical persistence in the consumption process as shown by Christiano, Eichenbaum and Evans (1999).

Exogenous spending and investment. The SW model also augments the dynamic IS equation in the basic New Keynesian model by incorporating investment and exogenous spending. The latter is introduced to account for exogenous and important aggregate economic activities arising from government purchases and open-economy (net exports).

Investment adjustment cost. Further more, and to be also consistent with the hump-shaped response of investment to a monetary policy shock, the model assumes that households face costs of changing the rate of investment.

A generalized Taylor Rule. The simple interest-rate rule in the basic framework is replaced by the generalized Taylor rule based that systematically responds not only to inflation and the output gap, but also to the lagged interest rate and the growth rate of the latter, following policy conventions adopted by many central banks such as the Federal Reserve Board or The European Central Bank.

The supply-side frictions add capital and its variable utilization rate, monopolistic labor market with staggering wages, backward-indexation to prices and wages.

Capital and variable capital utilization. Households rent capital services to firms and decide how much capital to accumulate given the capital adjustment costs they face. Following the long tradition of RBC models such as Greenwood, Hercowitz and Huffman (1988) and King and Rebelo (2000), the model incorporates a variable capital utilization rate. This tends to smooth the adjustment of the rental rate of capital in responses to changes in output.

Monopolistic labor market and wage stickiness. As in the case of firms in the basic setting that produce differentiate goods, labor is also differentiated by a union, so there is some monopoly power over wages, which results in an explicit wage equation. The SW model further allows for the introduction of sticky nominal wages á la Calvo (1983), in parallel with the staggered nominal prices. Furthermore, the simple Dixit and Stiglitz (1977) aggregator in the intermediate goods and labor market is replaced by the more general aggregator of Kimball (1995). The introduction of this strategic complementarity, i.e., real rigidity, allows for estimating a more reasonable degree stickiness in both prices and wages, as shown by Eichenbaum and Fisher (2007).

Backward indexation in prices and wages. These Kimball aggregator settings and Calvo (1983) formalisms in both prices and wages are also augmented by the assumption that prices (wages) that are not reoptimized are partially indexed to past price-inflation (wage-inflation) rates. Prices are therefore set in function of current and expected marginal costs, but are also determined by the past inflation rate. Similarly, wages depend on past and expected future wages and inflation. This indexation scheme helps to replicate the observed hump-shaped pattern of inflation development (Galí and Gertler (1999)).

2.2.3 Shocks

The stochastic dynamics in the SW model is driven by seven orthogonal structural shocks.

The demand-side shocks in the SW model consist of four disturbances. The basic New Keynesian model features two demand-side shocks—the demand shocks that directly affect the discount rate, and monetary policy shocks. SW add two additional shocks to their model. Since investment and exogenous spending are incorporated to the basic model, SW also add shocks to the development of these variables, that is, *investment specific technology shocks* and *exogenous spending shocks*. SW also modify the discount-rate shocks to the *risk premium shocks*, to explain the comovement of consumption and investment, the phenomenon that the shocks to the households discount rate cannot explain. Overall, and to put it differently, the demand-side shocks include two shocks that affect the intertemporal margin (risk premium and investment-specific technology shocks) and two policy shocks (monetary policy and exogenous spending shocks).

The supply-side shocks are the rest of the three shocks. In addition to technology shocks in the basic framework, the SW model features two additional shocks to its supply curves in prices and wages. *Price markup shocks* and *wage markup shocks* are included, respectively, in the New Keynesian Phillips curve in prices and the New Keynesian Phillips curve in wages. Those markup disturbances represent cost-push shocks. These two markup shocks affect the intratemporal margin (intratemporal decision of households and firms).

The SW model has been accredited to be highly influential, because that framework shows that a medium-scale New Keynesian DSGE model, with appropriate shocks and frictions to it, can not only achieve a time series fit that is comparable to less restrictive (and reduced-form) vector autoregression models, but also is usable for monetary policy analysis. Since then, many central banks have started using versions of this monetary model in simulation and forecasting exercises, thus establishing discipline to decision-making and communication processes for the subsequent monetary policy conduct.

3 The Crisis

The Great Recession that began in the Great Financial Crisis in 2008 struck households, the aggregate economy and DSGE modelers like an earthquake. After the collapse of the Lehman brothers, financial turmoils such as bank runs, housing foreclosures roll over each other, resulting in the devastation of the economy as a whole. Many families lose jobs, unemployment soars at an unprecedented level during the post-war era. The U.S. economy were deeply damaged and aftershocks are still shattering.

The workhorse DSGE models that are built on the New Keynesian paradigm were highly criticized for their failure to predict the crisis. This failure is often attributed to lack of financial block in the reference (i.e., SW) DSGE model to account for the key factor behind the crisis, the nature behind which is principally financial. Other aspects of the celebrate SW model that has been at the heart of criticism include the absence of unemployment, that is, the workhorse framework lacks the unemployment component to account, among others, for interaction between financial frictions and unemployment fluctuations, the dynamics of labor force participation during and after the crisis

TABLE 1. THE GREAT RECESSION IN PERSPECTIVE

	Output	Consum-ption	Invest-ment	Emp-loyment	Hours Worked
Average Recession	-4.4	-2.1	-17.8	-3.8	-3.2
The Great Recession[a]	**-7.2**	**-5.4**	**-33.5**	**-6.7**	**-8.7**
The Great Depression[b]	-36.0	-23.0	-69.0	-27.0	—

Note: numbers show percentages changes, peak to trough.
[a] For the post WWII recessions. Source: Christiano (2017)
[b] For 2007Q4-2009Q3. Source: Christiano (2017)
[c] For 1929-1933. Source: Christiano, Motto and Rostagno (2003)

period, and so on. Failing to predict the crisis and the recession of considerable impact, DSGE modelers have been struggling to understand the causes of the Great Financial Crisis and the long-lasting nature of the Great Recession.

