UC Riverside
UC Riverside Electronic Theses and Dissertations

Title
Essays on Inflation and Wage Dynamics: Theory and Evidence

Permalink
https://escholarship.org/uc/item/51p1r1bg

Author
Kim, Insu

Publication Date
2010

Peer reviewed|Thesis/dissertation

eScholarship.org Powered by the California Digital Library
University of California

UNIVERSITY OF CALIFORNIA
RIVERSIDE

Essays on Inflation and Wage Dynamics: Theory and Evidence

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Economics

by

Insu Kim

March 2010

Dissertation Committee:

Dr. Marcelle Chauvet, Chairperson
Dr. Jang-Ting Guo
Dr. Aman Ullah

Copyright by
Insu Kim
2010

The Dissertation of Insu Kim is approved:

Committee Chairperson

University of California, Riverside

ACKNOWLEDGEMENTS

First, I am deeply grateful to my advisor, Dr. Marcelle Chauvet, for her excellence support. She was always there to talk about my research ideas and opinions and to give advice. She constantly motivated and encouraged me to develop my research ideas. She also taught me macroeconomics and how to write papers. Her encouragement and guidance led me to find creative ideas and to complete several papers. It was a pleasure to study macroeconomics under her kind guidance. I would like to give her two thumbs up.

I am also indebted to Dr. Jang-Ting Guo and Dr. Aman Ullah for their lectures in 2005-2006, which turned out to be crucial in doing my empirical and theoretical research.

I would like to give a special thanks to my parents, Young-Kwan Kim and Myung-Ja Kim, my brothers Sangsoo Kim, Hansu Kim, and my lovely wife Hyun-Kyoung Kim. Without their unconditional supports, this dissertation could not be completed.

Finally, I thank Trinidad Beleche, Jie Li, Neha Raykar, and Minsoo Kim for their help in writing this dissertation and in discussing research ideas. I thank Garnett Smith, Hung-Lin Chen, Kwangwoo Lee, Jae-Hee Son, and Jae-Woo Kim for the wonderful friendship at the University of California, Riverside.

DEDICATION

To my parents

ASTRACT OF THE DISSERTATION

Essays on Inflation and Wage Dynamics: Theory and Evidence

by

Insu Kim

Doctor of Philosophy, Graduate Program in Economics
University of California, Riverside, March 2010
Dr. Marcelle Chauvet, Chairperson

This dissertation proposes a new Phillips curve that is able to endogenously generate inflation persistence in a profit-maximizing framework featuring sticky prices, in response to the critique to ad-hoc approaches directly incorporating a lagged inflation term into the Phillips curve by assuming that a fraction of firms reset their prices by automatic indexation to past period's inflation rate. In order to generate a lagged inflation term as a source of inflation persistence, I assume that although firms change their prices at discrete time intervals, they can not completely adjust prices due convex costs of changing prices. Hence, this dissertation introduces dual price stickiness with respect to the frequency and size of price adjustment. In addition to the dual price stickiness, this dissertation investigates the potential presence of dual wage stickiness: with respect to both the frequency as well as the size of wage adjustments. In particular, I derive a model

of wage inflation dynamics assuming that although workers adjust wage contracts at discrete time intervals, they are limited in their abilities to adjust wages as much as they might desire.

The dual price (wage) stickiness model nests the baseline model, based on Calvo-type price (wage) stickiness, as a particular case. Empirical results favor the dual price (wage) stickiness model over the baseline model that assumes only one type of stickiness in several dimensions. In particular, it outperforms the baseline model in the ability to explain the observed “reverse dynamic” cross-correlation between price (wage) inflation and real output - which the baseline model fails to capture.

This dissertation also proposes an alternative new Keynesian modeling approach to evaluate the relative contribution of inflation expectations and inertia to inflation dynamics. Particular attention is given to avoid potential spurious regression analysis. My findings indicate that while the rising inflation in the 1970s is likely to be connected with changes in inflation expectations, the positive inflation trend in the 1960s is related to the role of a lagged inflation term in the Phillips curve. The results also provide evidence that the role of inflation expectations differs substantially before and after 1980. In particular, the coefficient associated with inflation expectations from the early 1980s to the end of the sample is half the values prevailing in the late 1960s and the 1970s. Finally, the findings indicate that there is little evidence supporting a rational, model-consistent inflation expectation.

Contents

List of Tables		x
List of Figures		xi
Chapter 1	Introduction……………………………………………………………….	1
Chapter 2	The Micro-foundations of Inflation Persistence in New Keynesian Phillips Curve	6
2.1	Introduction…………………………………...…………………..	6
2.2	Firms' Problems and the Phillips Curve……………..………………...	13
2.2.1	The Final-Goods-Producing Firm……………………………………...	13
2.2.2	The Intermediate-Goods-Producing Firm……………………………...	15
2.3	Bayesian Estimation of a DSGE Model ..……………………………..	19
2.3.1	A Small Scale DSGE Mode................. ..…………………………......	19
2.3.2	Estimation Results.............................. ..……………………………..	21
2.3.3	The Dynamic Correlation Between the Output Gap and Inflation.........	25
2.3.4	Impulse Response and Autocorrelation Functions……………..........	27
2.3.5	Subsample Estimation Result………………………………..............	30
2.4	Conclusion………………………………………………….............	31
Chapter 3	Dual Wage Stickiness: Theory and Some Evidence	33
3.1	Introduction………………………………………………….............	33
3.2	A Model Economy……………………………………………..............	37
3.2.1	Households………………………………………………..................	37
3.2.2	Households and Wage Setting……………………………...….........	40
3.2.3	Firms and Price Setting…………………………………...................	44
3.2.4	Monetary Policy and the Taylor Rule………………………..............	46
3.3	Empirical Results: Bayesian Estimation……………………............	46
3.3.1	The Data………………………………………………………..........	47
3.3.2	Empirical Model …………………………………………............	47
3.3.3	Empirical Results……………………………………………...........	50
3.3.4	The Relative Importance of Each Friction of the Model……............	53

3.3.5	Impulse Response Analysis………………………………………..............	57
3.3.6	The Dynamic Correlation Between Wage Inflation and Output….........	60
3.3.7	The Observed and Theoretical Persistence of the Model Variables.......	62
3.3.8	Sub-sample Analysis…………...………….……………………..........	64
3.3.9	Counterfactual Analysis………..............……………………….…......	66
3.4	Conclusion……………………………………………………...............	69
Chapter 4	Inflation Dynamics: the Changing Role of Expectations and Inertia	71
4.1	Introduction……………………………………………………..............	71
4.2	The New Keynesian Phillips Curve: Issues and Motivations…...............	76
4.2.1	The Forward-looking Behavior in Price-setting and the NKPC….........	76
4.2.2	Empirical Issues: The Evidence of the Forward-looking Behavior........	77
4.2.3	A Question of the Tests of the NKPC: Are Inflation Expectations Model-Consistent?..	80
4.2.4	Empirical Issues: Is Lagged Inflation Necessary to Generate Inflation Persistence?...	82
4.2.5	An Alternative Modeling Approach to Investigate the Role of Inflation Expectations and Lagged Inflation In Inflation Dynamics......	83
4.3	The Driving Forces of Inflation………………………………..........	85
4.3.1	What Drives Inflation?..	85
4.3.2	Labor's Share of Income and the Output Gap as Driving Forces of Inflation: Statistical Evidence………………………………….............	88
4.3.3	Labor's Share of Income and the Output Gap as Driving Forces of Inflation: Graphical Evidence………………………………….............	89
4.4	A Test of the Role of Expectations…………………………….........	91
4.4.1	An Alternative Test of the Role of Expectations: Statistical Analysis...	92
4.4.2	A Substantial Change in the Role of Expectations: Graphical Analysis………………………………………………………...........	94
4.4.3	A Substantial Change in the Role of Expectations: Statistical Analysis………………………………………………………...........	97
4.5	Are Inflation Expectations Formed in a Model-consistent Way?...........	102
4.6	Conclusion: Summary of Findings………………………..............	105
Chapter 5	Conclusion………………………………………………….........	108
Bibliography		110

List of Tables

Table 2.1 Bayesian Estimation for DSGE Model………………………………...... 22

Table 2.2 Bayesian Estimation of DSGE Model: With Eq. (16)…………………... 24

Table 2.3 Bayesian Estimation of DSGE Model: Subsample Analysis…………… 30

Table 3.1 Bayesian Estimation of DSGE Model…………………………………... 51

Table 3.2 The Relative Importance of Each of the Frictions………………………. 54

Table 3.3 Subsample Estimation Results……………………………………...... 65

Table 3.4 Counterfactual Analysis………………………………………………… 67

Table 4.1 Estimation Results of Equation (9)……………………………………… 89

Table 4.2 Estimation Results of Equation (10)…………………………………...... 93

Table 4.3 Panel A: Estimation Results of Equation (10): The SPF………………... 98
Panel B: Estimation Results of Equation (10): The Green Book……...... 98

Table 4.4 Estimation Results of Equation (11)…………………………………...... 100

Table 4.5 Panel A: Estimation Results of Equation (15): The SPF………………... 104
Panel B: Estimation Results of Equation (15): The Green Book……...... 104

List of Figures

Figure 2.1 Dynamic Correlation Between the Output Gap and Inflation…………. 26

Figure 2.2 Impulse Response Functions…………………………………..……. 28

Figure 2.3 Autocorrelation Function……………………………………...……. 29

Figure 3.1 The Degree of Wage Stickiness and Trade-off…………………..……. 49

Figure 3.2 Impulse Response Functions…………………………………..……. 58

Figure 3.3 The Dynamic Correlation Between Output and Wage Inflation………. 61

Figure 3.4 Autocorrelation Functions of Variables…………………………..……. 63

Figure 4.1 The Output Gap and One Year Ahead Labor Income Share……..……. 86

Figure 4.2 a. Inflation and Weighted Average of Output Gaps……………...……. 90
b. Inflation and the Weighted Average of Labor Income Shares...……. 90

Figure 4.3 a. Inflation Explained by the Backward-looking Component…………. 94
b. Inflation and Fitted Value…………………………………...……. 95

Figure 4.4 Inflation and Oil Price………………………………………………. 101

Chapter 1

Introduction

The dynamic cross-correlation that has been observed between price inflation and real output indicates that current output is negatively related to past price inflation, while also being positively correlated to future price inflation. Taylor (1999) stresses that the ability to explain the "reverse" dynamic correlation between price inflation and real output is an important "measure of success" of monetary models. The data also show that past wage inflation is negatively correlated to current output, and that current output is positively related to future wage inflation. Similarly, the ability to explain the reverse dynamic correlation between wage inflation and output could be considered to be a success of a sticky wage model. The goal of this dissertation is to develop a new Keynesian model that is able to replicate the reverse dynamic correlation between price (wage) inflation and output in a maximizing framework featuring dual price (wage) stickiness and rational expectations.

Staggered contract models based on Calvo (1983) have been widely employed in the literature (e.g., Erceg, Henderson and Levin 2000; Christiano, Eichenbaum and Evans 2005; Smets and Wouters 2007; Justiniano and Primiceri 2008; among several others). These models assume that a fraction of firms (workers) completely adjust their prices (wages) at discrete time intervals in response to changes in the economic environment. However, the assumption that firms (workers) are able to adjust their prices (wages) optimally without any restrictions whenever they periodically change their prices (wages) is questionable. For example, although the firm investigated by Zbaracki et al (2004) changes prices once a year, “the firm reacted to major changes in supply and demand conditions slowly and/or partially because of the convexity of the costs [of price adjustment].” The convex costs of price adjustment such as communication, negotiation costs and the costs of antagonizing customers can preclude firms from adjusting prices as much as they might desire. The interaction between firms and consumers can make prices sticky with respect to the size of price adjustment.

Similarly, although workers may re-optimize their wages at certain time intervals, wages could be only partially adjusted in response to changes in economic conditions because wages are determined through the interaction between workers and firms. Analogous to the idea the firms have limited abilities to fully adjust prices due to the interaction between consumers and firms in the goods market, which is formally introduced through the use of quadratic adjustment costs (e.g., Rotemberg 1982), households' limited abilities that arise as a result of the interaction between firms and households in the labor market could also be modeled using the quadratic costs of adjusting wages. As an increase in prices yield antagonizing customers (e.g., Rotemberg 1982), a rise in wages is likely to upset firms, resulting in firms’ resistance.

In this respect, this dissertation derives a new sticky price (wage) model assuming that although firms (workers) adjust their prices (wages) infrequently, they still face the convex costs of price (wage) adjustment. In essence, my models combine both Calvo’s (1983) pricing and the quadratic price adjustment cost proposed in Rotemberg (1982). The findings favor the dual price (wage) stickiness model over the baseline model based on only one type of stickiness. First, although firms (workers) reset their prices (wages) at certain intervals of time, estimates of the parameter associated with the quadratic costs of price (wage) adjustment are significantly different from zero, rejecting the null hypothesis that prices (wages) are fully adjusted without any restrictions in response to changes in economic conditions. The inclusion of quadratic price (wage) adjustment costs yields a substantial improvement of the model in fitting the data. Second, the observed dynamic correlation between price (wage) inflation and real output can be better replicated under dual price (wage) stickiness. While the baseline model fails to generate the expected lead-lag relationship between price (wage) inflation and real output, the introduction of quadratic costs of price (wage) adjustment in the proposed model helps replicate the reverse dynamic cross-correlation between past price (wage) inflation and current output.[1] Overall, the dual sticky price (wage) model provides an improved explanation of price (wage) inflation dynamics.

This dissertation also investigates some fundamental issues on the new Keynesian Phillips curve. A large body of literature has employed the new Keynesian Phillips curve (NKPC) to investigate monetary policy and its relationship with business cycles. However, there is little consensus on some fundamental issues. First, some authors question the role of expectations in inflation dynamics, and instead advocate that a backward-looking framework fits the data better. Second, others criticize the use of lagged inflation implied by backward-looking models to explain inflation persistence on the grounds that the rationale for its inclusion is not based on micro-foundations. The third outstanding issue is with respect to the measures that should be employed as driving

[1] In particular, the proposed model explains the fact that a rise in current output is associated with a subsequent increase in price (wage) inflation.

forces of inflation. Recently, some authors have emphasized labor's share of income rather than output gap as the main determinant of inflation.

This dissertation proposes an alternative NKPC modeling approach to address these major ongoing discussions without assuming that inflation expectations are formed in a model-consistent way. In particular, we model inflation as a function of the closed form solution of the backward-looking Phillips curve as well as people's beliefs about future inflation. Inflation driven by the former is related to the part that is determined by current and past economic variables measuring demand pressure and marginal costs of production (e.g., the output gap and labor's share of income). Inflation driven by people's beliefs is associated with observed inflation expectations that leave open the possibility of deviation from rational expectations. The model allows us to identify the role of expectations and lagged inflation in explaining inflation dynamics separately, avoiding potential spurious regression analysis in the relative importance of lagged inflation and inflation expectations. Estimation is conducted using the generalized method of moment (GMM).

The findings indicate some interesting results that can shed light on the current debates regarding the NKPC framework. The findings indicate that both expectations and lagged inflation are quantitatively and statistically important in explaining inflation dynamics. In addition, the findings also indicate that output gap and labor's share of income work in tandem in driving inflation. This dissertation also finds an intriguing new result that to our knowledge has not yet been reported in the NKPC literature. In particular, we find a substantial change in the role of expectations in the Phillips curve over the last decades. The coefficient associated with inflation expectations from the early 1980s to the end of the sample is half the values prevailing in the late 1960s and the 1970s. In addition, I find that while the positive trend inflation in the 1970s is related to people's beliefs about future inflation, the rising inflation of the 1960s and the variations in inflation after post-1980 are closely connected with current and past values of driving forces of inflation. Finally, we report an interesting finding that inflation predicted by current and past values of output gap and labor's share of income may have a low-frequency component, implying that detrending inflation by the use of a random walk process or the HP-filter has a potential risk of eliminating what can be explained by current and past values of driving forces of inflation. In particular, Cogley and Sbordone (2008)'s results obtained after controlling a low frequency component in inflation could be obtained after controlling the backward-looking component, thus mistakenly supporting the purely new Keynesian Phillips curve.

The structure of this dissertation is as follows. Chapter 2 develops a new Phillips curve under the assumption of dual price stickiness and investigates how well the model explains inflation dynamics. Chapter 3 derives a new wage Phillips curve in a maximizing framework featuring dual wage stickiness and rational expectations and evaluates the new wage Phillips curve. Chapter 4 proposes an alternative modeling approach to investigate fundamental issues on the new Keynesian Phillips curve and discusses the contribution of inflation expectations and lagged inflation to inflation dynamics and the driving force of inflation. Finally, I conclude the main findings of my dissertation.

Chapter 2

The Micro-foundations of Inflation Persistence in New Keynesian Phillips Curve

2.1 Introduction

The traditional formulation of the Phillips curve that presumed a structural relationship between unemployment and inflation was discredited in the 1970s as it contradicted the observed stagflation in this period. From a theoretical point of view, the criticisms were based on the lack of microfoundations and structural relationships, the latter leading to the impossibility of evaluation under alternative policy regimes. Concurringly with the low inflation experienced during the Great Moderation period, a stream of research focused on developing an alternative framework that would seemingly overcome many of the criticisms to the traditional Phillips curve. The standard New Keynesian Phillips curve (NKPC) is derived from a model of optimizing behavior on the part of the price setters in the presence of nominal rigidities. The model links sticky prices, inflation, and movements in the real economy and it gives a structural interpretation that allows analysis of changes in inflation. The NKPC is built mostly on the models of staggered contracts of John Taylor (1979, 1980), and Guillermo Calvo (1983), and the quadratic price adjustment cost model of Julio Rotemberg (1982), and is broadly used in the analysis of monetary policy (Richard Clarida, Jordi Gali, and Mark Gertler 1999). In these models, price rigidity is often the main transmission mechanism through which monetary policy affects the economy - when firms face difficulties in changing some prices, they may respond to monetary shocks by changing instead their production and employment levels.

Although the NKPC has some theoretical appeal, there is a growing literature on its empirical shortcomings regarding its ability to match some stylized facts on inflation dynamics and the effects of monetary policy. In particular, the standard NKPC models (Calvo 1983, Taylor 1999, Rotemberg 1982) have often been criticized due to the failure to generate inflation persistence (e.g. Fuhrer and Moore 1995, Nelson 1998, Angeloni et al 2006). In addition, these models do not yield the result that monetary policy shocks first impact output, and subsequently cause a delayed and gradual effect on inflation (e.g. Gregory Mankiw 2001, Karl Walsh 2003). Instead, it predicts that credible disinflations cause booms rather than recessions (e.g. Laurence Ball 1994a) in addition to failing to capture inflation persistence (e.g. Jeffrey Fuhrer and George Moore 1995, Nelson 1998b, McCallum 1999, Mankiw 2001, Dellas 2006a,b, Gali and Gertler 1999, Sbordone 2002, Rudd and Whelan 2005, and Roberts 2005). Accordingly, although the price level responds sluggishly to shocks, the inflation rate does not in these models. Fuhrer and Moore (1995) and Nelson (1998), among others, suggest that in order for a model to fully explain the time series properties of aggregate inflation and output it may require that its framework implies that not only the price level but also the inflation rate is sticky.

In response to those critiques, this paper proposes a new Phillips curve that endogenously generates inflation persistence as a result of optimizing behavior from agents. In addition, a result of the model is that a credible commitment to a lower inflation target always generates an economic recession - disinflations are gradual and are associated with economic slowdowns or deep recessions. The model is also able to capture the cross-dynamic correlation between inflation and output gap.