The present section discusses why the recent financial crisis is called "Great", why it is called the *slow recovery*, what causes the crisis, and why the DSGE modelers could not predict the crisis. In particular, the discussion focuses on why DSGE models did not have factors pertaining to financial frictions and unemployment fluctuations that could predict and account for the severity of the crisis.[2)]

3.1 The Great Financial Crisis and the Great Recession

The performance of the U.S. economy in 2008-2009 was less than stellar. From late 2007 to the third quarter of 2009, the U.S. economy was devastated by what is later called the Great Financial Crisis. The economic downturn was so devastating and long-lasting, that the subsequent recession is called the *Great Recession*—the very first recession since WWII.

Table 2 shows that some key macro variables, such as output, consumption, investment, employment and hours worked show significant decreases during and after the crisis. For instance, output dropped by 7.2 percent during the this recession, compared to the average of 4.4. percent for postwar recessions. Consumption shows a 5.4-percent decrease in comparison to the corresponding number of 2.1 percent. Employment, by the same token, dropped by 6.7 percent against 3.8 percent. Those numbers of key macro aggregates tell that the recent recession needs the prefix "Great."[3)]

Figure 2 tells another, yet silent characteristics to call the recent recession "Great": how uncommonly long for the economy to suffer and recover. Figure 2 displays labor productivity (output per working-age person, adjusted for inflation) from 1977 to 2014. The shaded areas indicate

2) The recent assessments of the recent financial crisis and the Great Recession can be found in Christiano, Eichenbaum and Trabandt (2018) and Gertler and Gilchrist (2018). The discussion below largely depends on the former.

3) The Great Recession is not however, named by "Depression" since it was not the worst U.S. economic downturn, compared to economic performances during the Great Depression in Table 1.

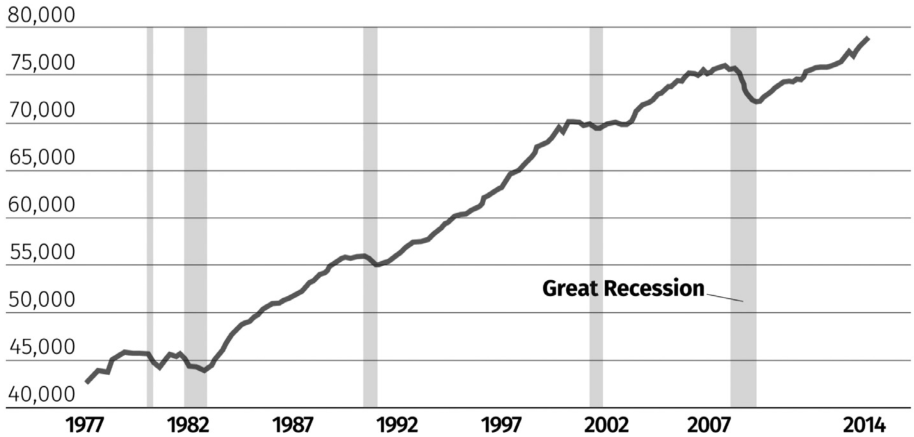

FIG. 2. THE US REAL GDP PER WORKING-AGE INDIVIDUAL (AGE 15-64)
(IN 2009 US DOLLAR)

SOURCE: CHRISTIANO (2017)

the starting and ending dates for recessions, according to the National Bureau of Economic Research (NBER). The figure shows that it took more than five years (up until the first quarter of 2013) for the U.S. economy to return to the 2007 level of output per capita. The productivity trend lines for the previous four recessions, on the other hand, show that the economy usually reverts back to the original trends more quickly. Even now, the U.S. economy underperforms, roughly 10 percent below the 2007 trend growth.

3.2 What Brought the Crisis?

The general consensus on the causes of the financial crisis is formed by many researchers, including Bernanke (2009) and Christiano (2017). That shared view argues that the financial crisis was precipitated by its rollover nature by which highly levered shadow banks repeatedly finance their long-term assets by short-term debt. Shadow-banking sector means that financial institutions not protected by the Federal Reserve and Federal Deposit Insurance Corporation.

This rollover crisis was triggered by the US housing sector. The housing prices started rising significantly in the 1990s. The S&P/Case-Shiller U.S. National Home Price Index rose by a factor of roughly 2.5 between 1991 and 2006. In mid-2006, then, housing prices began to fall, leading to a drop in the asset values heavily invested by shadow banks financed by mortgage-backed securities (MBS). The Federal Reserve provides a safety net for the shadow-banking sector, which actually turned out to prepare the conditions to allow for a rollover crisis. The shadow banks, in turn, sold their asset-backed securities (ABS) at fire-sale prices, resulting in the acceleration of severity of the financial crisis and the subsequent Great Recession.