Several authors have proposed alternative NKPC framework that can account for some of the empirical facts. The most popular ones are extensions of the Calvo's staggered prices or contracts based on sticky information models or backward rule-of-thumbs. Mankiw and Reis (2002) propose a model in which information is costly and, therefore, is disseminated slowly. Each period a fraction of the firms sets prices based on outdated information, whereas the other fraction sets the optimal price path based on new information about the state of the economy. In this framework prices adjust continuously but information does not. The sticky-information model is consistent with inflation persistence and yields the result that disinflations cause recessions, rather than booms. Whereas some recent papers find empirical support for sticky information (e.g. Carroll 2003, Klenow and Willis 2007), others find evidence that firms review their prices more often than the frequency of price changes (e.g. Fabiani et al 2005, Coibion 2010). A more disputable empirical implication of this model is the result that prices change frequently, contradicting widespread micro-data studies, which find that firms keep prices unchanged for several months. This evidence is consistently present in most countries and across different data sources (e.g. Bils and Klenow 2004, Angeloni 2006, Álvarez 2006, Nakamura and Steinsson 2008, Klenow and Malin 2009, among several others).

Some widely used alternative models assume that a fraction of the firms changes its prices according to a backward looking rule of thumb. In Gali and Gertler (1999) firms set new prices based on past prices of other firms with a correction for recent inflation, instead of based on profit maximization. Christiano, Eichenbaum, and Evans (2005), Steinsson (2003), and Smets and Wouters (2003, 2007), among others, assume that part of the firms adjust their prices by automatic indexation of prices to past inflation. These models explain inflation inertia as they incorporate a lagged inflation term into the resulting hybrid NKPC, which is based on both a forward-looking term and a backward-looking term.[2] These models have in common the arbitrary role given to past inflation as at least some agents are backward-looking in the process of setting prices and, as a result, firms do not reoptimize prices each given period.

The hybrid NKPC models, such as the one proposed by Gali and Gertler (1999), are generally criticized for being ad-hoc as they lack a theory of how firms behave to motivate their structure (see e.g. Rudd and Whelan 2007, Woodford 2007, Cogley and Sbordone 2008, Benati 2008, Chari, Kehoe and McGrattan 2009, etc.). The indexation models of Christiano et al (2005), Steinsson (2003), and Smets and Wouters give more structure to the hybrid model as a fixed share of random Calvo-type firms could set their prices optimally each period while the rest changes according to past aggregate inflation, since it is readily observable. Thus, in their framework the lagged inflation term is derived from firms' decisions.

[2] Several other models also obtain inflation persistence using backward looking behavior, irrationality in the formation of inflation expectations, adaptive learning by agents, or time-varying inflation rate (e.g. Paloviita 2004, Roberts 1997, Milani 2005, Cogley and Sbordone 2005, or see Woodford's 2007 survey.

However, these modified hybrid NKPC models - as the sticky information models -imply that that prices are adjusted continuously, contrarily to the Calvo-based model of Gali and Gertler (1999) in which there is a constant probability that a firm will change its price in a given period. Thus, the general indexation models are not supported by micro-data evidence as they imply that all firms change their price every period (Rudd and Whelan, 2006). Notice that continuously price updating is an implication of many NKPC models including Fisher (1977), Lucas (1973), Reis (2006), Christiano et al (2005), Smets and Woulters (2003), Rotemberg(1982), Kozicki and Tinsley (2002) (see the comprehensive survey by Álvarez et al 2008).

This paper proposes a new model that explains the dynamics of output and inflation. We consider that firms face two sources of price rigidities, related to both the ability to change the price frequently and to the cost of sizeable adjustments. We investigate whether firms not only can not change prices often at discrete time intervals but also face costs of changing prices that prevent them from completely adjusting them. Calvo (1983)'s staggered price setting has been the most frequently used framework in the literature to derive the NKPC. In Calvo-type price setting, a fraction of firms optimizes their prices at discrete time intervals, and whenever firms change their prices they are able to adjust it to the optimal level (Robert, 1992). Eichenbaum and Fisher (2007) also interpret the Calvo pricing as reflecting firms' response to various costs associated with the process of setting new prices in a profit-optimizing framework. In doing so, firms completely adjust their price in response to changes in various costs.

Another popular framework is Rotemberg (1982) in which firms set prices to minimize deviations from the optimal price subject to quadratic frictions of price adjustment.

This paper utilizes both Calvo (1983)'s staggered price setting and the quadratic price adjustment cost model proposed by Rotemberg (1982). This is examined by modeling firms that change their prices at discrete time intervals but still face their abilities limited in fully adjusting prices due to convex, variable costs. While both the Calvo pricing and the quadratic price adjustment cost are designed to model sticky prices, they have different implications with respect to the frequency and size of price adjustment. While the former is related to the frequency of price changes, the latter is associated with the size of price changes. Physical menu cost (fixed cost) or implicit and explicit contracts might explain why many individual prices remain unchanged for several periods. On the other hand, several dimensions of managerial and customer costs might imply variable costs of price adjustment that increase with the magnitude of price adjustment, limiting firms' ability with respect to the size of price changes. These costs might arise from “fearing to upset customers”, customer costs (negotiation, communication) or managerial costs (information gathering, decision making).[3] The solution of the model implies prices are not continuously adjusted, and the firms who do adjust prices do not fully adjust them due to convex costs of adjustment.

In order to investigate the presence of two types of price stickiness as wells as the resulting inflation dynamics, this paper develops a new Phillips curve in a optimizing framework featuring dual price stickiness. In the dual price stickiness model, current

[3] See e.g. Blinder et al (1998) and Zbaracki et al (2004) that provide some microeconomic evidence for antagonizing customers.

inflation depends on inflation expectations, lagged inflation, and real marginal cost. In contrast to the Calvo-cum-indexation models by Gali and Gertler (1999) and Christiano et al (2005), a lagged inflation term is endogenously generated in a forward-looking framework. Since price stickiness arises from both the size and frequency of price adjustments, current price depends on lagged price twice and, hence, a lagged inflation term is endogenously generated from the optimizing behavior of the firms. Thus, inflation is backward looking without assuming a backward-looking component in price setting. -- that is, agents remain forward looking and follow optimizing behavior. The new Phillips curve based on dual stickiness nests the baseline NKPC as a special case. The proposed model is a micro-founded alternative to the ad-hoc hybrid NKPC and the sticky information Phillips curve.

The proposed Phillips curve is derived from a small-scale dynamic stochastic general equilibrium (DSGE) model, which is estimated using Bayesian techniques. Empirical results indicate that the parameter estimates associated with the two types of price stickiness are highly significant, supporting the proposed model. We also provide additional evidence on the need of a lagged inflation term in generating the observed "reverse dynamic" cross-correlation between inflation and the output gap. Taylor (1999) considers as a yardstick of a success of monetary models their ability to generate the "reverse dynamic" cross-correlation between the output gap and inflation. In particular, this model provides a theoretical foundation on why the current output gap has a delayed, gradual impact on inflation as the dynamic correlation between the two variables. Such an effect is produced because even the chosen new price at discrete time intervals is only partially adjusted due to quadratic costs. In this respect, the dual wage stickiness model is favored over the baseline NKPC because the latter fails to generate the "reverse dynamic" cross-correlation between the two variables.

Other common ways in the literature to evaluate the model success in capturing inflation dynamics are by examining the estimated parameter associated with lags of inflation in the Phillips curve, the autocorrelation functions for inflation, and the impulse response functions (Gadzinski and Orlandi 2004). First, we find strong evidence of intrinsic inflation persistence as the coefficients associated with lags of inflation in the Phillips curve are positive and significant. Second, the autocorrelation function for the estimated inflation is high and decay gradually, indicating that intrinsic inflation is highly persistent. The estimated inflation autocorrelation closely tracks the observed data. Third, the response of inflation to a one-standard-deviation contractionary monetary policy shock shows the marked differences between the baseline NKPC and the proposed model. In the baseline model, the impact of a monetary policy shock on inflation is immediate. In the proposed model, by contrast, the response of inflation is gradual, displaying significant inertia, which is more consistent with outside lags regarding the impact of monetary policy on inflation, and substantial econometric evidence. Finally, the estimated parameters closely match extensive micro-data evidence regarding the frequency of price changes and the size of price adjustment.

The paper is organized as follows. Section 2 sets up the model problem and derives the implied new Phillips curve. Section 3 shows the estimation results, and Section 4 concludes.

2.2 Firms' Problems and the Phillips Curve

2.2.1 The Final-Goods-Producing Firm

The economy has two types of firms: a representative final goods-producing firm and a continuum of intermediate goods-producing firms. The final goods-producing firm purchases a continuum of intermediate goods, $Y_{i,t}$, at input prices, $P_{i,t}$, indexed by $i \in [0.1]$. The final good, Y_t, is produced by bundling the intermediate goods:

$$Y_t = \left[\int_0^1 Y_{i,t}^{1/\lambda_f} di \right]^{\lambda_f} \tag{1}$$

where $1 \leq \lambda_f < \infty$. The final-good-producing firm chooses $Y_{i,t}$ to maximize profit in a perfectly competitive market taking both input ($P_{i,t}$) and output prices (P_t) as given, solving the following problem:

$$\max P_t \left[\int_0^1 Y_{i,t}^{1/\lambda_f} di \right]^{\lambda_f} - \int_0^1 P_{i,t} Y_{i,t} di \tag{2}$$

subject to the technology described in (1). The first order condition of the final goods-producing firm implies that:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\lambda_f /(\lambda_f - 1)} Y_t \tag{3}$$

where $\lambda_f /(\lambda_f - 1)$ measures the constant price elasticity of demand for each intermediate good. The relationship between the prices of the final and intermediate goods can be obtained by integrating (3):

$$P_t = \left[\int_0^1 P_{i,t}^{1/(1-\lambda_f)} di \right]^{1-\lambda_f} \tag{4}$$

Equation (4) is derived from the fact that the final goods-producing-firm earns zero profits. The final good price can be interpreted as the aggregate price index.

2.2.2 The Intermediate-Goods-Producing Firm

In the literature, the most common way to derive the NKPC is based on the work of Calvo (1983), in which a fraction $(1-\theta)$ of firms are able to reset their prices to optimize profits while the remaining firms keep their prices unchanged. In the Calvo economy, as implied by equation (4), the aggregate price level evolves according to:

$$P_t = \left[(1-\theta)\tilde{P}_{i,t}^{1/(1-\lambda_f)} + \theta P_{t-1}^{1/(1-\lambda_f)} \right]^{1-\lambda_f} \tag{5}$$

We denote $\tilde{P}_t$ the optimal price set by the intermediate good-producing firms. The firms that can reoptimize their price at time *t* choose the same price in equilibrium, $\tilde{P}_{i,t} = \tilde{P}_t$ for all i.[4] Since individual prices are optimized infrequently, the aggregate price level also adjusts sluggishly, making current price level depend on its own lag.

Another popular way of introducing nominal rigidities is to assume that prices are sticky because firms face costs of changing their prices. Rotemberg (1982) proposes that firms face quadratic price adjustment cost that can reflect convex, variable costs. We assume that each intermediate goods-producing firm faces a quadratic adjustment cost of adjusting its nominal price given by:

[4] For details, see Woodford (1996) and Yun (1996).

$$QAC = \frac{c}{2}\left(\frac{\tilde{P}_t}{P_t} - \frac{\tilde{P}_{t-1}}{P_{t-1}}\right)^2 Y_t \tag{6}$$

Equation (6) implies that it is costly for current individual price to deviate from past price level, which makes prices sticky.

The aggregate price level also moves slowly due to the sluggish adjustment in individual prices. In this respect, both the Calvo pricing and the quadratic cost of price adjustment models are similar since they result in sticky prices. However, they yield different implications with respect to the frequency and size of price adjustment. While the Calvo model is associated with the frequency of price changes, the quadratic price adjustment cost model is related to firms' decisions about the magnitude of price adjustment. The Calvo pricing implies that firms change prices infrequently due to implicit or explicit contracts and fixed costs of changing prices. On the other hand, the size of price adjustment is more closely related to variable costs (rather than fixed costs) such as managerial costs (information gathering, decision making costs), customer costs (negotiation, communication costs) and “managers’ fear of antagonizing customers” which are reported by Zbaracki et al (2004) as microdata evidence. Variable costs could limit firms' ability to fully adjust their prices when they decide to change them because the cost of changing prices increases with the size of the price adjustment. For example, the firm investigated by Zbaracki et al (2004) changes prices only partially in response to changes in demand and supply conditions due to the convexity of price adjustment costs. We assume that firms face convex cost in adjusting the size of their prices and also implict or explict contracts that preclude them from adjusting prices frequently.

The intermediate goods-producing firm maximizes real profit from selling its output in a monopolistically competitive market assuming that price is fixed with the Calvo probability θ in any given period. In addition, firms face a quadratic adjustment cost in adjusting their prices. The firm chooses $\tilde{P}_t$ to maximize

$$E_t \sum_{k=0}^{\infty} (\theta\beta)^k \left[\frac{(\tilde{P}_t - mc_{t+k})Y_{i,t+k}}{P_{t+k}} \right] - \frac{c}{2}\left(\frac{\tilde{P}_t}{P_t} - \frac{\tilde{P}_{t-1}}{P_{t-1}} \right)^2 Y_t \tag{7}$$

subject to the demand function described by equation (3) and by equation (5). mc_t represents real marginal cost. Firm i's profit depends on $\tilde{P}_t$ as long as it cannot re-optimize its price. The average duration of price contracts is calculated as $1/(1-\theta)$ in the Calvo model. When the quadratic price adjustment cost is zero, the above problem leads to the NKPC based on the assumption that firms completely adjust their prices whenever they reset them.

The first order condition of the constrained maximization problem given in (7) can be rewritten in terms of real values as follows:

$$E_t \sum_{k=0}^{\infty} (\theta\beta)^k \left[(\tilde{p}_t \tilde{X}_{t+k} - mc_{t+k})(\tilde{p}_t \tilde{X}_{t+k})^{-a} Y_{t+k} \right] - c(\tilde{p}_t - \tilde{p}_{t-1})Y_t \tag{8}$$

where $\tilde{X}_{t+k} \equiv 1/\pi_{t+1}\pi_{t+2}....\pi_{t+k}$, $\tilde{p}_t \equiv \tilde{P}_t / P_t$ and $a \equiv \lambda_f /(\lambda_f - 1)$. Log-linearization of (8) gives rise to:

$$E_t \sum_{k=0}^{\infty} (\theta\beta)^k \left[(\hat{p}_t + \hat{X}_{t+k} - \hat{m}c_{t+k}) \right] = \frac{c}{1-a}(\hat{p}_t - \hat{p}_{t-1}) \tag{9}$$

where $\hat{p}_t$ $\hat{X}_{t+k}$ and $\hat{m}c_{t+k}$, respectively, denote the log-deviation of $\tilde{p}_t$ $\tilde{X}_{t+k}$ and mc_{t+k} from their steady state values. The equality in equation (9) results from the trade-off between the marginal cost (r.h.s) and the marginal benefit (l.h.s.) from changing prices after considering future inflation and real marginal cost. A rise in prices has a positive effect on profit, whereas an increase in future inflation or in real marginal cost of labor has a negative impact on profit. The marginal cost of adjusting prices associated with variable costs increases with the size of the price adjustment.

Log-linearizing the Calvo pricing described by equation (5) yields the following equation:

$$\hat{p}_t = \frac{\theta}{1-\theta}\hat{\pi}_t \tag{10}$$

Thus, $\hat{p}_t - \hat{p}_{t-1} = \theta/(1-\theta)(\hat{\pi}_t - \hat{\pi}_{t-1})$. Plugging this into equation (9), rearranging the terms, and deleting the hat on the variables for convenience yield:

$$\pi_t = \Lambda_1 E_t \pi_{t+1} + \Lambda_2 \pi_{t-1} + \lambda mc_t \tag{11}$$

where $\Lambda_1 \equiv \eta/\tau, \Lambda_2 \equiv \kappa/\tau, \lambda \equiv (1-\theta\beta)/\tau, \tau \equiv [\theta/(1-\theta) + (1+\theta\beta)\kappa], \eta \equiv \theta\beta[1/(1-\theta) + \kappa],$ $\kappa \equiv c(1-\theta\beta)\theta/(a-1)(1-\theta).$

The derivation of the new Phillips curve reveals how the two sources of price stickiness considered endogenously generate a lagged inflation term. Since prices stickiness arise from both the size and frequency of price adjustments, current price depends on lagged price twice and, hence, a lagged inflation term is endogenously generated from the optimizing behavior of the firms.

The proposed model nests the NKPC as a particular case. When the quadratic cost of price adjustment is zero, our model collapses into the NKPC of the form:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\theta)(1-\theta\beta)}{\theta} mc_t. \tag{12}$$

The NKPC is often criticized due to the failure to generate the observed inflation persistence and hump-shaped responses. Ball (1994) shows that the NKPC implies that announced, credible disinflation policy can cause booms rather than recessions. These troubles arise because the inflation rate changes quickly due to the role of inflation expectations. Announced, credible disinflation policy gives rise to a fall in inflation expectations, which in turn leads to an immediate drop in the inflation rate, causing real money balance to increase. In this way, credible disinflation policy is able to cause a boom rather than a recession. In this respect, it is important to generate a gradual, hump shaped response of inflation to a monetary shock. A lagged inflation term plays an important role in avoiding such a problem because it makes inflation move slowly in response to a monetary policy shock.

2.3 Bayesian Estimation of the DSGE Model

In this section, we introduce a small scale DSGE model and present evidence supporting the presence of dual price stickiness in terms of estimation results and the ability to replicate the observed “reverse dynamic" cross-correlation between the output gap and inflation. In addition, we show that the dual price stickiness model is able to match the observed inflation persistence.

2.3.1 A Small Scale DSGE Model

We consider a small scale DSGE model consisting of three equations: the IS curve, the Phillips curve, and the Taylor rule. The IS curve is derived from maximizing the expected present discounted value utility function, $U(C_t, 1 - N_t) = \frac{C_t^{1-1/\sigma}}{1-1/\sigma} - \frac{N_t^{1-1/\varphi}}{1-1/\varphi}$, subject to the budget constraint, $C_t + \frac{B_t}{P_t} = \frac{W_t}{P_t} N_t + (1+i_{t-1})\frac{B_{t-1}}{P_t} + \Pi_t$, where C_t is the composite consumption good, N_t is hours worked, Π_t is real profits received from firms, and B_t is the nominal holdings of one-period bonds that pay a nominal interest rate i_t.[5] The IS curve is:

$$y_t = E_t y_{t+1} - \sigma(i_t - E_t \pi_{t+1}) + \varepsilon_t^y \tag{13}$$

where y_t and i_t denote the output gap and the nominal interest rate, respectively. The disturbance term, ε_t^y is the preference shock, which is assumed to follow the AR(1) process, $\varepsilon_t^y = \delta_y \varepsilon_{t-1}^y + \nu_t^y$ with $\nu_t^y \sim N(0,\ \sigma_y^2)$.

When the production function is assumed to be $Y_t = A_t N_t$, the relationship between real marginal cost and the output gap is given by $mc_t = \left(\frac{1}{\sigma} + \varphi\right) y_t$. Replacing real marginal cost with the output gap leads to the output gap version of the Phillips curve:

$$\pi_t = \Lambda_1 E_t \pi_{t+1} + \Lambda_2 \pi_{t-1} + \lambda_1 y_t + \varepsilon_t^\pi \tag{14}$$

where $\lambda_1 = \left(\frac{1}{\sigma} + \varphi\right)\lambda$. We interpret the disturbance term ε_t^π as the cost-push shock, which follows a normal distribution, $N(0, \sigma_\pi^2)$. The Taylor rule is of the form:

[5] see Walsh (2003) for more details.

$$i_t = \rho i_{t-1} + (1-\rho)(\alpha_\pi E_t \pi_{t+1} + \alpha_y y_t) + \varepsilon_t^i \qquad (15)$$

where the interest rate shock ε_t^i follows a normal distribution, $N(0, \sigma_i^2)$, and ρ measures the degree of the interest rate smoothing in monetary policy. We assume that policy makers are forward-looking in stabilizing inflation. However, they conduct monetary policy in response to current economic activity. The Federal Reserve's responses to inflation and the output gap are determined by α_π and α_y.

2.3.2 Estimation Results

2.3.2.1 Data and Priors

In order to estimate the DSGE model, we employ the output gap measure from the Congressional Budget Office (CBO), the effective Federal Funds Rate obtained from the Federal Reserve Bank of Saint Louis, and we use the implicit GDP deflator from the Bureau of Labor Statistics to calculate the inflation rate. The data range from 1960:1 to 2007:4.