3.3 What Caused the Slow Recovery?

And, why has the recent recession lasted so long? The reason is that the chain of events described above reinforce the households desire to save rather than to invest. If markets worked efficiently, then the interest rate would have fallen to balance the demand and supply of savings/ But when the nominal interest rate is bounded at the zero lower bound, the interest rate could not fall. Because interest rates could not fall enough to clear lending markets, something else had to bring the investment and saving to its equilibrium. This is achieved by the fall in aggregate income to clear the lending markets, by reducing saving as households avoid reducing their consumption further. This then results in the fall in the aggregate demand, leading to a weak economic activity, a significant fall in employment, rising unemployment, thus further exacerbating the economy to recover. This *paradox of thrift* is believed to be actually happening during the recovery (Christiano (2017)).

3.4 What Prevents DSGE Models From Predicting the Crisis?

The workhorse DSGE models prior to the crisis did not predict that the financial factors gradually make the US economy vulnerable to the financial crisis. Those models did not put emphases on financial frictions. The question is why not.

As a matter of practice, any modelers have to make choices regarding which shocks and frictions to focus in their analysis. One reason why modelers did not emphasize financial frictions can be found in the economic stability observed in the U.S. called the *Great Moderation*. Many postwar recessions in the United States as well as western Europe during that period did not seem closely tied to what is happening in financial markets. For example, the savings and loans crisis in the US economy in the late 1980s and early 1990s happened only locally, and that affair did not show any significant spillovers to result in any severe recessions. The meltdown of stock markets in 1987, the collapse of the tech bubble in 2001 only show minor impact on the economic activities. In many instances, the post-war financial turmoils were just seen as a series of epiphenomena, thus did not seem to show any significant effects on the way macroeconomists pay special attention to their modeling to describe the aggregate economy. Also, mounting confidence in the pre-crisis DSGE paradigm due to its good performance before the crisis disguises DSGE modelers in general so that they did not expect anything like the severe financial crisis to materialize.

3.4.1 Why No Financial Frictions?

A the same time, many studies suggest that modeling financial factors— financial frictions—into the DSGE models is not shown to have considerable effects. The most influential pre-crisis DSGE model with financial frictions—the financial accelerator mechanism with the external finance premium by Bernanke, Gertler and Gilchrist (1999)—is shown, for example, that those properties have only a modest quantitative effect on how the macro variables in the models responds to exogenous shocks (Lindé, Smets and Wouters (2016)). By the same token, and as another instance, Brzoza-Brzezina, Kolasa and Makarski (2013) compare the empirical performance of the standard New Keynesian models of Kiyotaki and Moore (1997)-type and Bernanke, Gertler and Gilchrist (1999)-type financial frictions. They report that neither model, especially the model with credit constraints by Kiyotaki and Moore (1997), show substantial improvements on the performance compared to the benchmark case, either in terms of marginal likelihood's or impulse response functions. Viewing the postwar US and euro data, as well as the properties shown by existing models of finial frictions, the DSGE modelers put more emphasis on other frictions than the one whose origin is financial.

3.4.2 Why No Unemployment?

Since inflation was low and stable with relatively low unemployment rate during the Great Moderation, by a seemingly successful monetary policy conduct following the celebrated Taylor-type interest rate rules, many macroeconomists did not pay particular attention to inflation-unemployment trade-off issue. Accordingly, the modelers build their monetary DSGE models without a particular focus on accounting for unemployment fluctuations over business cycles.

An important policy debate erupted, however, during the Great Recession. As pointed out by Galí (2011) and Galí, Smets andWouters (2012), one of the key shortcomings of the New Keynesian program is its lack of any reference to unemployment. The absence of unemployment from the reference DSGE (i.e., SW) model could also be interpreted as suggesting that there is no theoretical justification for central banks to asses, monitor and to take countermeasures on unemployment fluctuations in a systematic way. Through the lens of the traditional New Keynesian models, shocks and frictions underlying unemployment variations were not seen to be essential for understanding economic fluctuations in nominal, real and financial variables, nor a key ingredient in the design of policies. However, the Great Recession reveals the issues of particular importance concerning unemployment in relation to financial crises. Those include: Did financial frictions make the recession more severe by subsidizing unemployment? Why did labor force participation move in an anomalous way during the Great Recession?, and so on.

The conspicuous absence of financial frictions, together with no explicit treatment of unemployment in reference DSGE models suggest that the New Keynesian framework require those key ingredients in assessing the post-financial-crisis economy. The section that follows takes stock of the state of New Keynesian economics by surveying the developments in the recent literature in these directions, together with some new challenges facing the modelers and policymakers.

4 After the Crisis

The Great Financial Crisis and the Great Recession that follows have an enormous impact on DSGE models. The long-lasting nature of the financial crisis and the subsequent high and persistent unemployment lead macroeconomists to find ways not only to incorporate the financial sector and unemployment component, but also to consider phenomena not fully investigated by pre-crisis models. In what follow, we describe the current state of DSGE modeling strategies that seek to incorporate unemployment and financial frictions.

4.1 Unemployment

Over the past few years a growing number of researchers have sought to rectify the absence of unemployment by developing frameworks by combining the hallmark of the New Keynesian paradigm—nominal rigidities and consequent monetary non-neutralities—with labor market imperfections that give rise to unemployment.

4.1.1 Introducing Unemployment

Under the New Keynesian framework, unemployment is typically modeled in two ways: search and matching mechanisms or involuntary unemployment that gives rise to the forward-looking version of the original Phillips (1958) curve. Those modeling approaches to unemployment are discussed below.

4.1.2 Search and Matching

The first approach—the one that much of the literature on unemployment follows—combines the nominal rigidities with the labor market frictions of search and matching models in the tradition of Mortensen and Pissarides (1994), into some versions of the New Keynesian model. Walsh (2005) investigates how labor market frictions affect the size and persistence of the effects of monetary policy shocks in a version of the basic New Keynesian model. The scope of their analyses is limited, however, because they assume only staggered price setting, and wages are still assumed to remain flexible. Christoffel and Linzert (2006) and Sveen and Weinke (2008) relax the assumption of flexible wages, and introduced different forms of nominal and real wage rigidities.

The early contributions concerning the implications for monetary policy and its design stemming from the labor market frictions and unemployment can be found in Thomas (2008), Faia (2008), Faia (2009), Blanchard and Galí (2010), and Ravenna and Walsh (2011). Gertler, Sala and Trigari (2008) follow this approach to estimate a medium-scale DSGE model with search and matching frictions, and investigate the historical behaviors of the natural rate of unemployment and the output gap.

Some forms of Nash bargaining of wage coexisting with search and matching frictions and nominal rigidities are also typically assumed in most of the literature.　Thomas (2008) applies the sticky price formalism of Calvo (1983) to wages so that the wage stickiness creates the environment in which only a fraction of firms can bargain wages with workers.

4.1.3　Involuntary Unemployment

The second and a relatively new approach seeks to reinterpret the labor market in canonical New Keynesian model of sticky prices and wages á la Erceg, Henderson and Levin (2000).　This approach is pioneered by Galí (1996), and subsequent applications of this reinterpretation to the otherwise standard New Keynesian models can be found in Galí (2011a) and Galí (2011b).

In this new approach, the presence of market power in labor markets results in a positive average wage markups.　Unemployment in this framework is interpreted to reflect a positive average wage markup—a positive gap between the labor market conditions summarized by the prevailing real wage, and the disutility of work for the marginal worker employed given the marginal utility of consumption of households as criterion.　The unemployment rate in this approach is closely tied to developments in average wage markups.

The key advantage of this approach lies in its compatibility and convenience to introduce unemployment into DSGE models.　This approach is compatible because it preserves the standard and widely-used representative household DSGE framework.　It features standard forms of price and wage rigidities, household utility specifications, and the possible presence of time-varying desire markups, and so on, consistent with/conditional on the standard Taylor rules as monetary policy. This approach is convenient because the unemployment rate results from the difference between the equilibrium levels of employment and the labor force participation rate, the only additional variables to the reference monetary DSGE model (SW).

The application of this approach is still limited.　One important and the reference work that confirms the strength and usefulness of this approach is given by Galí, Smets and Wouters (2012). They introduce unemployment in a version of SW's medium-scale New Keynesian model.　Among other results, the estimated output gap in presence of the unemployment data is shown to correlate very well.　The correlation between the two variables is -0.95, thus confirming the celebrated Okuns law relation with a forward-looking and structural wage inflation relation that relate wage inflation to unemployment rate.　They also address how the unemployment rate as observable variable allows for the separate identification of wage markup shocks and labor supply shocks, thus overcoming the critique made by Chari, Kehoe and McGrattan (2009).

Another, yet only a few applications of this framework can be found in Matsumae and Hasumi (2016) who investigate the effects of government spending on unemployment in Japan.　Iwasaki, Muto and Shintani (2018) compare the natural rates of unemployment of the four advanced economies—the U.S. the U.K., the Euro Area, and Japan—in a nonlinear DSGE setting, to investigate whether downward wage rigidity is sill the source of the flattening wage Phillips curve as well as the missing wage inflation. Komatsu (2018) extends the Galí, Smets and Wouters (2012) model by adopting the Kimball (1995) aggregator in labor markets in place of Dixit-Stiglitz (1977) aggregator, in an attempt to estimate a more reasonable degree of wage stickiness for Japanese economy. He obtains a generalized wage inflation relation in which the New Keynesian wage Phillips curve by Galí, Smets and Wouters (2012) can be obtained as a special case.

4.2 Financial Frictions

The basic New Keynesian model introduced in the previous section abstract from capital market imperfections. That is, there is a single representative agent and no distinction is made between borrowers and lenders. Households can trade in state contingent securities available at any quantity, with the rate of return of the risk-free rate. This perfect financial market is assumed because it holds true in many issues prior to the crisis.

Yet, the recent financial crisis makes it evident that macro-financial linkages observed in the data cannot be ignored. The crisis confirms the existence of a tight link between systematic risks of the financial sector on one hand, and economic fluctuations on the other. For instance, economic upturns are often accompanies with higher leverages, while economic downturns are further exacerbated by deleveraging processes by many firms, making the recessions more severe. In this light, understanding the entrails and behaviors of financial market imperfections is also critical for the design of stabilization policy.