The DSGE parameters are collected in $\Phi = \{\theta, c, \sigma, \varphi, \rho, \alpha_\pi, \alpha_y, \delta_y, \sigma_\pi, \sigma_y, \sigma_i\}$. The priors on the model parameters are summarized in Table 2.1. We set a, the parameter that measures the degree of market power of each intermediate goods-producing firm to be 6. This implies a steady state markup of price over marginal cost of 20% as in Rotemberg and Woodford (1992) and Ireland (2001). We also set β and φ to be 0.99 and 1.5, respectively. We use 40,000 draws to estimate the DSGE model, but only start calculating posterior features after 20,000 draws. We use the Metropolis-Hastings algorithm to obtain the maximum likelihood estimates.

2.3.2.2 Results: Frequency and Size of Price Adjustments

Table 2.1: Bayesian Estimation for DSGE Model

Parameters	Prior distribution	Prior mean	Prior St. dev.	Posterior mean	95% of confidence interval
θ	beta	0.5	0.10	0.75	[0.69, 0.82]
c	normal	30	30.0	171.0	[143.2 , 197.4]
σ	invg	1	∞	0.16	[0.13 , 0.18]
ρ	beta	0.7	0.05	0.72	[0.69 , 0.76]
α_π	normal	1.5	0.25	1.72	[1.58 , 1.86]
α_y	normal	0.5	0.1	0.48	[0.33 , 0.62]
δ_y	beta	0.5	0.2	0.94	[0.91 , 0.97]
σ_π	invg	0.1	2	0.73	[0.66 , 0.80]
σ_y	invg	0.1	2	0.19	[0.15 , 0.22]
σ_i	invg	0.1	2	1.36	[1.23 , 1.48]

Note: This Table shows Bayesian estimation results for DSGE model. Equation (13) is adopted for the IS curve. Log likelihood is -971.9. The number of draws is 40000. We keep 20000 draws. Metropolis-Hastings algorithm is used. Estimates cover the sample period from 1960Q1 to 2007Q4.

The posterior mean of θ, which is a measure of the degree of nominal rigidity, is estimated to be 0.75, which implies that only a quarter of the firms is able to reset their prices to optimize profit while the remaining keep their prices unchanged. The estimate also implies that the average length of time between price changes is 4 quarters. Klenow and Malin (2009) report that prices do not change continuously, but instead change on average at least once a year.[6] Álvarez (2008) investigate firms in 18 countries and, based on surveys of the distribution of the number of price changes, find that prices generally change around once a year, with a median of 11.1 months. This paper also finds that the median duration of price changes is only 20% for consumer prices and 21% for producer

[6] Klenow and Malin (2008) find that there is heterogeneity in the price changes across sectors. In particular, durables change prices more frequently than nondurables and services; and nondurables change prices more often than services.

prices. Álvarez et al (2006) find that price changes are even less common in the Euro area. On average, in a given month only 15.1% of prices change, and the average length of time between price changes is from 4 to 5 quarters. These figures mean that price adjustment in the euro area is less frequent than in the US. Finally, Eichenbaum, Jaimovich and Rebelo (2009) propose a method to measure stick "reference" prices among shorter-lived new prices, and find that they change only every 11.1 months. Klenow and Malin (2008) generalize their definition of reference prices for the U.S. CPI and find that that the weighted median duration of reference prices is 10.6 months.[7]

The results from our proposed model regarding the frequency of price adjustments are, thus, very much in agreement with microdata evidence, as well as the with the estimated average duration of price spells. On the other hand, models that predict continuous (100%) price changes such as staggering contracts with general indexation, or sticky information models are in contrast with the low frequency of price adjustment that is observed in every country and with different data sources.

The posterior mean of the parameter associated with the quadratic adjustment cost, c, is estimated to be 171.0, with the 95% confidence interval ranging from 143.2 to 197.4, indicating that this estimate is statistically different from zero. The results are in accord with microdata evidence on the size of price adjustments. The general finding is that price changes are mostly smaller than the size of aggregate inflation (see e.g. Dhyne et al. 2006, Alvarez et al (2006), Klenow and Kryvstov 2008, etc.) More specifically, Klenow

[7] The reference price for each UPC as defined by Eichenbaum et al (2009) corresponds to the modal price in each quarter using weekly price data from a large U.S. supermarket chain. Klenow and Malin (2008) define the reference price in each month as the most common price of an item in the 13-month window centered on the current month.

and Kryvtsov (2008) show that in the U.S. 44% of consumer price changes are smaller than 5%, 25% are smaller than 2.5%, and 12% are smaller than 1%, in absolute value. Vermeulen et al. (2007) study the Euro area and find that a quarter of producer price changes is smaller than 1% in absolute value, and that the mean price change is only 4%.

The parameters associated with both Calvo-type price stickiness and Rotemberg (1982)'s quadratic costs are highly statistically significant. Thus, the estimation results indicate that the null hypothesis of no price rigidities with respect to the frequency and size of price adjustment is rejected, favoring the dual price stickiness model over the NKPC based only on one or or the other type of rigidity separately.

The estimated monetary policy parameters ρ, α_π, and α_y are similar to the ones reported in the literature. The parameter measuring the degree of interest rate smoothing is estimated to be 0.72. The estimate of α_π associated with the Fed's response to inflation expectations is 1.72. The parameter related to the response of the Fed to the output gap is estimated to be 0.48.

2.3.2.3 Robustness of Results

For a potential model misspecification of the IS curve, we consider the following form of the IS curve:

$$y_t = \mu_y E_t y_{t+1} + (1-\mu_y) y_{t-1} - \sigma(i_t - E_t \pi_{t+1}) + \varepsilon_t^y . \qquad (16)$$

Equation (16) nests (13) as a special case. The rationale for including the lagged output gap can be found, for example, in habit in consumption (Fuhrer 2000). Table 2.2 reports estimation results when we replace equation (13) with (16).

Table 2.2: Bayesian Estimation of DSGE Model: With Eq. (16)

Parameters	Prior distribution	Prior mean	Prior St. dev.	Posterior mean	95% of confidence interval
θ	beta	0.5	0.10	0.77	[0.70, 0.83]
c	normal	30	30.0	166.5	[140.3 , 195.1]
σ	invg	1	∞	0.14	[0.12 , 0.17]
μ_y	beta	0.5	0.1	0.70	[0.63 , 0.78]
ρ	beta	0.7	0.05	0.70	[0.66 , 0.74]
α_π	normal	1.5	0.25	1.80	[1.66 , 1.93]
α_y	normal	0.5	0.1	0.46	[0.32 , 0.59]
δ_y	beta	0.5	0.2	0.94	[0.91 , 0.97]
σ_π	invg	0.1	2	0.75	[0.67 , 0.82]
σ_y	invg	0.1	2	0.17	[0.14 , 0.21]
σ_i	invg	0.1	2	1.36	[1.23 , 1.49]

Note: This Table shows Bayesian estimation results for DSGE model. Equation (16) is adopted for the IS curve. Log likelihood is -973.1. The number of draws is 40000. We keep 20000 draws. Metropolis-Hastings algorithm is used. Estimates cover the sample period from 1960Q1 to 2007Q4.

The results obtained are very similar. The posterior mean estimate of θ is 0.77, implying that the average duration between price changes is again about 4 quarters. The posterior mean of c is estimated to be 166.5, ranging from 140.3 to 195.1. Thus, the presence of the two sources of price stickiness is supported once again. The estimate of μ_y is 0.70, indicating that the contribution of expectations to output gap dynamics is relatively more important than lagged output gap. The other common parameters are also stable across the different specifications.

2.3.3 Dynamic Correlation Between the Output Gap and Inflation

Taylor (1999) stresses that the ability to characterize the "reverse dynamic" relationship between the output gap and inflation is a yardstick of success of monetary models. In this respect, it is worth investigating whether the dual price stickiness model is able to replicate the observed "reverse dynamic" cross-correlation between the two variables. We also examine the role of a lagged inflation term in generating the observed dynamic cross-correlation between the two variables.

Figure 2.1: Dynamic Correlation Between the Output Gap and Inflation

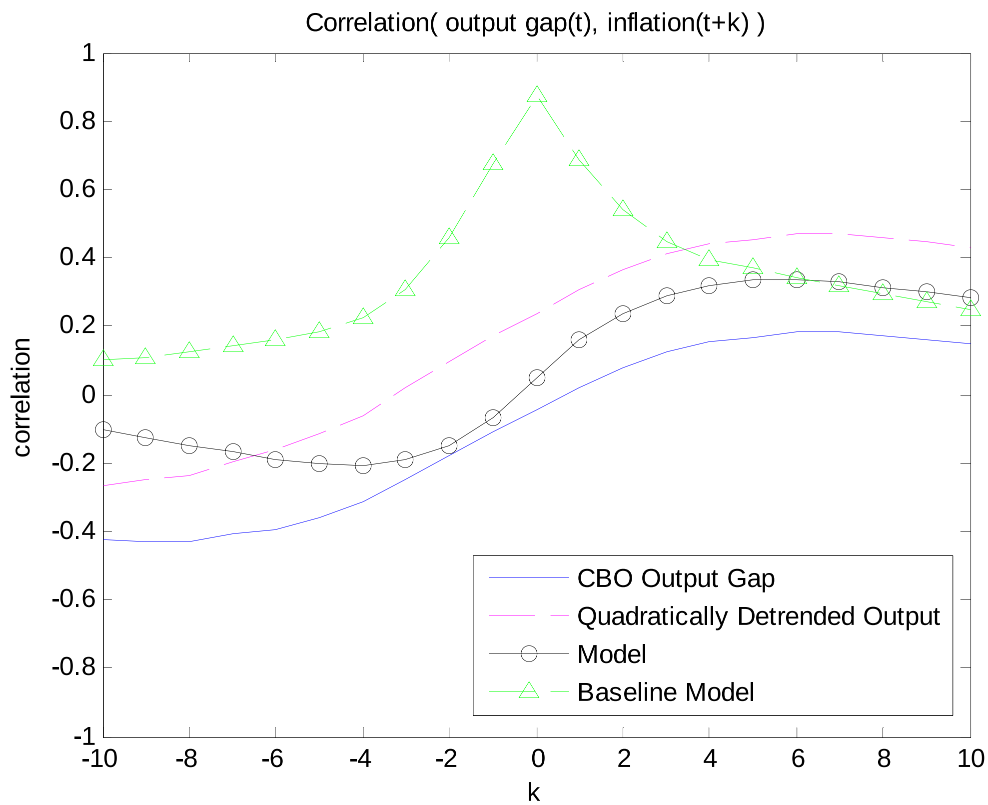


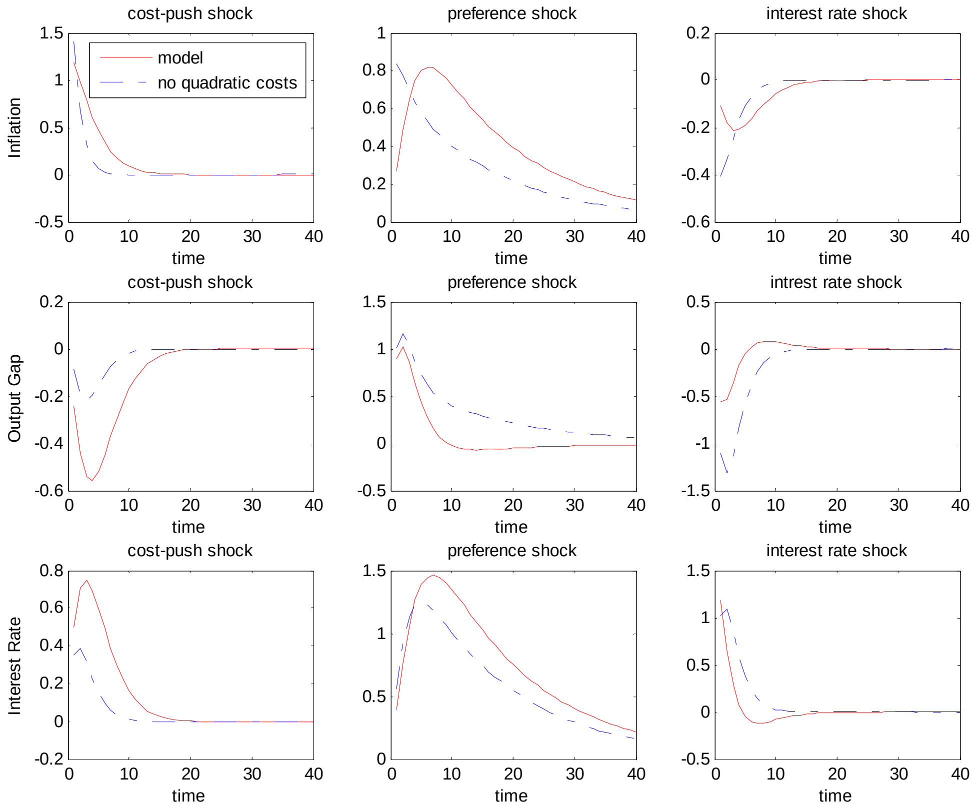
Figure 2.1 displays the correlation between inflation and output gap obtained from the estimates of the DSGE model reported in Table 2.2, the DSGE model estimated assuming that the quadratic adjustment cost is zero (the baseline NKPC model), and the observed correlation in data between inflation and output gap. As highlighted by Gali and Gertler (1999), the current output gap tends to be positively related with future inflation, whereas

the past inflation tends to be negatively associated with current output gap. Figure 2.1 shows that the DSGE model (the line with circles) performs well in replicating the observed dynamic correlation between inflation and the output gap -- a rise in current inflation is associated with a subsequent decline output gap, and a rise in output gap signals a rise in future inflation. Note that when we collapse the dual price stickiness model to the baseline NKPC assuming no quadratic costs, the model fails to predict the observed reverse dynamic correlation -- lagged output gap (inflation) is positively associated with future inflation (output gap). This evidence indicates that the lagged inflation term plays a crucial role in accounting for the output-inflation dynamics. In our model, although firms optimize their prices at discrete time intervals, the newly adjusted price sluggishly responds to changes in economic conditions due to quadratic costs of adjustment. Hence, inflation moves slowly. In this way, the dual price stickiness model is able to predict a delayed, gradual effect of the output gap on inflation.

2.3.4 Impulse Response and Autocorrelation Functions

This section investigates whether the estimated DSGE model is able to generate plausible impulse response functions and inflation persistence. The impulse response functions are generated using the estimates from Table 2.2. We also report the implied autocorrelation functions of inflation by the DSGE model. The first column of Figure 2.2 displays the responses of inflation, output gap, and interest rate to an one-standard-deviation cost-push shock. The cost-push shock leads to an immediate increase in inflation, and its effect dies off 10 quarters later. The Fed raises the interest rate in response to higher inflation, which causes the output gap to decrease. The shock has the

Figure 2.2: Impulse Response Functions

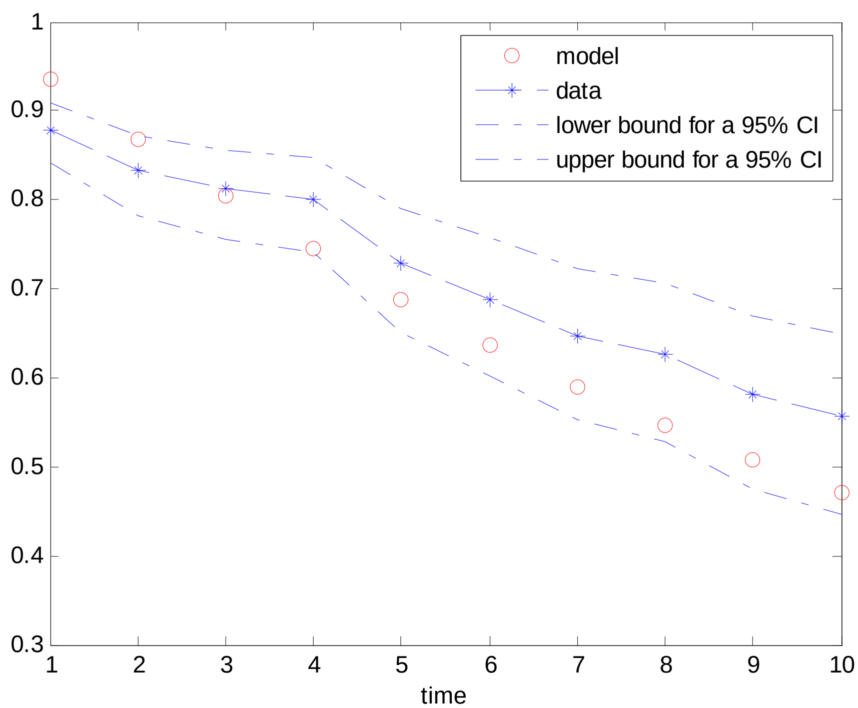


largest impact on output gap after around 4 quarters. The effects of a one-standard-deviation preference shock on the variables are shown in the second column of Figure 2.2. The shock results in an increase in inflation and in the output gap and, therefore, in the interest rate. In response to an increase in inflation and the output gap, the Fed raises the interest rate to stabilize the economy.

Turning to a one-standard-deviation monetary policy shock, we observe a delayed, gradual response of inflation following the shock. It is well-known in the literature that the baseline NKPC fails to generate a hump-shaped response of inflation to a monetary policy shock. The monetary policy shock has a postive effect on the interest rate and a negative impact on inflation and output.

We investigate whether the dual price stickiness model is able to match the observed inflation persistence. Figure 2.3 presents the autocorrelation function generated by the DSGE model and the data.

Figure 2.3: Autocorrelation Function



As shown in the Figure, the model-implied autocorrelation function closely matches the observed inflation persistence. As discussed in the literature (e.g., Gali and Gertler 1999), inflation persistence plays an important role in explaining costly disinflation. In addition, inflation persistence generated from a lagged inflation term leads to disinflation associated with recessions -- not with booms -- since inflation moves sluggishly.

2.3.5 Subsample Estimation Results

In this section, we reestimate the DSGE model using subsamples to check robustness of the results. The sample is divided between the subperiods before and after the early 1980s and reestimate the parameters of the DSGE model using the extended IS curve (full sample reported in Table 2.2). The sub-sample estimates of the DSGE model are reported in Table 2.3.

Table 2.3: Bayesian Estimation of DSGE Model: Subsample Analysis

Parameters	Pre-1979 estimate		Post-1983 estimate	
	Posterior mean	95% of confidence interval	Posterior mean	95% of confidence interval
θ	0.73	[0.65, 0.82]	0.79	[0.70, 0.88]
c	99.7	[70.9 , 128.3]	126.8	[90.3 , 164.1]
σ	0.23	[0.17 , 0.28]	0.54	[0.45 , 0.63]
μ_y	0.65	[0.56 , 0.75]	0.20	[0.16 , 0.24]
ρ	0.66	[0.61 , 0.72]	0.75	[0.71 , 0.79]
α_π	1.33	[1.22 , 1.44]	2.46	[2.27 , 2.64]
α_y	0.47	[0.33 , 0.61]	0.33	[0.20 , 0.48]
δ_y	0.92	[0.87 , 0.96]	0.98	[0.97 , 1.00]
σ_π	0.91	[0.77 , 1.05]	0.69	[0.59 , 0.79]
σ_y	0.21	[0.15 , 0.27]	0.14	[0.10 , 0.17]
σ_i	0.82	[0.70 , 0.93]	0.62	[0.53 , 0.72]
Loglikelihood	-404.2		-395.8	

Note: This Table shows Bayesian estimation results for DSGE model. The number of draws is 40000. We keep 20000 draws. Metropolis-hastings algorithm is used. Estimates cover the sample period from 1960Q1 to 1979Q4 and 1983Q1 to 2007Q4.

The parameter θ does not change much across sub-samples. It is estimated to be 0.73 for the pre-1979 period and 0.79 for the post-1983 period. On the other hand, the estimate of c is 99.7 for the first sample and 126.8 for the second sample. In addition, these estimates are lower than those obtained using the full sample. That is, the coefficient associated with quadratic adjustment costs is estimated to be higher in the post-1983 era. This moderate change in the parameter c implies that the costs of changing prices may be higher during the low inflation period. Overall, the presence of dual price stickiness is again confirmed by the data, showing that our results are robust across samples.