4.2.1 Introducing Financial Frictions

In a nutshell, embedding credit imperfections requires modeling borrowers and lenders. Financial frictions in the literature typically emerge at the level of capital management. This is typically done by separating the owner of capital from households. That is, capital management drop out from households budget constraint. The new owner of capital is often named as entrepreneurs. She rents capital services to rms, by taking loans from the financial intermediary, i.e., the banking sector. The banking sector, in turn, refinances loans from households by accepting deposits. Financial frictions are embedded into this process of financial intermediation, giving rise to constraints in either quantities or prices of loans.

There are two streams of literature on financial frictions prior to the crisis, namely, the collateral constraints and the external finance premium. Both approaches introduce financial frictions through loans. The former introduces frictions to quantities of loans, whereas the latter adds frictions via prices of loans.

4.2.2 The Collateral Constraint

The collateral—quantity of loans—constrains is introduced by the seminary work of Kiyotaki and Moore (1997). Iacoviello (2005) extends this approach to housing prices and monetary policy.

In this approach, agents are heterogenous in terms of their rate of time preference. This heterogeneity in terms of intertemporal decisions separate lenders and borrowers. The financial sector works as intermediaries between lenders and borrowers. In this environment, capital imperfections that require the borrowers to provide collateral for their loans is introduced as financial frictions. That is, entrepreneurs need collateral to take a loan, and the financial frictions in this approach directly affect the quantity of loans used as collateral. This constraint is also perturbed by shocks to the requirement of the loan-to-value ratio.

4.2.3 The External Finance Premium

The second approach—via the prices of loans due to the external financial premium—originates from research by Bernanke and Gertler (1989). Bernanke, Gertler and Gilchrist (1999) and Carlstrom and Fuerst (1997) follow Bernanke and Gertler (1989) to develop the New Keynesian general equilibrium models with financial accelerator property, thus providing the most influential workhorse monetary model of financial frictions.

In this framework, financial frictions result from the assumption that capital management by entrepreneurs is risky. Individual entrepreneurs are assumed to be risk-neutral, and are subject to idiosyncratic shocks. Entrepreneurs can observe those shocks for free, whereas the lenders need to pay some monitoring costs to learn the realization of those shocks. That is, in this model, it is costly for lenders to monitor a loan applicant, i.e., entrepreneurs. This consult state verification problem in tradition of Townsend (1979) drives an endogenous wedge—premium—between the lending rate and the risk free rate. While entrepreneurs are risk-neutral, households are assumed to be risk-averse, and to own the perfectly-competitive banking sector. That is, banks pay interest on deposits of households, and the rate on those deposits are equal to the risk-free rate and no extra profits are incurred every period. In other words, financial frictions in this economy is operative through prices of loans—the premium between the expected return on capital and the risk free rate.

4.2.4 Financial Frictions and Monetary Policy

The crisis also makes clear that the workings of financial markets matter for the economy and should be taken into account for the design of effective stabilization policies. This results in an enormous interest in developing theoretical frameworks that incorporate financial frictions in monetary policy analysis.

The issues concerning imperfect financial markets and policies include, to name a few, Non-Ricardian households who have limited access to financial markets (Galí, Lopez-Salido and Valles

(2007)), time-varying spreads between the loan rates and the risk-free rate (Curdia and Woodford (2010)), balance-sheet constraints on financial intermediaries (Gertler and Kiyotaki (2015)), optimal monetary policy in the presence of financial frictions (Cúrdia and Woodford (2016)), the effects of financial shocks as sources behind economic fluctuations (Christiano, Motto and Rostagno (2003)), macroprudential policies (Angelini, Neri and Panetta (2011)), idiosyncratic and time-varying volatilities, i.e., risk shocks (Christiano, Motto and Rostagno (2014)).

5 Discussion

Given stock of the current state and development of the New Keynesian models with financial frictions or unemployment, some of the key issues pertaining to these two lines of literature are to be presented below. We first provide discussion on issues underlying labor market inefficiencies, we then move on to focus on a few critical issues in considering the post-crisis models of financial frictions.

5.1 Unemployment

Here we focus our discussion of unemployment on the issues of importance after the crisis periods, but have not yet fully investigated in literature. That is, the issues of involuntary unemployment framework of Gali and the debate on sources of unemployment fluctuations in presence of financial frictions are to be discussed. Given that the involuntary unemployment is relatively new and the literature on the latter is still very limited, this discussion serves as the first comprehensive contributions to that literature on involuntary unemployment models. By the same token, since the literature that unify two streams of models of unemployment and financial frictions is still weak, this discussion also makes its contributions to that literature.

5.1.1 Sources of Unemployment Fluctuations

As a tradition of Macroeconomics, the sluggish adjustment of unemployment during recessions and recovery processes are typically explained by *downward wage rigidities*, following the seminal work of Keynes (1936). Yet, given the nonnegligible impact of financial frictions on many macro variables, much of—and growing—literature on financial frictions suggests that many traditional shocks are replaced by financial factors, and and some even point to the irrelevance of labor market shocks and frictions in accounting for the unemployment developments. That is, the literature has not reached the consensus on the answer.