Turning to the parameters of the Taylor rule, the estimates measuring the degree of the interest rate smoothing are lower in the first sample period. The finding indicates a drastic change in the estimate of α_π showing that the Fed has responded more aggressively to expected future inflation in the second sample period. These results are consistent with Clarida, Gali and Gertler (2000). On the other hand, the response of the Fed to current economic activity is estimated to be slightly lower in the second sample, compared to the first one. Finally, the estimated standard deviations of the shocks are smaller in the second sample, which is consistent with the increased stabilization of the economy during the Great Moderation period.

2.4 Conclusion

The most common way to generate inflation persistence in the literature is to assume that a fraction of firms reset their prices by automatic indexation to past period's inflation rate (e.g., Gali and Gertler 1999, Cristiano, Eichenbaum and Evans 2005, Smets and Wouters 2007, Justiniano and Primiceri 2008). These ways have been often criticized due to automatic indexation that is designed to directly incorporate a lagged inflation term into the Phillips curve to generate inflation persistence without microfoundations (Woodford 2007 and Chari, Kehoe, and McGrattan 2009). In response to this challenge, this paper builds the dual price stickiness model, in which a lagged inflation term is endogenously generated in the model. The dual price stickiness model, in contrast to the NKPC, is satisfactorily able to explain the observed dynamic behavior between the output gap and inflation. This model provides a theoretical foundation why the current output gap has a delayed, gradual impact on inflation as the observed dynamic correlation between the output gap and inflation shows. Such a effect is produced because even the chosen new price at discrete time intervals is partially adjusted due to quadratic costs. Evidence on the dual price stickiness with respect to the frequency and size of price adjustment are robust across samples. Overall, our results favor the dual price stickiness model over the new Keynesian Phillips curve.

Chapter 3

Dual Wage Stickiness: Theory and Some Evidence

3.1 Introduction

The dynamic correlation that has been observed between wage inflation and real output indicates that current output is negatively related to past wage inflation, while also being positively correlated to future wage inflation. Taylor (1999) stresses that the ability to explain the reverse dynamic correlation between price inflation and real output is an important "measure of success" of a sticky price model. Similarly, the ability to explain the reverse dynamic correlation between wage inflation and real output could be considered to be a success of a sticky wage model.

Wage dynamics have important implications for households, firms, and for monetary and fiscal policies. The goal of this chapter is to construct a wage inflation equation that is able to provide not only an improved characterization of wage dynamics for policy analysis, but also to replicate the reverse dynamic correlation between wage inflation and real output. In particular, this chapter proposes a novel framework that successfully combines two types of wage stickiness.

Staggered wage contract models based on Calvo (1983) have been widely employed in the literature (e.g., Kollmann 1996; Erceg, Henderson and Levin 2000; Christiano, Eichenbaum and Evans 2005; Smets and Wouters 2007; Justiniano and Primiceri 2008; among several others). These models assume that a fraction of workers completely adjust their wages at discrete time intervals in response to changes in the economic environment. However, the assumption that workers are able to adjust their wages as much as they would like to when they periodically negotiate their wage contracts is not realistic. Because wages are determined through the interaction between workers and firms, the workers' ability to fully adjust their wages can be limited. As a consequence, although workers may re-optimize their wages at certain time intervals, they are only partially adjusted in response to changes in economic conditions.

In this respect, this chapter investigates the existence of dual types of wage stickiness: one with respect to the frequency of wage adjustments and another with respect to the magnitude of those adjustments. More specifically, the proposed model introduces, in addition to Calvo-type wage stickiness, the quadratic costs of wage adjustment that make it costly for current wages to deviate from previous period wages. In this way, workers' limited abilities to fully adjust wages are formally taken into consideration. Although both the Calvo-type wage setting and the quadratic costs of wage adjustment play a similar role in generating wage stickiness, their implications are different with respect to the frequency and size of wage adjustments. That is, while Calvo-type wage stickiness is related to the timing/frequency of wage adjustment, the quadratic costs of wage adjustment are associated with the magnitude of wage changes when workers reset their wage contracts. In the proposed dual wage stickiness model, current wage inflation depends on past and expected future wage inflation, current and expected future price inflation, and wage markup.[8] The lagged wage inflation term is introduced into the model due to these two sources of wage stickiness.

In order to investigate the presence of dual wage stickiness and wage inflation dynamics, this chapter builds a dynamic stochastic general equilibrium (DSGE) model that allows workers and firms to optimally set their wage contracts and prices, respectively, in monopolistically competitive labor and goods markets. The central bank conducts monetary policy using the Taylor rule. The proposed model extends the baseline sticky wage model by Erceg, Henderson and Levin (EHL baseline, 2000) to include our proposed feature, dual wage stickiness.[9]

The DSGE model is estimated using Bayesian techniques. The findings favor the dual wage stickiness model over the baseline model based on only Calvo-type wage stickiness. First, although households reset their wages at certain intervals of time, estimates of the parameter associated with the quadratic costs of wage adjustment are significantly different from zero, rejecting the null hypothesis of no quadratic wage adjustment costs. Second, the marginal likelihood clearly supports the dual wage stickiness model over the baseline model, which relies only on Calvo-type wage stickiness (Calvo 1983). The inclusion of quadratic wage adjustment costs yields a substantial improvement of the model in fitting the data. Third, the observed dynamic correlation between wage inflation and real output can be better replicated under dual

---

[8] Wage markup is defined as the difference between the real wage rate and the marginal rate of substitution between consumption and leisure.

[9] While the Calvo-cum-wage-indexation model by Christiano, Eichenbaum and Evans (2005) assumes that wages change continuously, the proposed model assumes that wages are adjusted infrequently. The Calvo-cum-wage-indexation model allows all workers to adjust their wages optimally or automatically in any given period.

wage stickiness. While the baseline model fails to generate the expected lead-lag relationship between wage inflation and real output, the introduction of quadratic costs of wage adjustment in the proposed model yields the observed negative (positive) relationship between past (future) wage inflation and real output. The dual wage stickiness model is able to explain the fact that a rise in current output is associated with a subsequent increase in wage inflation. Overall, the presence of dual sticky wage stickiness helps provide an improved explanation of wage inflation dynamics.

In order to check the stability of the structural parameters, the DSGE model is estimated using two subsamples. The full sample, from 1960:1 to 2007:4, is divided before and after 1980. The findings demonstrate that while most of the structural parameters are stable over subsamples, there are substantial changes in monetary policy along the lines of the ones found in Clarida, Gali and Gertler (2000). In particular, the response of the Federal Reserve to inflation is different across subsamples.

The rest of this chapter is organized as follows. The sticky wage model is derived in the next section assuming the two types of wage stickiness. The wage equation in the DSGE model is derived from the solution to the households' problems. Section 3.3 presents the empirical results from estimation of the proposed DSGE model using Bayesian techniques. Evidence on dual wage stickiness is provided in terms of the marginal likelihood and dynamic correlations of the variables. In addition, this section investigates robustness of the estimation results to sub-sample analysis. The last section concludes this chapter.

3.2 A Model Economy

3.2.1 Households

There is a continuum of households indexed by $i \in [0,\ 1]$. Following EHL (2000), this chapter assumes that each household is a monopolistic supplier of a differentiated labor service. A representative labor aggregator combines households' differentiated labor services into units of labor for use in the production sector. While each household has monopoly power over a differentiated labor service, the labor aggregator faces perfect competition, making zero profits.[10] Each household chooses the amount of consumption, the amount of contingent claims and set his/her wage. The intertemporal utility function of household i is given by

$$E_t \sum_{k=0}^{\infty} (\beta)^k \left[\frac{1}{1-1/\sigma} C_{i,t+k}^{1-1/\sigma} - H_{i,t+k} \right]. \tag{1}$$

Household i maximizes the expected utility function subject to the budget constraint,

$$C_{i,t} + \frac{J_{t,t+1} B_{i,t+1}}{P_t} + \frac{C}{2} \left(\frac{W_{i,t}/P_t}{W_{i,t-1}/P_{t-1}} - 1 \right)^2 I_{i,t} = \frac{W_{i,t}}{P_{t-1}} H_{i,t} + \frac{B_{i,t}}{P_t} + \frac{\Pi_{i,t}}{P_t} \tag{2}$$

where $C_{i,t}$, $H_{i,t}$, $B_{i,t}$, $P_{i,t}$, $W_{i,t}$ and $\Pi_{i,t}$ denotes real consumption, hours worked, state-contingent claims, the price index, wages, and a share of profits, respectively. $J_{t,t+1}$ is the price of state contingent claims that pays one dollar if a particular state of nature is realized in period $t+1$. Each household owns an equal share of all firms and receives equal profit ($\Pi_{i,t}$) from firms. The indicator function $I_{i,t}$ is equal to 1 when household i

[10] As in Erceg, Henderson and Levin (2000), this chapter does not assume capital. See EHL for details.

resets its wage contract and otherwise is equal to zero. The indicator function is introduced because of the assumption that each household keeps its wage contract unchanged with a constant probability α_w in any given period. In the Calvo economy, a constant fraction $(1-\alpha_w)$ of households that receive a random wage-change signal are allowed to reoptimize their wage contracts every period, whereas the remaining households keep their wages unchanged in any given period.[11]

The quadratic costs of wage adjustment appear in the budget constraint to restrict each household's ability to fully adjust its wages in response to changes in economic environment. The costs of wage adjustment increase with the magnitude of the adjustment, resulting in sticky wages. It is worth emphasizing that households face the quadratic costs of adjusting wages only when they reset their wage contracts.[12]

In the literature, wage rigidities are typically introduced through either a Calvo-type staggered wage setting (e.g., EHL 2000) or the quadratic wage adjustment costs (e.g., Kim 2000). Since these modeling approaches play the same role in making wages sticky, within the literature either one or the other is considered to be a potential source of wage stickiness. However, despite the similarity between the two approaches in terms of wage stickiness, they reflect different dimensions of the decision problems that households face. Households are likely to face two problems regarding wage setting in the micro level: (1) when to change wages, (2) how much to change wages. The second problem is especially

[11] The timing/frequency of wage changes is exogenously determined in the Calvo economy. The time interval between wage changes is given by $1/(1-\alpha_w)$ on average.

[12] A more detailed discussion of the difference between the Calvo-type wage setting and the quadratic adjustment costs with respect to households' problems is provided later in section 2.2.

critical when households' abilities to fully adjust their wages are limited. This chapter attempts to limit households' abilities to adjust their wages by the use of the quadratic costs that have often been employed in the literature for the costs of investment and price adjustment. Analogous to the idea the firms have limited abilities to fully adjust prices due to the interaction between consumers and firms in the goods market, which is formally introduced through the use of quadratic adjustment costs (e.g., Rotemberg 1982), households' limited abilities that arise as a result of the interaction between firms and households in the labor market could be modeled using the quadratic costs of adjusting wages. While the first problem of households is related to Calvo-type staggered wage setting, the second problem is associated with the quadratic wage adjustment costs.

The costs of wage adjustment are evaluated with respect to real wages. We assume that the costs of adjusting wages are trivial when nominal wages rise as much as inflation increases. It is because both firms and households can think that it is likely to be fair.[13] However, when households want to increase nominal wages more than inflation, firms will resist real wage increases due to higher real labor costs.[14] Since the degree of firms' resistance will increase with the size of real wage adjustment, households can not adjust their wages as much as they might desire. The costs of adjusting wages are likely to increase with the degree of firms' resistance.

[13] When nominal wages rise as much as inflation increases, firms face the same labor costs of production because real wages remain unchanged. Households can also keep their purchasing power unchanged. In this respect, nothing is changed to both firms and households. So, the costs of wage adjustments are likely to be trivial.

[14] While increases in real wages can lead to firms' resistance, reductions in real wage can give rise to households' resistance.

Following EHL (2000), this chapter assumes that a set of complete state-contingent claims are available to households, which ensures that these agents are homogeneous with respect to holdings of contingent claims and consumption. Since such claims are able to provide complete insurance from the idiosyncratic income risk that arises from staggered wage contracts and the wage adjustment cost, households make identical decisions with respect to consumption and holdings of contingent claims.

The maximization of the objective function with respect to consumption and holdings of contingent claims subject to the budget constraint leads to the Euler equation. Log-linearizing the first order condition gives rise to the familiar IS curve that can be written as

$$y_t = E_t y_{t+1} - \sigma(r_t - E_t \pi_{t+1}) \tag{3}$$

where y_t denotes output. The nominal interest rate r_t is defined as the log-deviation of $[J_{t,t+1}]^{-1}$ from the steady state. The parameter σ measures the intertemporal elasticity of substitution.

3.2.2 Households and Wage Setting

Household i supplies a differentiated labor service $H_{i,t}$ to the labor aggregator, which combines a continuum of individual types of labor supplied into an aggregate labor service, H_t, using a CES aggregator function described by

$$H_t = \left[\int_0^1 H_{i,t}^{(\theta_w - 1)/\theta_w} di \right]^{\theta_w/(\theta_w - 1)} \tag{4}$$

where the parameter $\theta_w \geq 1$ is the elasticity of substitution across differentiated labor services. The labor aggregator purchases individual types of labor at a given wage $W_{i,t}$ for labor type i and sells each unit of labor to the production sector at the aggregate wage rate W_t. The perfectly competitive labor aggregator chooses $H_{i,t}$ to maximize its profit, taking each household's wage as given. The aggregator's objective function is described by

$$W_t \left[\int_0^1 H_{i,t}^{(\theta_w - 1)/\theta_w} di \right]^{\theta_w/(\theta_w - 1)} - \int_0^1 W_{i,t} H_{i,t} di. \qquad (5)$$

The first order condition associated with this problem leads to the demand for labor supplied by household i

$$H_{i,t} = \left(\frac{W_{i,t}}{W_t} \right)^{-\theta_w} H_t. \qquad (6)$$

Integrating (6) results in the following equation

$$W_t = \left(\int_0^1 W_{i,t}^{1-\theta_w} di \right)^{1/(1-\theta_w)} \qquad (7)$$

which shows the relationship between W_t and $W_{i,t}$. The wage rate W_t could be interpreted as the aggregate wage index.

Household i chooses its nominal wage by maximizing the objective function (1) subject to both the budget constraint and the labor demand function (6), assuming that the newly optimized wage remains in effect with the probability α_w in any given period. Solving household i's problem with respect to $W_{i,t}$ is equivalent to maximizing the objective function:

$$E_t \sum_{k=0}^{\infty} (\alpha_w \beta)^k \left[\Gamma_{t+k} \frac{W_{i,t}}{P_{t+k}} H_{i,t+k} - H_{i,t+k} \right] - \frac{C}{2} \left(\frac{W_{i,t} / P_t}{W_{i,t-1} / P_{t-1}} - 1 \right)^2 \qquad (8)$$

subject to the labor demand curve (6), delivering the same first order condition. Γ_{t+k} represents the marginal utility of income at time $t+k$. The objective function (8) clearly shows each household's problem with respect to a wage $W_{i,t}$ for labor type i.

The first order condition associated with the object function (8) leads to the same optimal wage choice for all households that adjust their wages at time t.[15] Following Calvo's scheme, the aggregate wage level evolves according to

$$W_t = \left[(1-\alpha_w) \tilde{W}_t^{1-\theta_w} + \alpha_w W_{t-1}^{1-\theta_w} \right]^{1/(1-\theta_w)} \qquad (9)$$

where $\tilde{W}_t$ is the optimal wage chosen by households at time t. Log-linearizing the first order condition from (8) yields the following equation given by

$$E_t \sum_{k=0}^{\infty} (\alpha_w \beta)^k [\tilde{w}_t - p_{t+k} - mrs_{t+k}] = \frac{\bar{c}}{1-\theta_w} [\tilde{w}_t - \tilde{w}_{t-1} - \pi_t^p] \qquad (10)$$

where $\bar{c} = C / \left[c_{ss}^{-1/\sigma} h_{ss} \frac{w_{ss}}{p_{ss}} \right]$. x_{ss} is the steady state value of x for $x = c, h, w$ and p. The lower-case variables represent the log-deviations of variables of interest from steady state values. mrs_t denotes the marginal rate of substitution between consumption and hours worked. π_t^p is defined as $p_t - p_{t-1}$.

The log-linearization of equation (9) yields $\tilde{w}_t = (w_t - \alpha_w w_{t-1}) / (1-\alpha_w)$, therefore $\tilde{w}_t - \tilde{w}_{t-1} = (\pi_t^w - \alpha_w \pi_{t-1}^w) / (1-\alpha_w)$ where π_t^w is defined as $w_t - w_{t-1}$. When plugging

[15] see Woodford (2003) for details.

$\tilde{w}_t - \tilde{w}_{t-1}$ into equation (10), a lagged wage inflation term π_{t-1}^w is endogenously introduced into the model. In this way, the derivation process reveals how the two types of wage stickiness considered generate a lagged wage inflation term. Since dual wage stickiness makes wages sticky twice, current wages can be expressed as a function of w_{t-2}, which is necessary to generate a lagged wage inflation term. The wage Phillips curve describing the wage inflation dynamics can be written as follows:

$$\pi_t^w = \Lambda_1 E_t \pi_{t+1}^w + \Lambda_2 \pi_{t-1}^w - \Psi_1 E_t \pi_{t+1}^p + \Psi_2 E_t \pi_t^p + \lambda^w [mrs_t - (w_t - p_t)] \qquad (11)$$

where $\Lambda_1 \equiv \kappa_1 / \xi, \Lambda_2 \equiv \kappa_2 / \xi, \psi_1 \equiv \tau_1 / \xi, \psi_2 \equiv \tau_2 / \xi, \xi \equiv [\alpha_w(\theta_w - 1) + \bar{c}(1-\alpha_w\beta)(1+\alpha_w^2\beta)]$, $\kappa_1 \equiv (\alpha_w \beta)[(\theta_w - 1) + \bar{c}(1-\alpha_w\beta)]$, $\kappa_2 \equiv \bar{c}(1-\alpha_w\beta)\alpha_w$, $\tau_1 \equiv \alpha_w \beta\, \bar{c}(1-\alpha_w\beta)(1-\alpha_w)$, $\tau_2 \equiv \bar{c}(1-\alpha_w\beta)(1-\alpha_w)$, and $\lambda_w \equiv (\theta_w - 1)(1-\alpha_w)(1-\alpha_w\beta)/\xi$. The wage mark-up ($\mu_t^w$) as a driving force of wage inflation is defined as the difference between the real wage and the marginal rate of substitution, that is, $\mu_t^w \equiv (w_t - p_t) - mrs_t$. A lagged wage inflation term is derived endogenously due to dual wage stickiness. When the quadratic adjustment cost is zero, the proposed model collapses into the baseline model reported in the literature,

$$\pi_t^w = \beta E_t \pi_{t+1}^w + \frac{(1-\alpha_w\beta)(1-\alpha_w)}{\alpha_w}[mrs_t - (w_t - p_t)]. \qquad (12)$$

Since the proposed model nests equation (12) as a special case, the significant estimate of $\bar{c}$ can be interpreted as a test for the presence of the quadratic costs of adjustment.

The following identity relationship between real wages and wage inflation is considered:

$$W_t - P_t \equiv W_{t-1} - P_{t-1} + \Delta W_t - \Delta P_t. \tag{13}$$

In the next subsection, the new Keynesian Phillips curve is derived for DSGE model analysis.

3.2.3 Firms and Price Setting

This chapter assumes that the economy consists of two types of firms, the representative final-goods-producing firm and a continuum of intermediate-goods-producing firms. The final-goods-producing firm purchases intermediate goods and transforms a continuum of intermediate goods, indexed by $j \in [0,1]$, into the final good using a constant returns to scale production function of the Dixit-Stiglitz form:

$$Y_t = \left[\int_0^1 Y_{j,t}^{(\theta_p - 1)/\theta_p} dj \right]^{\theta_p/(\theta_p - 1)} \tag{14}$$

where $\theta_p \geq 1$ is the constant elasticity of substitution across intermediate goods. The final good, Y_t, is produced by combining intermediate goods from the perfectly competitive, representative firm, which maximizes its profit taking the prices of intermediate goods ($P_{j,t}$, $j \in [0,1]$) as given. Maximizing profit with respect to $Y_{j,t}$ yields the demand curve that an intermediate-goods-producing firm j faces

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\theta_p} Y_t. \tag{15}$$

Integrating (15) reveals the relationship between the price of the final good and the prices of intermediate goods, which can be written as

$$P_t = \left(\int_0^1 P_{j,t}^{1-\theta_p} dj \right)^{1/(1-\theta_p)}. \tag{16}$$

The price of the final good is viewed as the aggregate price index. It is assumed that a constant fraction $(1-\alpha_p)$ of firms can reset their prices with all other firms keeping their prices unchanged in any given period. Since the intermediate-goods-producing firms choose the same price, $\tilde{P}_t = P_{j,t}$ for all j in equilibrium, the aggregate price level evolves according to

$$P_t = \left[(1-\alpha_p)\tilde{P}_t^{1-\theta_p} + \alpha_p P_{t-1}^{1-\theta_p} \right]^{1/(1-\theta_p)}. \tag{17}$$

The Calvo pricing equation implies that the aggregate price level is a function of its own lag, which can potentially cause aggregate prices to change in a sluggish manner.

The model assumes an economy with firms producing intermediate goods according to constant returns to scale, $Y_{j,t} = A_t H_{j,t}$. A_t represents the neutral technology shock, which is identical across firms. The integration of the production function with respect to j leads to $Y_t = A_t H_t$. The log-linearization of $Y_t = A_t H_t$ yields

$$y_t = a_t + h_t \tag{18}$$

where a_t and h_t are the log-deviations of A_t and H_t from steady state values, respectively. a_t follows an AR(1) process, $a_t = \delta_a a_{t-1} + v_t^a$, where v_t^a is distributed $N(0, \sigma_a)$.

The monopolistically competitive intermediate-goods-producing firm j chooses $\tilde{P}_t$ to maximize the following objective function,

$$E_t \sum_{k=0}^{\infty} (\alpha_p \beta)^k \left[\frac{(\tilde{P}_t - MC_{t+k}) Y_{j,t+k}}{P_{t+k}} \right], \qquad (19)$$

subject to the demand curve for the intermediate good j, equation (15).[16] MC_t denotes the marginal cost at time t. Combining the log-linearized version of equation (17) and the first order condition of equation (19) yields the new Keynesian Phillips curve:

$$\pi_t^p = \beta E_t \pi_{t+1}^p + \frac{(1-\alpha_p \beta)(1-\alpha_p)}{\alpha_p} mc_t . \qquad (20)$$

where mc_t is defined as the distance between the real wage and the marginal product of labor, $(w_t - p_t) - mpl_t$.

3.2.4 Monetary Policy and the Taylor Rule

The central bank conducts monetary policy using the Taylor rule to set short-term interest rates in response to inflation and output.

$$r_t = \rho r_{t-1} + (1-\rho)(\alpha_\pi E_t \pi_{t+1}^p + \alpha_y y_t) \qquad (21)$$

The parameter ρ measures the degree of interest rate smoothing in monetary policy. To stabilize the economy, the central bank adjusts nominal interest rates gradually in response to changes in the expected inflation and output. The central bank's response to inflation and output is determined by the magnitude of α_π and α_y, respectively.

3.3 Empirical Results: Bayesian Estimation

[16] Firms can face costs of adjusting wages. However, those costs of adjusting wages are not related to the newly optimized price. So, we ignore it in the above objective function.

3.3.1 The Data

The data used are quarterly U.S. series for interest rate, price inflation, real wages, hours worked, and real GDP. The sample period ranges from 1960:1 to 2007:04. Aggregate price is measured by the GDP deflator. Hours worked and nominal wages (nominal compensation per hour) are from the non-farm business sector. Real wages are obtained by dividing nominal compensation per hour by the GDP deflator. The effective federal fund rate is used to represent interest rates. The real wage and hours worked are detrended using the HP-filter. Output is detrended by the use of the Congressional Budget Office's potential output. Price inflation is defined as the quarterly log difference in the GDP deflator. Wage inflation is similarly defined as the log difference in nominal wages.

3.3.2 Empirical Model

Following Ireland (2004), in order to consider the potential misspecification in the IS and Phillips curves related to the presence of lags of price inflation and output, we replace equation (3) and (20), respectively, with:

$$y_t = \varphi E_t y_{t+1} + (1-\varphi) y_{t-1} - \sigma(r_t - E_t \pi_{t+1}) \tag{22}$$

$$\pi_t^p = \beta(\gamma E_t \pi_{t+1}^p + (1-\gamma)\pi_{t-1}^p + \frac{(1-\alpha_p \beta)(1-\alpha_p)}{\alpha_p} mc_t . \tag{23}$$

These equations nest equation (3) and (20) as a special case when φ and γ, respectively.[17] The estimates of φ and γ determine the relative importance of the lagged

[17] This dissertation reports estimation results of the DSGE model with φ (or γ) fixed to be 1. See Table 4.3.

terms in explaining output and inflation dynamics. A rationale for the lagged output term in the IS curve can be found, for example, in habit in consumption (Furher 2000), which significantly improves the model's fit to the data (e.g., Smets and Wouters 2007). A lagged price inflation term can be introduced into the Phillips curve by assuming that a fraction of firms index their prices to past inflation, as in Gali and Gertler (1999) and Christiano et al (2005).[18] Rabanal and Rubio-Ramirez (2005) use Bayesian techniques to show that the introduction of price indexation significantly improves the model's fit to the data. In line with these studies, the DSGE model is estimated with equation (23) and (24), letting the data determine the relative importance of forward-looking behavior and backward-looking behavior.

For empirical analysis, we add exogenous shocks to (11), (21), (22) and (23). Each exogenous shock can be written as follows:

$$\varepsilon_t^k = \delta_k \varepsilon_{t-1}^k + \nu_t^k \tag{24}$$

where each innovation ν_t^k is normally distributed $N(0, \sigma_k)$ for $k = w, r, y, p.$ We assume that $\delta_r = \delta_w = 0.$[19] The shocks are interpreted as the wage-push, interest rate, demand, and cost-push shocks, respectively. All of these shocks, including the technology shock, are assumed to be uncorrelated with each other.

[18] The indexation model is often criticized on the grounds that it is not consistent with microeconomic evidence. In response to this critique, Chauvet and Kim (2009) show that a lagged price inflation term is not the consequence of backward-looking behavior of firms, but rather, is due to price stickiness with respect to the frequency and size of price adjustment in a forward-looking framework.

[19] Although not reported here, the estimation results indicate that the estimates of δ_r and δ_w are not significantly different from zero.

In the dual wage stickiness model, the degree of wage stickiness is determined by the frequency and size of wage changes. Therefore, from an empirical perspective, as the estimate of $\bar{c}$ increases (decreases), the estimate of α_w may decrease (increase). In this case, the total degree of wage stickiness remains unchanged for a set of combinations with these parameter estimates. With this concern in mind, $\bar{c}$ is first estimated with α_w fixed, but changing the average duration of wage changes, $1/(1-\alpha_w)$, from 2 to 8 quarters.[20]

Figure 3.1: The Degree of Wage Stickiness and Trade-off

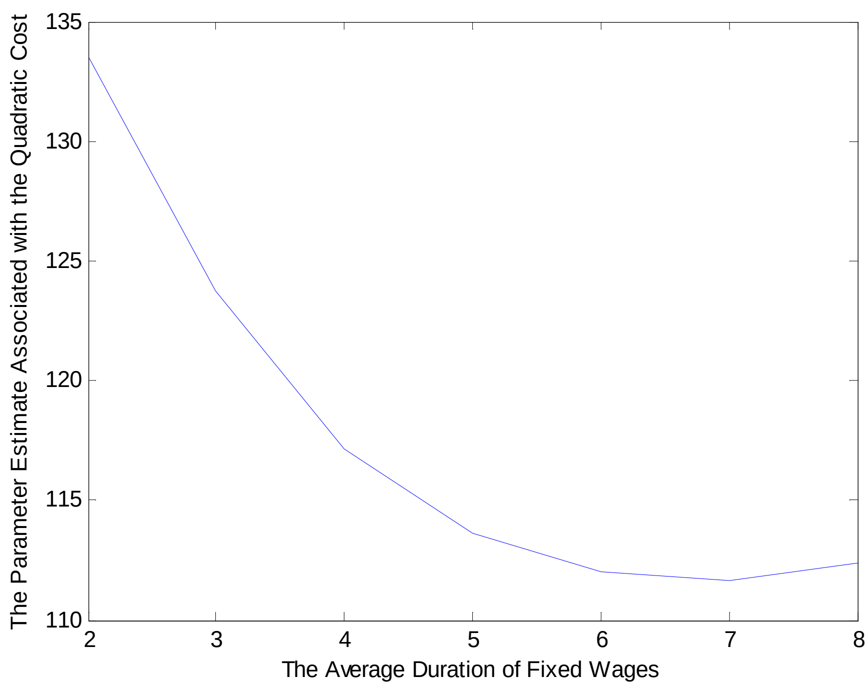


Figure 3.1 displays the estimated mode of $\bar{c}$ corresponding to an integer value of the average duration $1/(1-\alpha_w) \in [2,8]$. The standard deviation of $\bar{c}$ is estimated to be

[20] The average durations of fixed prices and wages are calculated by $1/(1-\alpha_p)$ and $1/(1-\alpha_w)$.

between 15 and 16 for all cases, implying that the estimate of $\bar{c}$ is statistically different from zero. Although it is assumed that households re-optimize their wages at discrete time intervals, the estimates of the parameter associated with the quadratic costs are significantly different from zero. This evidence of the presence of the quadratic costs of wage adjustment as an additional source of wage stickiness is quite robust to the range of the average frequency of wage changes. The estimated average duration between wage changes tends to be negatively related to the estimate associated with the quadratic costs of wage changes. The values of the log-likelihood are quite similarly computed to be between -465 to -467 for all cases considered in Figure 3.1.[21] Due to these problems, the estimates of $\bar{c}$ and α_w turn out to be sensitive to the choice of the prior distribution of these parameters. Therefore, the parameter α_w is set at 0.75, which is equivalent to assuming that households negotiate their wages every 4 quarters. After surveying both direct and indirect evidence in the literature, Taylor (1999) reports that the average frequency of wage changes is about one year. It is worth emphasizing that in the literature, in contrast to price rigidities, wages rigidities -- with respect to the frequency of wage changes -- are not controversial. In this respect, we focus on the empirical relevance of quadratic costs of wage adjustment in section 3.3 and on the Calvo-type wage stickiness in section 3.4.

3.3.3 Estimation Results

[21] Note, however, that when the assumed average frequency deviates from the range $[2, 8]$, the log-likelihood value changes significantly.

The DSGE model parameters are collected in the parameter vector, $\Phi = \{\alpha_p, \beta, \sigma, \bar{c}, \varphi, \gamma, \rho, \alpha_\pi, \alpha_y, \delta_\pi, \delta_y, \delta_a, \sigma_\pi, \sigma_y, \sigma_i, \sigma_w, \sigma_a\}$. The parameter θ_w is set equal to 6. As discussed in the previous subsection, the parameter α_w is assumed to be 0.75. A Bayesian approach is adopted to estimate the model parameters. The posterior distribution for the estimated coefficients is obtained using the Metropolis-Hastings algorithm.

Table 3.1: Bayesian Estimation of DSGE Model

Parameters	Prior distribution	Prior mean	Prior St. dev.	Posterior mean	95% of confidence interval
α_p	beta	0.66	0.05	0.83	[0.80 , 0.86]
β	normal	0.99	0.01	0.99	[0.97 , 1.00]
σ	invg	0.10	2.00	0.06	[0.05 , 0.08]
$\bar{c}$	normal	0.00	25.0	117.2	[91.6, 142.5]
φ	beta	0.50	0.10	0.66	[0.60 , 0.72]
γ	beta	0.50	0.10	0.34	[0.26 , 0.42]
ρ	beta	0.70	0.05	0.77	[0.74 , 0.80]
α_π	normal	1.50	0.15	1.70	[1.57 , 1.83]
α_y	normal	0.50	0.10	0.52	[0.38 , 0.65]
δ_π	beta	0.50	0.10	0.05	[0.01 , 0.09]
δ_y	beta	0.50	0.10	0.87	[0.83 , 0.92]
δ_α	beta	0.50	0.10	0.88	[0.84 , 0.93]
σ_π	invg	0.10	2.00	0.21	[0.19 , 0.24]
σ_y	invg	0.10	2.00	0.04	[0.03 , 0.04]
σ_i	invg	0.10	2.00	0.31	[0.28 , 0.33]
σ_w	invg	0.10	2.00	0.44	[0.40 , 0.48]
σ_a	invg	0.10	2.00	0.58	[0.53 , 0.62]

Note: Table 3.1 shows Bayesian estimation results for DSGE model. The parameter, α_w, is assumed to be 0.75, which implies that the average duration of fixed wages is 4 quarters. The number of draws is 50,000. This chapter keeps 25,000 draws. The Metropolis-hastings algorithm is used to obtain the posterior distribution. Estimates cover the sample period 1960Q1 to 2007Q4. Log-likelihood is -466.6.

Table 3.1 reports the prior and posterior distribution of each coefficient. The Calvo parameter for staggered price setting is estimated to be around 0.83, which implies that the average contract duration is about 5.9 quarters. The estimated mean of this parameter is in line with the one obtained in Gali and Gertler (1999). However, the estimated duration of fixed prices is much higher than the values reported in micro studies such as Bils and Klenow (2004) and Nakamura and Steinsson (2008). In particular, in Nakamura and Steinsson (2008), the average frequency of price changes is about 3 quarters. The posterior mean estimate of β is consistent with the conventional estimate from the literature. The elasticity of intertemporal substitution σ is 0.06, which is lower than assumed in the prior distribution. Since the Calvo wage stickiness parameter α_w is set to be 0.75, a main point is to test the null hypothesis of $\bar{c}$, that is, to test the existence of any additional sources of wage stickiness associated with the size of wage adjustment. When the null hypothesis is not rejected, the model collapses into the baseline model in which wage setters completely adjust wages whenever they reset their contracts. The prior for $\bar{c}$ is set to be zero, which is consistent with the literature. However, in contrast with the literature, the estimate of $\bar{c}$ is significantly different from its prior mean, supporting the proposed sticky wage model. As shown in Figure 3.1, these results are quite robust to a possible set of wage stickiness with respect to the frequency of wage changes.

The coefficient on output expectations (φ) is estimated to be 0.66, which implies that expectations play a relatively more important role than past output in determining current output. In contrast, the estimate of γ (0.34) suggests that past inflation in the

Phillips curve plays a dominant role in inflation dynamics. In the next subsection, this chapter further investigates the importance of these backward-looking components in terms of the value of marginal likelihood. There is a debate on the relevance of lagged inflation in determining current inflation. While Sbordone (2005), Cogley and Sbordone (2008) and others are in favor of the purely new Keynesian Phillips curve, Rudd and Whelan (2006) and several other papers in the DSGE literature provide evidence on the empirical relevance of lagged inflation in fitting the data.

Turning next to the monetary policy parameters, the parameter measuring the degree of smoothing is estimated to be 0.77. There is a range of evidence regarding the substantial degree of interest rate smoothing in the literature (e.g., Clarida, Gali and Gertler 2000). The response of the Federal Reserve to inflation is estimated to be 1.70, ranging from 1.57 to 1.83. The parameter estimate associated with the Fed's response to output is 0.52.

3.3.4 The Relative Importance of Each Friction of the Model

In the literature, the most common way of characterizing staggered wage setting is to employ a variant of Calvo's (1983) mechanism as a source of wage stickiness with respect to the frequency of wage adjustment. Deviating from the existing literature, this chapter introduces an additional source of wage rigidities through the quadratic costs of adjusting wages. The introduction of wage rigidities with respect to the size of wage adjustment, in addition to Calvo-type wage stickiness, raises the question of whether the friction is empirically relevant in explaining wage inflation dynamics. In response to this question, the contribution of the quadratic costs of wage adjustment to explaining the data is evaluated in terms of the marginal likelihood. This section also examines the contribution of other frictions to the marginal likelihood.

Table 3.2: The Relative Importance of Each of the Frictions

Parameters	Benchmark	$\varphi = 1$	$\gamma = 1$	$\alpha_p = 1$	$\bar{c} = 1$	$\alpha_w = 1/3$ $\& \bar{c} = 0$
α_p	0.83	0.84	0.88	-	0.77	0.88
α_w	-	-	-	-	0.91	-
β	0.99	0.98	0.98	0.99	1.00	0.98
σ	0.06	0.07	0.08	0.66	0.14	0.73
$\bar{c}$	117.1	110.2	100.8	117.7	-	-
φ	0.66	-	0.72	0.65	0.51	0.07
γ	0.35	0.33	-	0.14	0.55	0.26
ρ	0.77	0.80	0.76	0.80	0.78	0.77
α_π	1.70	1.61	1.84	1.80	1.63	1.65
α_y	0.51	0.53	0.53	0.42	0.51	0.76
δ_π	0.03	0.03	0.93	0.87	0.31	0.01
δ_y	0.88	0.91	0.88	0.89	0.99	0.85
δ_α	0.88	0.87	0.90	0.91	0.88	0.90
σ_π	0.21	0.21	0.05	0.96	0.23	0.22
σ_y	0.03	0.04	0.04	0.03	0.03	0.35
σ_i	0.30	0.30	0.31	0.31	0.26	0.31
σ_w	0.43	0.43	0.43	0.44	0.80	2.55
σ_a	0.57	0.57	0.57	0.57	0.58	0.57
Marginal likelihood	-466.7	-477.8	-489.0	-585.7	-590.6	-688.5

Note: This Table shows the estimates of the mode of the model parameters using Bayesian techniques. Note that α_p =1/3 (α_w =1/3) implies that the average frequency of price (wage) changes is 1.5 quarters. The estimates cover the sample period 1960Q1 to 2007Q4. In the 6th column, the present paper adopts the same prior for α_p and α_w.

Table 3.2 presents the estimates of the mode of the model parameters and the marginal likelihood to evaluate the relative importance of each friction of the DSGE model, such as the backward-looking components in the IS and Phillips curves, price and wage stickiness, by examining the relevance of each friction one at a time. The marginal likelihood is computed using the Laplace approximation.

For comparison, the second column of Table 3.2 reports the estimates of the mode of the parameters of the proposed DSGE model as a benchmark, which are quite similar to the posterior mean estimates from Table 3.1. The third column shows the estimates of the mode of the DSGE model parameters when the purely forward-looking IS curve is employed. These estimates are similar to those of the benchmark model. However, the marginal likelihood is lower than that of the benchmark model (which has a difference of about 11), indicating that the lagged output term improves the model fit.

Regarding the model with the purely forward-looking Phillips curve reported in the fourth column, the marginal likelihood significantly falls from -466.7 to -489.0. The Bayes ratio is computed to be greater than 0.47×10^{10}, which, according to Jeffreys' rule (1961), implies that the lagged inflation term leads to a significant improvement in explaining inflation dynamics. This evidence is consistent with Rabanal and Rubio-Ramirez (2005). It is worth noting that the estimate of the AR(1) coefficient (δ_{π}) significantly increases from 0.03 to 0.93 when the lagged inflation term is not included. This result suggests that when the purely forward-looking Phillips curve is adopted, the AR(1) process probably replaces the role of the lagged inflation term in describing the data.

Reducing the average duration between price changes to 1.5 quarters (that is, $\alpha_p = 1/3$) gives rise to a drastic fall in the marginal likelihood. The findings indicate that price stickiness plays a crucial role in accounting for inflation dynamics. The substantial decline in the marginal likelihood can be explained by the fact that the slope of the Phillips curve turns out to be greater than one when the parameter α_p is set to be 1/3.[22] When compared with the estimate (about 0.037) of the slope, in line with the findings of Gali and Gertler (1999), lowering the degree of price stickiness causes the slope of the Phillips curve to be unrealistic, creating a situation in which the model fails to fit the data. As a consequence, the marginal likelihood drops considerably from -466.7 to -585.7 in the 5th column when compared with the benchmark model. In this case, the estimates of both δ_π and the standard deviation of the cost-push shock turn out to be much higher than the ones from the benchmark model.