On the one hand, the work that addresses this issue from the perspective of nominal wage rigidities tends to find that exogenous movements in workers' market power play a dominant role in labor market frictions. Galí, Smets and Wouters (2012), for example, investigate the sources behind unemployment without financial frictions but with nominal wage rigidities, to show that identified wage markup shocks are the key driver behind unemployment development. Galí, Smets and Wouters (2012) further argue—based on the high correlation between the unemployment rate and their output gap—that "variations in wage markups, whether exogenous or induced by wage rigidities, are a key factor underlying inefficient output fluctuations". Foroni, Furlanetto and Lepetit (2018) also support this claim based on evidence obtained through structural vector autoregressions, by imposing sign restrictions on the responses of both unemployment and the labor force participation to the two labor market disturbances.

On the other hand, and among others, Christiano, Eichenbaum and Trabandt (2015) (henceforce CET) investigate—in their analysis of the Great Recession—the key drivers of the high unemployment rate during the Great Recession by endogenizing the labor force participation rate. They estimate an DSGE model with financial frictions, but no nominal wage rigidities to show that their model does reasonably well at accounting for unemployment development during the crisis, implying the irrelevance of inefficient fluctuations in wage markup as sources behind the unemployment rate. Zhang (2018) also argues—based on his estimated medium-scale DSGE model with BGG-type financial frictions and Mortensen-Pissarides-type labor market frictions—that financial shocks contribute significantly to the surge in the U.S. unemployment rate during the crisis.

This distinction is critical because the celebrated Okun's law relates unemployment to movements of the economy away from its natural level—the output gap. This implies that the sources behind unemployment fluctuations are also the key factors underlying inefficient output fluctuations. The fundamental question is: which market shocks and frictions matter in unemployment fluctuations during the crisis—labor or financial? Yet, the literature is not unanimous on the answer to this fundamental question, largely due to the complexities arising out of modeling both financial frictions and unemployment. The latter, e.g., search and matching mechanisms, significantly alters the entire structure of the typical DSGE model settings, thus making it difficult to correctly assess the impact of financial factors on inefficient labor market variations. This issue can be reconciled if one is able to identify labor market shocks—wage markup and labor supply shocks—as well as financial disturbances, while maintaining a convenient and widely-used representative agent framework.

5.1.2 Involuntary Unemployment

As told, and given a new yet exciting approach to introduce unemployment by Galí, this section focuses on discussion pertaining to this emerging literature. To the best of our knowledge, there is no literature survey on unemployment in DSGE models primarily focusing on the involuntary unemployment models. Thus, the discussion below makes first comprehensive contributions to that literature.

Here we list two major challenges that arise out of this particular reinterpretation of labor market structure of the reference DSGE models. In a nutshell, both of these issues concerns nominal wage rigidities. They can be named as an assumption of a single source of unemployment, and exogenous wage rigidities. Below, we discuss them one at a time.

Wage rigidities as a single source behind unemployment variations A first challenge of this unique framework to introduce unemployment is its entire focus on a single source of unemployment other than nominal wage rigidities. The presence of the latter pertains not only to the average level, but also to the fluctuations of, unemployment variations. As a matter of fact, and has been already evident from the discussion so far, the precise mechanism represented as the search and machine models are not explicitly incorporated to account for the unemployment dynamics. One complication arises out of an effort to introduce both staggered price and wage formalisms into labor market frictions, because the models in that labor market literature typically assume that the labor participation—another important but not yet fully investigate labor variable—is inelastically supplied, so that variations in unemployment just mirror those counterparts of employment variable. Given that the labor force participation played some key roles in understand both economic and unemployment fluctuations during the crisis (Fujita (2014)), sources of unemployment fluctuations obtained from the labor force dynamics other than employment are largely ignored by the current vintages of unemployment models.

Exogenous wage rigidities Second, nominal wage rigidities in this framework are assumed to be exogenously given. Nominal wages in the involuntary unemployment literature are set by workers as a consequence of their market power in labor markets. This exclude the possible (and important) roles played by bargaining. This assumption of exogenous wage rigidities are not an innocuous assumption pertaining to this particular approach to unemployment. It holds true in most of the New Keynesian models of nominal wage rigidities tracing back to Erceg, Henderson and Levin (2000). The workhorse DSGE models of Smets and Wouters (2003), Smets and Wouters (2007) and Christiano, Eichenbaum and Evans (2005) are no exceptions. However, as pointed out in Galí (2011), the predictions and empirical evidence by the New Keynesian models with exogenous wage rigidities is not consistent with the evidence on wage setting dynamics in the United States and Europe. Those inconsistency may arise out of the assumption of exogenously-given wage rigidities, and labor market frictions in some forms of bilateral wage bargaining seem to be missing entirely.

5.2 Financial Frictions

Next, we discuss key challenges the DSGE models with financial frictions are facing to understand and capture some prominent post-crisis phenomena. Here we focus on two of those key issues highly debated after the crisis. They include an unsettled debate on sources underlying business cycle fluctuations, and nonstationary and nonlinear feature of asset bubbles that precede the financial crisis.