Turning to the 6th two column, the absence of the quadratic costs of wage adjustment (that is, $\bar{c} = 0$) gives rise to a significant fall in the marginal likelihood. While the Calvo-cum-wage-indexation model developed by Christiano, Eichenbaum and Evans (2005) does not significantly improve the fit of the baseline model (e.g., Rabanal and Rubio-Ramirez 2005), the dual wage stickiness model is able to provide a better fit to the data. Smets and Wouters (2007) evaluate a partial indexation model as a variant of the Calvo-cum-wage-indexation model in terms of the marginal likelihood, and find that assuming partial indexation of wages to past inflation does not lead to a significant

[22] Note that the slope of the new Keynesian Phillips curve, $(1-\alpha_p\beta)(1-\alpha_p)/\alpha_p$, increases as the degree of price stickiness (α_p) decreases.

improvement of the marginal likelihood. The estimate of the Calvo wage stickiness parameter (α_w) indicates that the average frequency of wage changes is 11 quarters. This estimate seems to be unrealistic when compared to what is found in the literature.[23] When the quadratic costs in wage setting are ignored, its contribution to the degree of wage stickiness may be absorbed by the Calvo-type wage stickiness. Overall, the findings favor the dual wage stickiness model over the baseline model based only on Calvo-type wage stickiness.

Next, in order to investigate the need of dual wage stickiness to the model dynamics, the Calvo wage stickiness parameter is reduced to 1/3, assuming that wages are adjusted every 1.5 quarters, and the parameter $\bar{c}$ related to the quadratic costs is controlled to be zero. In this way, the empirical relevance of dual wage stickiness is explored. The marginal likelihood for this case turns out to be -688.5, which is considerably lower than the one computed in the benchmark model. The findings indicate that two types of wage stickiness play an important role in fitting the model to the data. The contribution of the Calvo-type wage stickiness to the marginal likelihood can be measured by the difference between the last two columns. The difference of the marginal likelihood is about 100, providing evidence on Calvo-type wage stickiness.

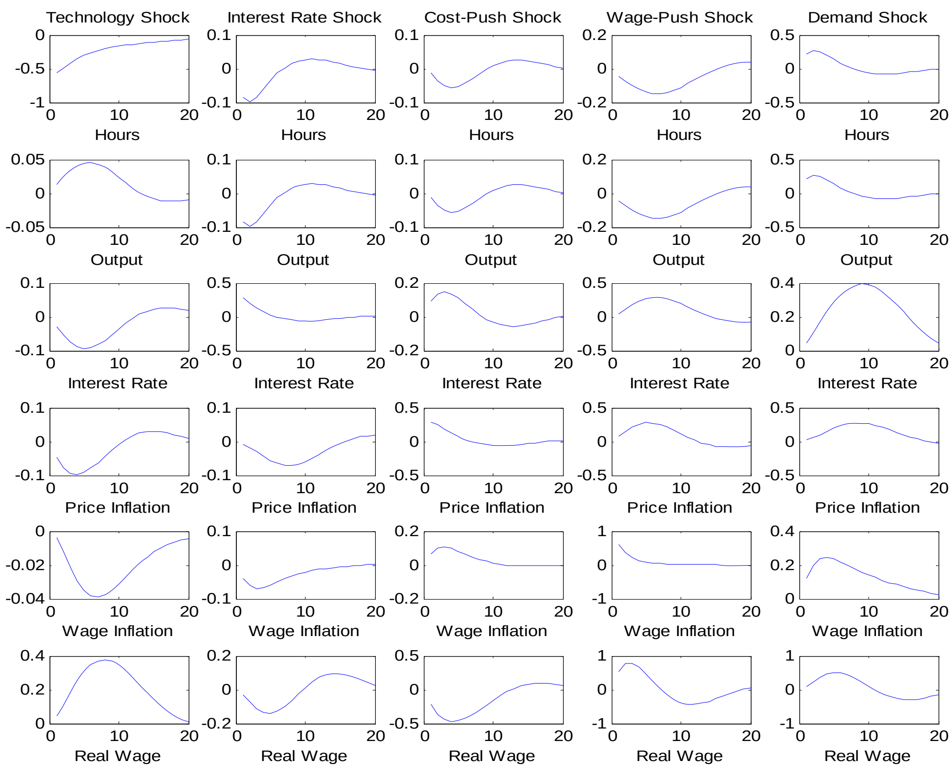
3.3.5 Impulse Response Analysis

In this subsection, the impulse responses to the various shocks using the posterior mean estimates of the DSGE model are reported in Table 3.1. Figure 3.2 exhibits the

[23] For example, Taylor (1999) provides (in)direct survey evidence of the average frequency being 4 quarters.

impulse responses of hours worked, real output, the nominal interest rate, price inflation, wage inflation and the real wage to each shock.

Figure 3.2: Impulse Response Functions



The first column of Figure 3.2 presents the responses of the endogenous variables to a one-standard-deviation technology shock. The shock causes hours worked to fall immediately, which is in line with Gali's (1999) empirical findings. However, the fall in hours worked is in contrast to implications of the standard RBC model, as addressed by Gali (1999). Following the technology shock, output starts to increase slowly. The gradual increase in real output results in an immediate fall in hours worked because the economy is able to produce more output with fewer hours due to an increase in productivity. Price inflation declines because the technology shock reduces the marginal cost of production. Both an increase in output and a relatively large decrease in inflation yield a fall in the short-term interest rate. Technology shocks also lead to a fall in wage inflation. This dissertation finds that the response of wage inflation to technology shocks is very weak in the post-1983 period (these results are available upon request). This result is consistent with the findings of Liu and Phaneuf (2007) using VARs.[24] As shown in the figure, real wages increase in response to a technology shock.

The second column exhibits the effects of a negative one-standard-deviation interest rate shock on the variables over time. This contractionary monetary policy shock leads to a decline in hours worked and real output. The monetary policy shock causes price and wage inflation to decrease as well. The same shock gives rise to a gradual decrease in real wages, as shown in VAR studies (e.g., Christiano et al 2005). The sticky price model with flexible wages fails to generate a gradual adjustment of real wages in response to monetary policy shocks. In this respect, models featuring both price and wage stickiness might be more appropriate in accounting for a gradual response of real wages to monetary policy shocks.[25] Indeed, Rabanal and Rubio-Ramirez (2005) show that models featuring both staggered price and wage contracts dominate models based only on staggered price contracts to explain the data.

[24] Liu and Phaneuf (2007) argue that the weak response of wage inflation could be a result of a change in monetary policy during the Volcker-Greenspan era.

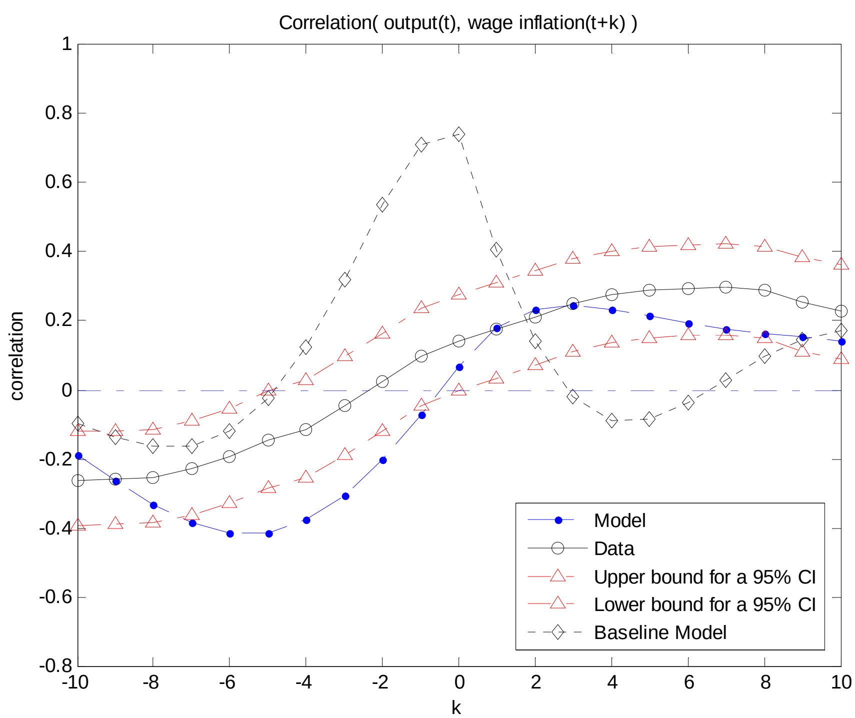
[25] Note that the sticky wage model with flexible prices implies that real wages increase in response to contractionary monetary policy shocks. This model does not explain the observed cyclical behavior of real wages.

The responses of the variables to a one-standard-deviation cost-push shock are presented in the third column. While the cost-push shock drives wages and price inflation up, the same shock reduces hours worked and real output. The rise in price inflation leads to an increase in the interest rate, allowing the Fed to stabilize price inflation. Following a cost-push shock, real wages decline due to a weaker response of wage inflation compared to price inflation. The fourth column displays the effects of a one-standard-deviation wage-push shock. The movement of hours is very similar to output, similar to responses to other kinds of shocks, excluding that to a technology shock. The wage-push shock works to reduce output and the number of hours worked over time. While the impact of cost-push shocks on output almost dies off within about 10 quarters, wage-push shocks have a relatively long-lasting effect on output. In response to wage-push shocks, the interest rate rises due to the Fed's attempt to stabilize price inflation. The wage-push shock drives real wages up as well. Finally, looking at the last column, all variables rise as a result of a one-standard-deviation demand shock. The rise in output and prices causes the interest rate to increase when facing upward pressures in both output and inflation. The interest rate stays above the steady state for more than 20 quarters following demand shocks.

3.3.6 The Dynamic Correlation Between Wage Inflation and Real Output.

Taylor (1999) views the ability to generate the reverse dynamic cross-correlation between price inflation and output as a yardstick to evaluate the success of monetary models. The first essay shows that the new Keynesian Phillips curve with a lagged inflation term is able to replicate the observed dynamic correlation between the two variables by simulating a small scale DSGE model.[26] Their results indicate that the presence of the lagged inflation term plays a crucial role in explaining the fact that a rise in output causes a subsequent increase in future price inflation, and that an increase in past price inflation leads to a fall in current output. These properties of the data are in stark contrast to the implication of the purely new Keynesian Phillips curve, supporting the hybrid new Keynesian Phillips curve. Turning to the dynamics of wage inflation, it might be interesting to examine if the dual wage stickiness model is able to replicate the observed reverse dynamic cross-correlation between wage inflation and output.

Figure 3.3: The Dynamic Correlation Between Output and Wage Inflation



[26] Chauvet and Kim (2009) employ the sticky price model with flexible wages. In addition to the new Keynesian Phillips curve with a lagged inflation term, they adopt the same IS curve and the Taylor rule as the ones employed in this chapter.

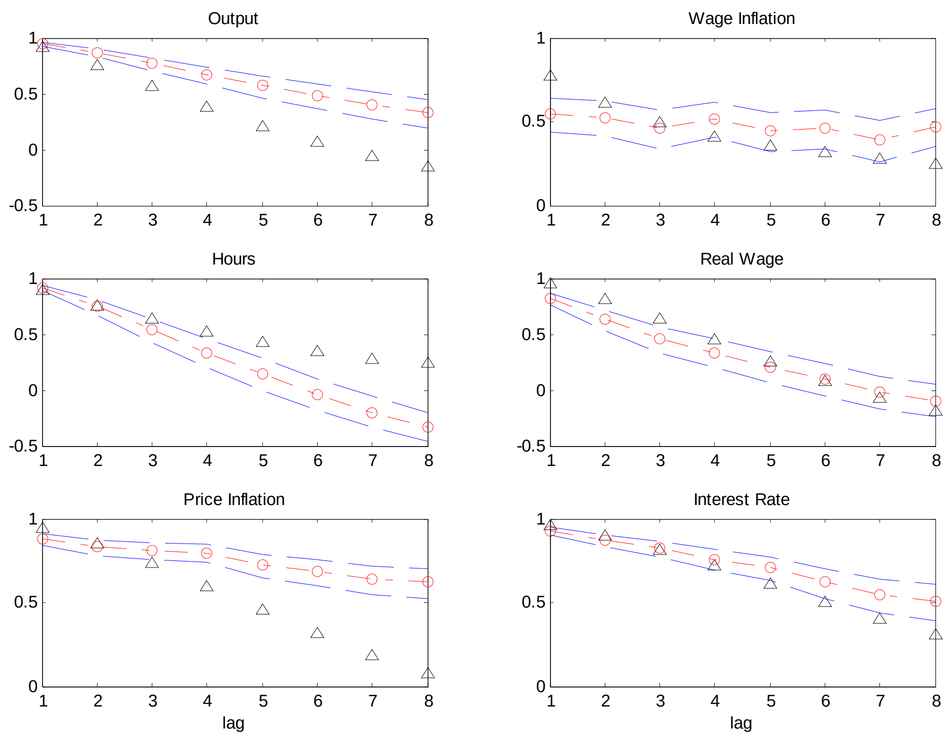
For this purpose, Figure 3.3 compares the observed dynamic cross-correlation with the model-implied dynamic cross-correlation between output and wage inflation. In Figure 3.3, the data show that past wage inflation is negatively correlated to current output, and that current output is positively related to future wage inflation. As the figure shows, the model is able to deliver a reasonable description of the observed dynamic cross-correlation between the two variables. In particular, the delayed, gradual impact of output on wage inflation is generated due to the presence of the lagged wage inflation term in the wage Phillips curve. The lagged wage inflation term generated by dual wage stickiness forces wage inflation to adjust slowly in response to changes in output. Note that the newly re-optimized wages are only partially adjusted in response to changes in economic conditions due to the convex costs of wage adjustment. As a result, a rise in output leads to a subsequent increase in wage inflation. As the figure shows, the absence of the quadratic wage adjustment costs causes the model to fail to explain the fact that output affects wage inflation with lags. While the data shows that output leads to wage inflation, the baseline model allows wage inflation to lead to output. In this respect, the dual wage stickiness model is favored over the baseline wage stickiness model. The ability to explain the dynamic correlation of these two variables can be viewed as a success of the dual wage stickiness model.

3.3.7 The Observed and Theoretical Persistence of the Model Variables

To investigate whether the DSGE model is able to match the observed persistence in output, in price and wage inflation, in hours worked, and in real wages, Figure 3.4

compares the autocorrelation functions of the variables of interest observed from the data and generated from the model. In Figure 3.4, the model-implied autocorrelation functions (triangles) are generated using the posterior mean estimates of the model parameters reported in Table 3.1. Dashed blue lines display the 95% confidence intervals of the observed persistence (presented as circles) of the data.

Figure 3.4: Autocorrelation Functions of Variables



The autocorrelation function of output does well in accounting for the observed persistence, but there is still room for improvement in fitting the observed autocorrelations of output. The DSGE model under-predicts the observed persistence of output. In contrast to output, the model-implied persistence of hours worked over-predicts the observed persistence of hours. For price inflation, it is generally accepted that the introduction of lagged inflation to the Phillips curve significantly improves the fit of inflation persistence (e.g., Rabanal and Rubio-Ramirez 2005). However, the autocorrelation function of price inflation still does not closely match the observed persistence. It could be the case, as discussed in the recent literature, that there might be additional sources of inflation persistence, such as learning or more lags of price inflation (e.g., Milani 2005, Roberts 2005). In terms of wage inflation, the model-implied autocorrelation function of wage inflation is able to explain the observed persistence reasonably well. Interestingly, although wage inflation is less persistent when compared to other variables, the observed autocorrelation function is relatively high for many periods. For the real wage, the new Keynesian model with both staggered price and wage contracts closely replicates the observed persistence in real wages. Finally, the model is able to fit the observed persistence of the nominal interest rate. Overall, the model provides a good description of the observed persistence in key macroeconomic variables.

3.3.8 Sub-samples Analysis

To check the stability of the structural parameters, this section compares the estimates obtained using subsamples split around 1980. The first subsample runs from 1960:1 to 1979:4, the period known as the Great Inflation. The second sub-sample ranges from 1983:1 to 2007:4, which corresponds to the Great Moderation, a period in which there was a substantial decrease in the observed volatility of output and inflation. Table 3.3 presents the posterior distributions of the parameters across periods. In estimating the model, the present paper assumes that households adjust their wages every 4 quarters on average.

Table 3.3: Subsample Estimation Results

Parameters	Pre-1979 estimate		Post-1983 estimate	
	Posterior mean	95% of confidence interval	Posterior mean	95% of confidence interval
α_p	0.80	[0.76 , 0.83]	0.83	[0.79 , 0.86]
β	0.99	[0.97 , 1.00]	0.99	[0.97 , 1.00]
σ	0.13	[0.08 , 0.17]	0.09	[0.06 , 0.11]
$\bar{c}$	74.9	[50.6 , 99.4]	83.6	[55.4, 109.9]
φ	0.64	[0.56 , 0.72]	0.61	[0.55, 0.66]
γ	0.37	[0.26 , 0.47]	0.33	[0.24 , 0.43]
ρ	0.72	[0.67, 0.78]	0.84	[0.81 , 0.86]
α_π	1.34	[1.22 , 1.47]	2.07	[1.90 , 2.23]
α_y	0.56	[0.41 , 0.69]	0.46	[0.32 , 0.60]
δ_π	0.08	[0.01 , 0.16]	0.05	[0.01 , 0.10]
δ_y	0.88	[0.82 , 0.94]	0.94	[0.90 , 0.98]
δ_α	0.87	[0.80 , 0.94]	0.91	[0.87 , 0.96]
σ_π	0.26	[0.21 , 0.31]	0.19	[0.16 , 0.22]
σ_y	0.04	[0.03 , 0.06]	0.02	[0.02 , 0.03]
σ_i	0.21	[0.19 , 0.24]	0.15	[0.13 , 0.17]
σ_w	0.34	[0.29 , 0.39]	0.51	[0.45 , 0.58]
σ_α	0.67	[0.59 , 0.76]	0.47	[0.41 , 0.52]

Note: This table shows Bayesian estimation results for DSGE model. The number of draws is 50,000. I keep 25,000 draws. The Metropolis-hastings algorithm is used to obtain the posterior distribution is used.

The degree of price stickiness is estimated to be stable across subsamples. Regarding wage rigidities, although the average duration of one year is assumed, wage stickiness associated with the quadratic costs is robustly found across subsamples. Interestingly, the posterior mean of $\bar{c}$ has increased in the second period. This finding implies that the wage adjustment costs could be relatively lower for the high inflation period. However, considering the 95% confidence intervals of $\bar{c}$, the difference is not significantly different. Overall, the dual wage stickiness model is once again supported by the data.

The findings indicate that there have been substantial changes in monetary policy and the volatility of the various shocks. The estimates of ρ describing the degree of interest rate smoothing are significantly different across periods (and that the 95% confidence intervals across periods do not overlap). The estimate of α_π measuring the Fed's response to inflation for the pre-1979 period is greater than the one for the post-1983 period. The Federal Reserve seems to have reacted more aggressively to changes in inflation in the second period. These results are consistent with the findings of Clarida et al (2000), and are in contrast to the findings of Kim and Nelson (2006) and Smets and Wouters (2007), which suggest only a moderate change in monetary policy. Differences between these two periods are also found in the standard errors of the demand, interest rate, technology shock, and cost-push shock. The decrease in the volatility of these shocks indicates that they could have been a potential source of the Great Moderation. In contrast, the estimated standard error of the wage-push shock increases in the post-1983 period. Although the details are not reported in this chapter, the volatility of the wage-push shock has been increasing since around 2000.

3.3.9 Counterfactual Analysis

While Clarida et al (2000) point to a shift in monetary policy as a source of the reduction in volatility of macroeconomic variables in the post-1983 period, Stock and Watson (2003), Smets and Wouters (2007), and others provide evidence that the decline of the shocks plays a major role in lowering the volatility of key macroeconomic variables. In response to this debate, it will be useful to examine the potential source of the Great Moderation using a counterfactual exercise with the model estimates reported in Table 3.3.

This counterfactual exercise examines whether the estimated monetary policy rule of the 1960s and 1970s could have induced an increase in the volatility of output and price inflation in the period of the Great Moderation, that is, assuming that the loose monetary policy was still in effect in the second period. The counterfactual exercise also replaces the estimated standard deviations of the second subsample with those of the first subsample to examine how it affects the volatility of key macroeconomic variables in the post-1983 period.

Table 3.4: Counterfactual Analysis

	Counterfactual Analysis: 1983:1-2007:4				
	Data	Policy	Shocks	Structure	Policy & Shocks
Output Gap	1.24	0.84	1.35	1.00	1.31
Price Inflation	2.76	1.59	1.40	0.89	2.50

Note: This table shows counterfactual analysis using the DSGE model estimates in Table 3.3. The first column shows the ratio of the standard deviation of each variable in the first sample period to the one obtained in the second period. The remaining columns display the ratio of the standard deviation of each variable generated from the counterfactual experiment to the model-implied standard deviation in the second sample period.

The first column of Table 3.4 displays the ratio of the standard deviation of each variable in the pre-1980 period to the one in the post-1983 period. The ratios indicate that the standard deviations of output and inflation in the first sample period are 1.24 and 2.76 times greater than the ones obtained using the second sample period. The remaining columns show the ratios of counterfactual standard deviations of the model to implied standard deviations of the variables in the second subsample.

The second column of Table 3.4 shows that replacing the estimated Taylor rule of the second sample period with the one obtained in the first subsample can lead to a rise in the volatility of price inflation in the second period, but not in volatility of output. The increased volatility of price inflation by 59% arises from the weaker response of the Fed to inflation in the first sample period. In contrast to price inflation, the volatility of output even declines in this exercise because the estimated Taylor rule implies a relatively stronger response to the economic activity in the first sample period. These results are broadly consistent with Boivin and Giannoni (2006) and Justiniano and Primiceri (2008). In this respect, a shift in monetary policy is not likely to be a source of lower volatility of output, although it contributes to the reduction of price inflation volatility.

On the other hand, when the estimated standard deviations of the shocks in the second sample period are replaced with the ones from the first period, the variability of the two variables increase by 35% and 40%, respectively, in the second sample period. Although the ratio for output is somewhat larger than the data, the results point to the shocks as a main source of the Great Moderation with respect to output. This chapter confirms the findings of Stock and Wotson (2003), Smets and Wouters (2007) and Justiniano and Primiceri (2008).

These findings indicate that a shift in monetary policy is the most important source of the lower inflation volatility. However, the ratio for price inflation produced using the counterfactual exercise regarding monetary policy is still much smaller than the one computed using the data. Hence, a change in monetary policy is not enough to account for the observed ratio of price inflation.

The fourth column reports the results when the first sample estimates of all structural coefficients except for both the Taylor rule coefficients and the standard deviations of the shocks are used in the counterfactual analysis. A change in economic structure fails to explain considerable changes in volatility of output and price inflation.

Finally, when both the estimated tight monetary policy and lower volatility of the shocks in the post-1983 period are replaced with the ones from the first period, the predicted ratios get quite close to the values computed using the data, which measure the relative volatility between the two periods. This experiment suggests that the economy could have experienced volatility of price inflation in the second period as high as that experienced in the first period if there had not been changes in both monetary policy and the volatility in the shocks across subsamples. For output volatility, it is worth noting that while the estimated Taylor rule in the first sample period can reduce output variability, a higher volatility of the shocks induces a higher variability of the variable. This experiment implies that a combination of tight monetary policy and reduced shocks better explains the decline in output volatility of the second sample period.

3.4 Conclusion

This chapter develops a model of wage inflation dynamics that is able to provide not only a better description of wage dynamics for policy analysis, but also to replicate the reverse dynamic correlation between wage inflation and output. In particular, this chapter proposes a novel framework that successfully combines two types of wage stickiness. The dual wage stickiness model is favored by U.S. data in terms of marginal likelihood as well as the ability to explain the dynamic correlation between wage inflation and output gap. Furthermore, estimation results are robust across periods and DSGE model specifications as shown in Table 3.2 and 3.3. These results imply that although wage contracts are renewed at discrete time intervals, wage setters cannot fully adjust their wages, therefore supporting the presence of dual wage stickiness. The findings also indicate substantial changes in the standard errors of the shocks and monetary policy. Based on these findings and counterfactual analysis, the reduction in volatility of the shocks is the most important driver of the decline of output gap variation. For price inflation, a shift in monetary policy plays a relatively more important role in reducing inflation volatility. However, changes in both monetary policy and shocks are necessary to account reasonably well for lower variations of price inflation.

Chapter 4

Inflation Dynamics: the Changing Role of Expectations and Inertia

4.1. Introduction

A large body of literature has employed the new Keynesian Phillips curve (NKPC) to investigate monetary policy and its relationship with business cycles. However, there is little consensus on some fundamental issues. In recent years, there has been a fierce debate surrounding the closed form solution of the NKPC in empirical studies that examine the ability of the NKPC to explain inflation dynamics. Some researchers favor the NKPC on the grounds that it provides a good description of the observed inflation path. For example, Sbordone (1998, 2002), Gali and Gertler (1999) and Woodford (2001) investigate the goodness of fit of the NKPC closed form solution and conclude that it closely matches the observed inflation dynamics. On the other hand, others find little evidence of the empirical fitness of the NKPC framework. For example, a series of papers by Rudd and Whelan (2005a, 2005b, 2006, 2007) show that the (hybrid) NKPC is not supported by the data and that the backward-looking Phillips curve yields a better empirical fit. Kurmann (2005) estimates the uncertainty surrounding the NKPC point estimates, and the results cast doubt on the findings by Sbordone (1998, 2002) and Gali and Gertler (1999).

The second issue, initiated by Fuhrer and Moore (1995), is closely connected to the first, regards the contribution of lagged inflation to inflation dynamics. The NKPC is often criticized on the grounds that it fails to explain costly disinflation since sticky price models do not guarantee "sticky inflation". In the NKPC, a sharp decrease in expectations can cause an abrupt drop in inflation because current inflation depends on expectations about future inflation. It is often believed that the failure to generate inflation persistence results from excluding lagged inflation from the NKPC model. Gali and Gertler (1999) and Christiano, Eichenbaum and Evans (2005) incorporate lagged inflation into the NKPC by assuming that a fraction of firms index prices to lagged inflation. However, as argued by Rudd and Whelan (2007), Woodford (2007), Cogley and Sbordone (2008), Benati (2008) and others, these approaches fail to explain the use of lagged inflation under the scope of micro-foundations. The lack of micro-foundations motivated researchers to provide alternative approaches to explain inflation persistence without relying on lagged inflation as an ad-hoc feature.[27] On the other hand, the first essay shows that a lagged inflation term can be endogenously introduced into the NKPC when prices are sticky with respect to the frequency and size of price adjustment.[28]

The third outstanding issue is with respect to the measures that should be employed as driving forces of inflation. Recently, some authors have emphasized labor's

[27] Milani (2007) holds that introducing learning to dynamic stochastic general equilibrium models can generate inflation inertia. Cogley and Sbordone (2008) consider persistent monetary policy as a source of inflation inertia. After controlling for low-frequency components of inflation caused by monetary policy, they find that lagged inflation is unnecessary to generate inflation persistence.

[28] Chauvet and Kim (2009) show that the observed "reverse dynamic" cross-correlation between the output gap and inflation could be replicated by the hybrid NKPC in a small-scale DSGE model, whereas the purely forward-looking NKPC fails to generate it. Their results provide evidence on the need of a lagged inflation term in explaining inflation dynamics.

share of income rather than the output gap as the main determinant of inflation. This choice has important implications for monetary policy, as discussed in detail in Woodford (2001).

A widely-used method to investigate the ability of the NKPC to explain inflation dynamics is based on a closed form solution that can be derived by iterating the NKPC forward (See, e.g., Sbordone 2002, Kurmann 2005, and Rudd and Whelan 2005b, 2006). The methods based on the closed form solution of the NKPC assume that agents form expectations in a rational, model-consistent way.[29] This chapter therefore conducts a test of whether a model-consistent inflation expectation is supported by the data, and reports that there is little evidence supporting a rational, model-consistent inflation expectation, which also suggests that existing tests based on a model-consistent inflation expectation assumption in the literature might yield misleading results.

This chapter proposes an alternative NKPC modeling approach to address these major ongoing discussions without assuming that inflation expectations are formed in a model-consistent way. In particular, we model inflation as a function of the closed form solution of the backward-looking Phillips curve as well as people's beliefs about future inflation. Inflation driven by the former is related to the part that is determined by current and past economic variables measuring demand pressure and marginal costs of production (e.g., the output gap and labor's share of income). Inflation driven by people's beliefs is associated with observed inflation expectations that leave open the possibility of

[29] As equation(5) and (6) show, the relationship between the NKPC and the closed form solution reveals that inflation expectations are formulated in a rational, model-consistent way in the new Keynesian Phillips curve.

deviation from rational expectations.[30] The model allows us to identify the role of expectations and lagged inflation in explaining inflation dynamics separately, avoiding potential spurious regression analysis in the relative importance of lagged inflation and inflation expectations. Estimating the Phillips curve by directly employing inflation expectations and lagged inflation, as in the literature, could be problematic because both variables are highly correlated, thus preventing us from identifying the role of inflation expectations as distinct from lagged inflation or vice versa. In this respect, the proposed alternative approach employed in this chapter could provide more convincing results because they are based on the implication of the backward-looking model rather than directly adopting lagged inflation. Estimation is conducted using the generalized method of moment (GMM).

We find some interesting results that can shed light on the current debates regarding the NKPC framework. In fact, the disputes among researchers regarding the importance of expectations, lagged inflation, the output gap, and the labor share are justified to some extent as in our framework all these variables are found to be important in explaining inflation dynamics. In particular, we find evidence that both expectations and lagged inflation are quantitatively and statistically important in explaining inflation dynamics. In addition, the findings also indicate that the output gap and labor's share of income work in tandem in driving inflation.

[30] In section 5, this chapter conducts a test of whether inflation expectations are formulated in a way that the NKPC implies. We report that there is little evidence supporting rational, model-consistent inflation expectations. Details are discussed in section 2 and 5.

This chapter also finds an intriguing new result that to our knowledge has not yet been reported in the NKPC literature. In particular, we find a substantial change in the role of expectations in the Phillips curve over the last decades. The coefficient associated with inflation expectations from the early 1980s to the end of the sample is half the values prevailing in the late 1960s and the 1970s.[31] In addition, we find that while the positive trend inflation in the 1970s is related to people's beliefs about future inflation, the rising inflation of the 1960s and the variations in inflation after post-1980 are closely connected with current and past values of driving forces of inflation.

Finally, we report an interesting finding that inflation predicted by current and past values of the output gap and labor's share of income may have a low-frequency component, implying that detrending inflation by the use of a random walk process or the HP-filter has a potential risk of eliminating what can be explained by current and past values of driving forces of inflation. In particular, Cogley and Sbordone (2008)'s results obtained after controlling a low frequency component in inflation could be obtained after controlling the backward-looking component, thus mistakenly supporting the purely new Keynesian Phillips curve.

The structure of this chapter is as follows. Section 2 introduces and motivates the empirical issues regarding the NKPC framework. Section 3 discusses driving forces of inflation and, as a first step, estimates the backward-looking Phillips curve with two proxies for real marginal cost. Section 4 proposes an alternative test to assess the role of

[31] This finding should not be interpreted as an increase in inflation persistence in the Volcker-Greenspan era on the grounds that observed inflation expectations from the SPF and the Greenbook considered in this chapter are highly persistent. Inflation expectations could be a source of inflation persistence. A detailed discussion is provided later.

expectations and lagged inflation in inflation dynamics. Section 5 investigates whether people's beliefs about future inflation can be replaced with a model-consistent inflation expectation derived from the NKPC. The last section concludes.

4. 2 The New Keynesian Phillips Curve: Issues and Motivations

This section reviews the tests of whether inflation expectations matter in explaining inflation dynamics and raises some troubling questions about the tests that assume a model-consistent inflation expectation.

4.2.1 The Forward-looking Behavior in Price-setting and the NKPC

The NKPC is derived as a response to Lucas' critique to the econometric Phillips curve. The NKPC features a profit-maximizing framework under the assumption of rational expectations and nominal rigidities. Whenever firms facing a significant degree of price stickiness reset their prices, they predict future inflation in order to determine current prices. The forward-looking behavior allows profit-maximizing firms to set their prices minimizing deviations from the future optimal prices path, which is derived under the flexible prices assumption. For instance, in a period of rising inflation, price setting behavior that does not take future inflation path into account allows prices to deviate considerably from future optimal prices. This is because price adjustment costs limit firm's ability to respond – by changing prices – to higher inflation. When firms can minimize the deviations from optimal prices by raising current prices in advance, their sticky prices are less likely to deviate from the optimal path. In this fashion, inflation expectations are plausibly incorporated into the Phillips curve under the assumption of rational expectations by postulating a forward-looking behavior in price-setting. For this reason, the NKPC is often called the forward-looking Phillips curve and is formulated as:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda mc_t \tag{1}$$

where π_t is inflation, mc_t is real marginal cost at time t, β is the discount rate and $\lambda = (1-\theta)(1-\beta\theta)/\theta$ where θ measures a fraction of firms that keep their prices unchanged in any given period. The NKPC model is distinct from the traditional Phillips curve – often called the backward-looking Phillips curve, in which inflation is determined by past inflation.

4.2.2 Empirical Issue: The Evidence of the Forward-looking Behavior

In the literature, the statistical significance of β in equation (1) is often interpreted as evidence for the forward-looking Phillips curve (e.g. Gali and Gertler 1999 and Sbordone 2002). However, as pointed out by Rudd and Whelan (2006), such an interpretation is at stake since replacing inflation expectation with lagged inflation also provides evidence for the backward-looking Phillips curve. Thus, the statistical significance of the coefficient associated with inflation expectations provides little evidence to support either the forward-looking or the backward-looking model.

Iterating equation (1) forward yields the closed form Phillips curve, in which current inflation depends only on the discounted current and future marginal costs:

$$\pi_t = \lambda \sum_{k=0}^{\infty} (\beta)^k E_t mc_{t+k} \tag{2}$$

Similarly, the closed form solution of the backward-looking Phillips curve, $\pi_t = \beta_b \pi_{t-1} + \lambda mc_t$, is derived by iterating backward.

$$\pi_t = \lambda \sum_{k=0}^{\infty} (\beta_b)^k mc_{t-k} \tag{3}$$

The solution is in contrast to the closed form solution of the NKPC. While the closed form of the NKPC implies that expectations of future variables matter, the solution of the backward-looking Phillips curve suggests that past variables play crucial roles in determining current inflation. The different implications of the two models have motivated researchers to test whether the NKPC is supported by data using the closed form solution.

Sbordone (1998, 2002) investigates the theoretical predictions of the closed form solution of the NKPC using VAR forecasts and concludes that there is considerable support for the NKPC as it tracks the observed inflation quite well.[32] Woodford (2001) is in line with Sbordone (1998) on the grounds that the NKPC closely fits inflation dynamics when labor's share of income is employed. Gali and Gertler (1999) report similar results with the hybrid NKPC, which is a version of the model that includes both inflation expectations and lagged inflation. As in Sbordone (1998), they find that the theoretical predictions of the hybrid NKPC do a reasonably good job in explaining observed inflation. Besides theoretically evaluating the closed form solution of the hybrid NKPC, they directly estimate the model and argue that, in spite of its statistical significance, the backward-looking behavior is not quantitatively important. All in all,

[32] Sbordone (2002) assumes the paths of nominal labor compensation and labor productivity are given to approximate unit labor cost and use the estimate as a proxy of real marginal cost. Her approach differs in details, but it is essentially the same as evaluating equation (2).

these empirical studies appear to support the forward-looking behavior in price-setting or the NKPC.

Yet, a series of papers by Rudd and Whelan (2005a, 2005b, 2006, 2007) provide evidence for the backward-looking Phillips curve. In particular, Rudd and Whelan (2005a) consider:

$$\pi_t = A(L)\pi_{t-1} + \lambda \sum_{k=0}^{\infty} (\beta)^k E_t mc_{t+k} \tag{4}$$

where $A(L) = a_1 + a_2 L .... + a_p L^{p-1}$, and A(1) is the sum of coefficients on lagged inflation. This specification is used to examine whether adding the closed form solution of the NKPC to an AR(p) model leads to a substantial decrease in the coefficients associated with lags of inflation. As Rudd and Whelan hold, the virtue of their methodology is that it is less likely to spuriously support the forward-looking behavior because the test is based on the implication of the NKPC. Using the GMM estimation, they conclude that the forward-looking term appears to be "quantitatively unimportant" as opposed to the conclusion in Gali and Gertler (1999) that the backward-looking behavior is "not quantitatively important".[33]

Rudd and Whelan (2006) also assess the forward-looking behavior with the hybrid NKPC based on VAR forecasts of future values of real marginal costs as well as the GMM approach. Once again, their results support the backward-looking Phillips curve.

However, evidence for the backward-looking Phillips curve is in stark contrast to empirical studies suggesting both a significant degree of price stickiness and the forward-

[33] Their GMM estimation results indicate the closed form solution of the NKPC adds little explanatory power, increasing R-squared by 0.02. The sum of the coefficients on lagged inflation ranges from 0.74 to 0.91 for several specifications of the model; thus, supporting the backward-looking Phillips curve.

looking behavior in price-setting (Rudd and Whelan, 2006). The discrepancy between their tests and empirical studies leads us to investigate whether inflation expectations are formulated in the fashion implied by the NKPC. Hence, a rational, model-consistent inflation expectation is discussed in the next sub-section.

4.2.3 A Question of the Tests of the NKPC: Are Inflation Expectations Model-consistent?

Debates on the NKPC have focused on the closed form Phillips curve, i.e. equation (2) and (4). The tests based on the closed form solution hinge on the assumption that inflation expectations are formulated in a model-consistent way.

$$\pi_t = \beta E_t \pi_{t+1} + \lambda mc_t = \beta \left[\lambda \sum_{k=0}^{\infty} (\beta)^k E_t mc_{t+1+k} \right] + \lambda mc_t = \lambda \sum_{k=0}^{\infty} (\beta)^k E_t mc_{t+k} \qquad (5)$$

As shown in equation (5), the tests based on the closed form solution of the NKPC assumes a model-consistent inflation expectation, which is defined as

$$E_t \pi_{t+1} = \lambda \sum_{k=0}^{\infty} (\beta)^k E_t mc_{t+1+k} \ . \qquad (6)$$

In section 5, this chapter investigates whether inflation expectations are formulated in the manner that the Keynesian theories imply. In order to test whether people's beliefs about future inflation can be replaced with model-consistent inflation expectations, observed inflation expectations from the Survey of Professional Forecasters (SPF) and the Greenbook are employed. The test results propose that observed inflation expectations cannot be replaced with model-consistent inflation expectations in determining current inflation, indicating that inflation expectations are not predicted in the model-consistent way. Hence, when the formulation of inflation expectations is not carried out in the way that the Keynesian model implies, the tests under the assumption of model-consistent inflation expectations could lead to misleading results.

In addition to the critical assumption of model-consistent inflation expectations, the tests based on the solution suffer from two other problems: i) considerable uncertainty surrounding theoretical predictions of inflation,[34] and ii) the sensitivity of forecasts of real marginal costs to VAR specifications. Kurmann (2005) casts doubt on evidence for the forward-looking behavior in terms of the uncertainty of the fitted values of the closed-form solution.[35] He emphasizes that a series of point estimates of equation (2) computed using VAR forecasts suffers from considerable uncertainty. Kurmann (2003) and Rudd and Whelan (2005b) report that the predicted values of the closed form Phillips curve driven by equation (2) are highly sensitive to VAR specifications picked up to forecast future real marginal costs.[36] These findings also call into question previous results reported as evidence for the forward-looking model. Although Kurmann (2005) and Rudd and Whelan (2005b, 2006) criticize evidence for the forward-looking model, we still cannot conclude whether their results support the forward- or backward-looking model.