5.2.1 Sources of Economic Fluctuations

The debate on origins of business cycles has not been settled. As discussed above, RBC theory typically attributes a dominant roles in economic fluctuations to neutral technology shocks. On the other hand, some prominent DSGE models point to other disturbances as the main sources of business cycles. Justiniano, Primiceri and Tambalotti (2010), for example, argues that investment shocks account for between roughly 50 percent of variations in output and hours worked at business cycle frequencies.The hallmark of these DSGE models, however, are lack of explicit treatment of financial factors.

In the aftermath of the recent financial crisis, however, the role of financial data has gained considerable interest as a source of valuable information behind economic fluctuations. Using a large number of macroeconomic and financial variables and data, Christiano, Motto and Rostagno (2014) estimate their medium-scale DSGE model with financial frictions to conclude that fluctuations in risks of individual firms can account for the vast bulk of US business cycles. In Christiano, Motto and Rostagno (2014), risk corresponds to the variance of firm-specific shocks to technology, in other words, stochastic volatilities of shocks. A rise in the variance would lead to large shocks at the individual firm-level (e.g., bankrupt), whereas law of large numbers tell that their net impact becomes of minor importance on average. That is, such shocks would have no impact on aggregate output, if we abstract from financial frictions in individual firm levels. But with those financial frictions in place, such shocks could be an important source of economic instability. This is the motivation behind Christiano, Motto and Rostagno (2014), who explicitly consider these firm-level risks with a large number of financial data, and a different picture emerges. To put it differently, they articulate the notion that shocks to idiosyncratic risk of firms could generate a recession-like behaviors in aggregate economy. Based on the evidence obtained from their estimated DSGE model, Christiano, Motto and Rostagno (2014) argue that the dominant source of US GDP fluctuations are the risk shocks, that is, disturbances in the riskiness of individual firms.

Why are the risks shocks the major source of economic fluctuations? Take as example a recession triggered by a rise in the riskiness of firms. As the risks go up, lenders put a premium on the loan they make. This rising cost of borrowing forces firms to borrow less. Firms then demand less capital, leading to a fall in both the quantity and price of capital. The decline in investment also decreases consumption, inducing bankruptcies of firms Aggregate demand falls, and inflation drops as well to result in an economy-wide recession.

Importantly, the risk shocks also increase the cross-sectional dispersion of the rate of return on equities of firms. This distortion created by idiosyncratic risk resembles the cross-sectional price dispersion of sticky prices, and thus becomes another source of economic fluctuations. Christiano, Motto and Rostagno (2014) argue indeed the risks shocks are the major sources of economic fluctuations, and show that the risks shocks account for roughly 60 percent of the variance of US business cycles.

Since the impact of risk shocks captures a large portion of US economic fluctuations, they replace the roles of many standard shocks reported by previous empirical DSGE literature. For instance, Justiniano, Primiceri and Tambalotti (2010) argue that aggregate shocks to technology for firms to produce new capital account for 50 percent of GDP variations over business cycles. This is in stark contrast with the empirical evidence by Christiano, Motto and Rostagno (2014), who argue that the these investment-specific technology shocks account for only 13 percent of he business cycle variations in US GDP once idiosyncratic risks of firms are taken into account. Consistent with a growing number of empirical evidence obtained from models with financial frictions, financial variables and data, with their particular focus on individual-level behaviors of agents may play more significant and broader roles in the analysis of economic fluctuations than pre-crisis models suggest.

5.2.2 Bubbles

The financial crises, not only the recent one but also the crises in general, often show some of the more complicating and formidable phenomena. Those phenomena can be found in almost every time before the financial boom appear—asset bubbles. Those bubbles typically build up gradually reflecting any financial imbalances that often precedes financial crises, leading to an eventual crash. That earthquake or storm is marked by any forms of defaults, sudden-stop and tightening of credits, deleveraging, fall in asset price, and a huge contraction in aggregate demand, leading to decline in output and employment. The defining characteristic of these macroeconomic phenomena triggered by financial crises is its nonlinearity.

Standard business cycle analysis based on DSGE models are, however, principally designed to form stationary and linear models in which fluctuations buffered by exogenous shocks only perturb equilibrium levels of macro variables around steady state or trend. The workhorse DSGE models of financial frictions are no exception. For example, the introduction of financial accelerator mechanisms driven by endogenous (and often with exogenous) external finance premium often leads to amplification and propagation of the effects of traditional (non-financial) shocks (Bernanke, Gertler and Gilchrist (1999)). The state-of-the-art financial frictions model also allow for additional financially-driven fluctuations who origin is idiosyncratic and largely associated with risks (Christiano, Motto and Rostagno (2014). Yet, the current vintages of DSGE models cannot replicate an eventual crash that result from a gradual-build-up of financial risks stemming from financial imbalances. Those existing literature on financial frictions generally depend on a large exogenous shocks to capture large recessions of any size and persistence, and thus are regarded not representing the mechanisms behind those bubbles correctly.

The difficulty in addressing the issue of asset bubbles under the DSGE program arises because of the assumption of an infinitely-lived representative household, a hallmark of dynamic macroeconomic model. That assumption effectively rules out the existence of rational bubbles in equilibrium. The reason is as follow. The assets are usually hold by the representative household. In order for the bubbles to occur, those assets would have to, at least, grow at the rate of interest And since there is only single and infinitely-lived agent, the asset bubbles occurs within household. But, this violates the households transversality condition, and the optimization problem of the households are not well defined in the first place.

The importance of roles played by bubbles are self-evident. The latter drive booms and busts of asset prices, eventually resulting in many financial crises. Given the importance of the roles played by asset bubbles, it is surprising that many standard DSGE models have not sought to rectify the lack of reference model for the analysis of such phenomena.

6 Conclusion: Challenges for the Future

This paper surveys the challenges for macroeconomics and their monetary policy implications by tracing the evolution of DSGE models before, during, and after the crisis. The survey primarily focuses on the issues relevant to the financial crises: financial frictions, unemployment and monetary policy.

Some possible areas for future research are self-evident from the discussion above. To be more specific, we provide pointers of directions for future research below.

6.1 Unemployment

6.1.1 Sources of Unemployment Fluctuations

Involuntary unemployment with financial frictions. The challenge to reconcile the debate on labor-market-vs-financial-market-shocks can be met by quantitatively investigating how shocks and frictions originating from both labor and financial markets compete with each other, based on otherwise canonical medium-scale DSGE, e.g., Smets and Wouters (2007) model. One idea to for the future research to meet this challenge is to extend an estimated DSGE model of nominal wage rigidities and involuntary unemployment by Galí, Smets and Wouters (2012) with a financial accelerator mechanism á la Bernanke, Gertler and Gilchrist (1999). As both of these reference models introduce unemployment and financial frictions while still preserving the celebrated SW framework, this avenue for future research seems promising in assessing how shocks and frictions originating from both labor and financial markets compete with each other, including their eventual outcome of financial factors to unemployment fluctuations.

6.1.2 Involuntary Unemployment

Variable labor force. A direction for future research high on the agenda is for DSGE models to contain information arising from labor participation dynamics itself, other than traditional variations of employment. In other words, a promising avenue for future research is to incorporate variable labor participation structure into labor market frictions. Some initial attempts to accomplish variable labor force can be seen in Christiano, Trabandt and Walentin (2010).

Endogenous wage rigidities. Christiano, Eichenbaum and Trabandt (2016) provides an initial yet promising work in generating wage rigidities without an innocuous assumption that they are formed exogenously. They incorporate into a version of the Christiano, Eichenbaum and Evans (2005) model labor market search and matching frictions, by which workers and firms bargain in a way that reduces the sensitivity of wages to various macro variables. This results in wage stickiness arising endogenously, allowing for generating hump-shaped responses of many key macro aggregates, without resorting to arbitrary degrees of nominal wage rigidities. Understanding the dynamics between wage markups, unemployment, together with variable the labor force participation will be an important avenue worth exploring in future research.

6.2 Financial Frictions

6.2.1 Sources of Economic Fluctuations

The critical differences the risk shocks of Christiano, Motto and Rostagno (2014) make, and thus could be the promising avenues for future DSGE program are, at least, two folds.

Extensive use of financial variables and data. First, they include ample of more financial variables and data than previous DSGE models, even more than the earlier financial frictions models do. Christiano, Motto and Rostagno (2014) adds to the standard eight macro aggregates four financial data, including, for examples, the Dow Jones Wilshire 5000 index, and BAA-corporate bond spreads. As evidenced by Christiano, Motto and Rostagno (2014) in that they can replicate a large number of business cycle phenomena with newly available financial data, utilizing information whose characteristics are tightly linked to financial markets is high on agenda in post-crisis DSGE modeling.

Financial frictions in demand-side of capital. Second, the risk shocks of Christiano, Motto and Rostagno (2014) imply the importance of financial frictions associated with those who borrow from financial institutions. Pre-crisis approaches to financial frictions largely embed financial frictions at the level of financial intermediation, that is, the supply side of capital. Yet, in presence of financial data such as stork market indices, shocks to the supply of capital result in countercyclical movements in stock markets, implying they cannot be a major source of business cycles in financially-driven recessions. On the other hand, the risk shocks of Christiano, Motto and Rostagno (2014) directly affect individual firms who borrow from financial intermediaries. Since shocks to demand side of capital—risk shocks—give rise to procyclical movements in stock markets, risk shocks could play more vital roles in generating recession-like economic fluctuations by financial factors.

6.2 Bubbles

Monetary models of rational asset bubbles. Some attempts have began to be made to rectify anomaly of models inability to explain rational asset bubbles under the New Keynesian framework. Galí (2014) uses the three-generation and finite overlapping generation (OLG) model to shows that asset price bubbles may exist in equilibrium, and the fluctuations of the latter result in welfare-reducing volatility even when fundamental shocks are not included. Implications of alternative monetary policy rules on fluctuations and welfare are also provided, since the evolution of bubbles crucially depends on the interest rates rules adopted by central banks. Another recent effect to overcome the linearity assumption of DSGE models is proposed by Boissay, Collard and Smets (2016), who analyze a real model with asymmetric information in the interbank market. That market is assumed to be driven by a sequence of small shocks, leading to a model economy towards a region including multiple equilibria. Since some of those equilibria is characterized by a freeze in the interbank market, this allows for a credit crunch and a subsequent prolonged recession. This, we believe, is a promising future research direction, and the issues high on the agenda include monetary models with the asset price bubbles obtained above.

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