[34] Theoretical predictions of inflation are denoted as the fitted values of the closed form Phillips curve, as in Kurmann (2005).

[35] The motivation of this chapter comes from the fact that the fitted values of the closed form Phillips curve are a series of point estimates. Hence, it is possible to quantify uncertainty surrounding the point estimates of theoretical predictions using a bootstrap approach.

[36] For an extended VAR specification nesting the bivariate VAR specification (employed by Gali and Gertler (1999)) including labor share of income and inflation, the correlation coefficient between theoretical inflation and inflation drops significantly to 0.55 with the 90% confidence interval ranging from -.054 to 0.84.

Taken all together, tests of the forward-looking Phillips curve under the assumption of model-consistent inflation expectations in the literature are likely to be problematic in terms of the test power using either the VAR or the GMM approach. Hence, this chapter proposes an alternative test of whether the forward-looking behavior plays a crucial role in price-setting without assuming model-consistent inflation expectations. Another issue of inflation persistence is addressed in the next sub-section.

4.2.4 Empirical Issue: Is Lagged Inflation Necessary to Generate Inflation Persistence?

The NKPC fails to generate inflation persistence. Some researchers attempt to generate inflation persistence by allowing a fraction of firms to reset their prices by rule-of-thumb (Gali and Gertler, 1999) or indexation to past inflation (Christiano et al, 2005). However, those ad-hoc indexation approaches have been criticized by Rudd and Whelan (2007), Woodford (2007), Cogley and Sbordone (2008), Benati (2008) and others. The lack of micro-foundations in introducing lagged inflation triggers researchers to find alternative ways to generate inflation persistence without relying on a lagged inflation term in the Phillips curve. In particular, Milani (2007) estimates coefficients from a DSGE model assuming learning in parameters. His findings suggest that learning could generate inflation persistence, thus making a lagged inflation term unnecessary. In Cogley and Sbordone (2008), inflation persistence is a consequence of monetary policy under rational expectations – rather than the backward-looking behavior – because persistent monetary policy allows inflation to be persistent.[37] Thus, after controlling for trend inflation, they find that inflation persistence generated by lagged inflation is likely to be spurious. Some researchers argue that inflation persistence may arise from persistent shocks hitting the economy so that the role of lagged inflation is less important in generating persistence in inflation.

The most critical failure of the NKPC is that it cannot replicate the observed "reverse dynamic" cross-correlation between the output gap and inflation. It is worth emphasizing that the ability to generate the "reverse dynamic" cross-correlation is considered as a success of monetary models by Taylor (1999). The first essay shows that, in contrast to the NKPC, the observed "reverse dynamic" cross-correlation between the two variables can be successfully generated by the NKPC with a lagged inflation term in a small-scale DSGE framework, providing evidence on the need of a lagged inflation term. In addition, they show that a lagged inflation term can be incorporated into the forward-looking Phillips curve with micro-foundations when firms face dual price stickiness with respect to the frequency and size of price adjustment.

In response to the debate, this chapter presents an alternative way to investigate whether lagged inflation is necessary in explaining inflation dynamics in the next sub-section.

4.2.5 An Alternative Modeling Approach to Investigate the Role of Inflation Expectations and Lagged Inflation in Inflation Dynamics

[37] Cogley and Sbordone (2008) is in line with Cogley and Sargent (2006) and Stock and Watson (2007) favoring "the view that there has been substantial variation in U.S. inflation persistence over time associated with changes in monetary policy regime."

This chapter is motivated in a manner similar to Rudd and Whelan (2005a, 2006)'s approach but differs in that inflation is determined by people's beliefs of future inflation as well as by the weighted average of current and past values of real marginal cost, as shown in equation (7).

$$\pi_t = \phi E_t \pi_{t+1} + \lambda \sum_{k=0}^{\infty} (\beta_b)^k mc_{t-k} \tag{7}$$

The second term on the right hand side in equation (7) is derived from the backward-looking Phillips curve. Equation (7) has some advantages over (4) in determining the role of inflation expectations and lagged inflation. First, we do not need to assume that inflation expectations are formulated in a model-consistent way because we directly employ observed inflation expectations. Since the process by which the agents predict future inflation is unknown, it is natural for us to employ observed people's beliefs about future inflation from the SPF and the Greenbook without assuming rational predictions of future inflation. Second, equation (7) is less likely to support a spurious role of lagged inflation or inflation expectations in explaining inflation dynamics. In the hybrid NKPC, inflation depends on both inflation expectations and lagged inflation. Since those two variables are highly correlated, there is a potential risk of the spurious role of lagged inflation or inflation expectations in estimation results. The correlation coefficient between lagged inflation and observed inflation expectations from the SPF is estimated to be 0.895 for the full sample. When using equation (7), we can reduce the possibility of spurious regression. The closed form solution of the backward-looking model suggests that inflation is determined by current and past values of the output gap or labor's share of income as a proxy of real marginal cost. Since we do not directly use lagged inflation that is highly correlated to inflation expectations, (7) is expected to do a reasonably good job in identifying the contribution of beliefs about future inflation and lagged inflation, avoiding a spurious regression of lagged inflation or inflation expectations.

Before estimating equation (7), in the next section, we review the current debate surrounding driving forces of inflation (e.g., proxies of real marginal cost).

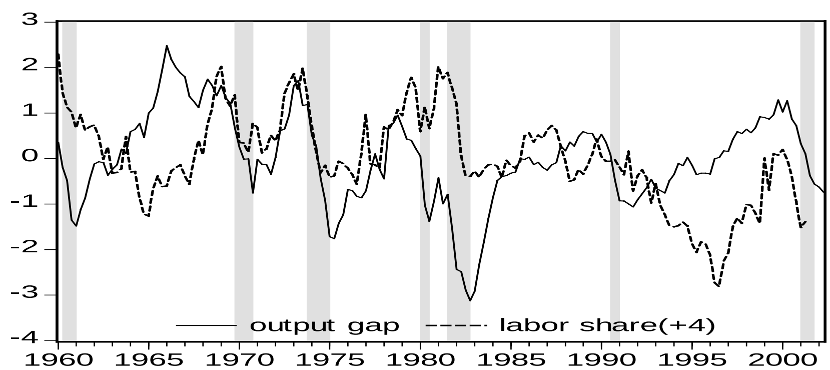
4.3 The Driving Forces of Inflation

4.3.1 What Drives Inflation?

In recent years, some researchers have highlighted labor's share rather than the output gap as a driving force of inflation. For example, Gali and Gertler (1999) favor the labor share on the grounds that the output gap involves "considerable measurement error" due to the significant variation in the natural rate of output. They emphasize that the labor share is theoretically derived as real marginal cost. In order to emphasize the advantage of using the labor share, they also report a negative and significant coefficient associated with the output gap in estimating the NKPC. Sbordone (2002) also prefers unit labor cost (equivalently labor's share of income) to the output gap in terms of the fit of the model. Woodford (2001) argues that unit labor cost could be a better measure of the true economic activity or the true output gap on the grounds that the detrended real GDP is negatively correlated with unit labor cost, which is theoretically derived as a real marginal cost. Furthermore, he discusses monetary policy in terms of the labor share as a driving force of inflation. These arguments are based on the fact that the new Keynesian theories imply a positive linear relationship between the true output gap and unit labor cost.

However, the reason for preferring the labor share to the output gap seems questionable. The failure to observe a positive relationship between the output gap and the labor share may not be because output gap measures fail to catch the true economic activity, but because the standard new Keynesian theories assume a perfectly competitive labor market.[38]

Figure 4.1. The Output Gap and One Year Ahead Labor Income Share



Notes: Each series is normalized around zero with one standard deviation.
The shaded area represents the NBER recession dates.

Figure 4.1 reports that one year-ahead the labor share and the current output gap tend to move together. From the end of 1960s to the beginning of 1980s, these two variables tended to move in the same direction. For the NBER recession dates displayed by shaded areas, the figure shows that both series decline together over the whole period. Based on the fact that the labor share is defined as the real wage rate divided by productivity, the output gap appears to have an effect on real wages with a year of lag due

[38] For details, see Carl E. Walsh (2003) for a positive relationship between the true output gap and labor income share. Recently, the imperfect labor market has been considered in the Keynesian models.

to staggered wage contracts.[39] Indeed, Taylor (1999) reports that the average frequency of wage changes is about a year after surveying (in)direct evidence in the literature. The conflict between the standard new Keynesian theories and the data may be reconciled by considering a labor market with sticky wages, rather than the considerable measurement errors in the output gap. Put differently, it is quite problematic to justify that the output gap fails to detect the "true" economic activity or "true" output gap for the simple reason that the data show evidence of a contemporaneous negative relationship between the output gap and the labor share. The problematic assumption of the perfectly competitive labor market leads to a misleading interpretation that the output gap fails to measure the "true" economic activity. As Rudd and Whelan (2007) indicate, output gap measures work quite well in detecting recession dates by NBER.[40] Considering the labor share depends on the real wage rate, the imperfect labor market could lead to the delayed response of real wages to the economic activity. This implies that the labor share rather than the output gap may fail to measure the economic activity. Nonetheless, this chapter puts both labor's share of income and the output gap as the potential driving forces of inflation. While the labor share could be interpreted as the productivity adjusted labor cost, the output gap could measure demand pressure. In this respect, the output gap may drive inflation in the demand side while the labor share could cause inflation in the supply side.

[39] The labor income share is defined as nominal compensation (wage times hours worked) divided by nominal GDP (price times output). Thus, labor share is rewritten as (real wage / productivity).

[40] In the line of Rotemberg and Woodford (1999), Rudd and Whelan (2007) hold that real marginal cost is likely to be procyclical due to "a number of factors—such as the existence of overtime premia, adjustment costs, or overhead labor." The failure of the labor share to capture cyclical movements permits Rudd and Whelan to support the output gap as a driving force of inflation.

4.3.2 Labor's Share of Income and the Output Gap as Driving Forces of Inflation: Statistical Evidence

In this section, driving forces of inflation are examined in the backward-looking Phillips curve framework. Equation (3) can be rewritten as:

$$\pi_t = \lambda \sum_{k=0}^{K} (\beta_b)^K mc_{t-K} + (\beta_b)^{K+1} \pi_{t-K-1} \tag{8}$$

This specification allows us to deal with infinite number of variables considered in the regression. As a driving force of inflation, the output gap or the labor share is often employed to estimate the Phillips curve in the literature. In order to let the data determine the true driving force of inflation, we assume a linear combination of two proxies of real marginal cost. Equation (8) can be expressed in the following form with a constant term added.

$$\pi_t = c + \lambda_1 \sum_{k=0}^{K} (\beta_b)^k y_{t-k} + \lambda_2 \sum_{k=0}^{K} (\beta_b)^k ls_{t-k} + (\beta_b)^{K+1} \pi_{t-K-1} \tag{9}$$

The output gap and the labor share are represented by y_{t-k} and ls_{t-k}, respectively, for time t and k lags. K is set to be 12. Table 4.1 presents results obtained from ordinary least squares (OLS) of the closed form solution of the backward-looking Phillips curve, equation (9). The solution is estimated using the same sample period (1960Q1 to 2002Q2) that Rudd and Whelan (2006) consider. Inflation and labor share data are as provided by the authors. We employ the Congressional Budget Office (CBO) output gap and quadratically detrended output gap as the relevant output gap measure.

Table 4.1: Estimation Results of Equation (9)

Output gap	β_b	λ_1	λ_2	R^2
CBO output gap	0.989 (0.005)	0.067 (0.006)	0.014 (0.005)	0.58
Quadratically detrended output gap	0.954 (0.008)	0.060 (0.009)	0.024 (0.010)	0.66

Notes: Constant term is included but it is not reported. Sample period: 1960:1~2002:2. This table reports the OLS estimates of Eq. (9). A Newey-West estimate of the covariance matrix was used. Standard errors are in parentheses.

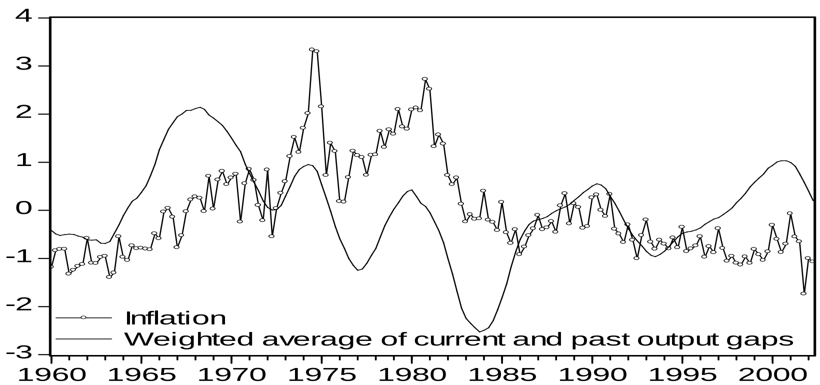
Results indicate that the labor share and the output gap are important determinants of inflation and these results are robust to the use of both the output gap measures. The estimate of λ_1 is highly significant for both output gap measures. The coefficient associated with the labor share, λ_2, is also statistically significant, hence providing evidence that the labor share plays a role in determining inflation. The magnitude of β_b is often interpreted as a measure of inflation persistence, which is determined by the number of periods for which the output gap or labor's share of income affect inflation. The estimates of β_b are close to 1**,** and imply that inflation is highly persistent.

4.3.3 Labor's Share of Income and the Output Gap as Driving Forces of Inflation: Graphical Evidence

We use equation (9) to investigate the determinants of inflation. Figures 4.2a and 2b report the second and third term of equation (9) on the right hand side, the weighted averages of the output gap and labor income share respectively. The estimates of the parameter β_b are used for Figure 4.2a and 2b.

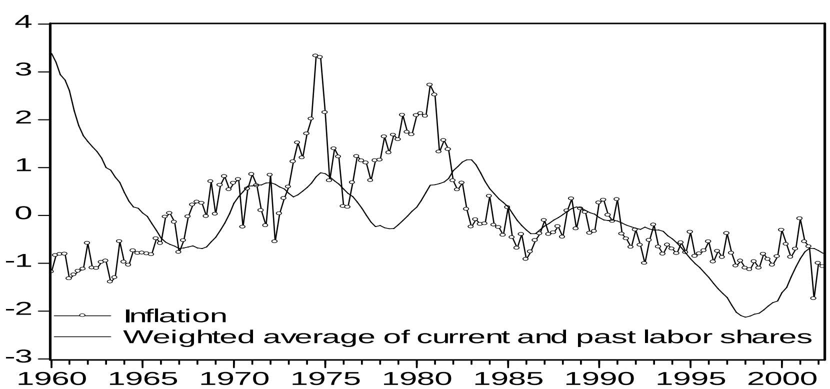
In Figure 4.2a, the positive relationship between the weighted average of current and past values of the CBO output gap and inflation suggests that current and past output gaps do play a crucial role in determining current inflation. Such co-movement between the two variables disappeared from the mid-1990s to the end of 1990s, which was the period of increased productivity growth that resulted from positive technological changes (Basu, Fernald and Shapiro, 2001).

Figure 4.2a. Inflation and Weighted Average of the Output Gaps



Notes: Each series is normalized. The CBO output gap is employed.
$\beta_b = 0.989$ *and* $K = 12$ *are used for weighted average.*

Figure 4.2b. Inflation and the Weighted Average of the Labor Shares



Notes: Each series is normalized.
$\beta_b = 0.954$ *and* $K = 12$ *are used for the weighted average.*

Overall, the output gap and inflation are closely related to each other in the short run. This result appears to be supportive of the output gap as a driving force of inflation.

Figure 4.2b also shows that on average, there is a positive relationship between the labor income share and the inflation rate. Except for the early to mid 1960s and early 1980s, the two series seem to be closely related. The rise in productivity during the second half of the 1990s might have led to the decline in labor's share of income because the labor income share is defined as the real wage divided by productivity. Although there was a large decline in the labor share in the 1990s, inflation rate slightly decreased. While the rise in the output gap in the 1990s works to drive inflation up, the decrease in the labor income share in the same period causes inflation to decrease. The effect of the labor share on inflation seems to dominate the impact of the output gap. This leads to a slight decrease in inflation in the 1990s. The fall in inflation in the 1990s cannot be explained without relying on the interaction between the output gap and the labor income share in driving inflation. Theoretical foundations of the output gap and the labor share as driving forces of inflation can be found in Matheron and Maury (2004). With a more refined supply-side than that retained by new Keynesian theories, they show that real marginal cost could be a function of both the labor share and the output gap.[41] Both variables seem to play a crucial role in driving inflation from theoretical and empirical perspectives.

4.4 A Test of the Role of Expectations

[41] See Matheron and Maury (2004) for details. In this chapter, they introduce material goods in addition to final goods and intermediate goods.

4.4.1 An Alternative Test of the Role of Expectations: Statistical Analysis

This section examines the role of inflation expectations by adding inflation expectations to equation (9). We assume that the driving force of inflation is a linear combination of the output gap and labor's share of income again. The addition of inflation expectations to Equation (9) delivers the following form of the orthogonality condition for GMM estimation.

$$E_t\left[\left(\pi_t - c - \phi\pi_{t+1} - \lambda_1\sum_{k=0}^{K}(\beta_b)^k y_{t-k} - \lambda_2\sum_{k=0}^{K}(\beta_b)^k ls_{t-k} - (\beta_b)^{K+1}\pi_{t-K-1}\right)Z_t\right] = 0\,. \quad (10)$$

K is set to be 12. Inflation expectations from the SPF and the Greenbook are employed. When the SPF is used, a set of instrument variables, Z_t, includes a constant term, $E_{t-1}\pi_{t+1}$, $E_{t-2}\pi_{t+1}$, $\{y_{t-k-1}, ls_{t-k-1}\}_{k=0}^{12}$ and π_{t-13}. Inflation expectations from the SPF are employed from the earliest available date, 1968Q4 to 2002Q2.[42] Inflation expectations from the Greenbook are also employed to check the robustness of results. Employing inflation expectations from the Greenbook, inflation expectations formed at time t-1, $E_{t-1}\pi_{t+1}$, are adopted from both the SPF and Greenbook as an instrumental variable because the variable $E_{t-2}\pi_{t+1}$ from the Greenbook has missing values in the early 70s. Since the Greenbook data set is available with 5 years of lag, the sample period is restricted from 1968Q4 to 2001Q4 when the Greenbook inflation expectations are used.

[42] Since labor income share and inflation data are taken from Rudd and Whelan (2006), the sample period is restricted to 2002Q2 again.

Table 4.2: Estimation Results of Equation (10)

$E_t \pi_{t+1}$	Output gap	ϕ	β_b	λ_1	λ_2	R^2
SPF	CBO output gap	0.762 (0.035)	0.855 (0.021)	0.083 (0.005)	0.051 (0.011)	0.87
	Quadratically detrended output gap	0.714 (0.032)	0.813 (0.032)	0.069 (0.006)	0.039 (0.015)	0.86
Green Book	CBO output gap	0.735 (0.040)	0.832 (0.030)	0.065 (0.006)	0.053 (0.013)	0.85
	Quadratically detrended output gap	0.726 (0.038)	0.781 (0.049)	0.056 (0.007)	0.046 (0.017)	0.86

Notes: Constant term is included but it is not reported. This table reports GMM estimates of Eq. (10). A Newey-West estimate of the covariance matrix was used. Standard errors are in parentheses.

Table 4.2 summarizes the estimates of $\phi, \beta_b, \lambda_1, \lambda_2$ obtained using equation (10). The over-identifying restrictions are satisfied by Hansen's J-test for all cases. The coefficient on inflation expectations ranges from 0.71 to 0.76, supporting the view that the forward-looking behavior in price-setting plays a crucial role in inflation dynamics. These values are highly significant for all cases. The significant estimates of ϕ provide evidence that the purely backward-looking Phillips curve favored by Rudd and Whelan (2006) is not supported by the data. However, estimation results also do not support the purely forward-looking Phillips curve, which is preferred by Sbordone (2002). The estimates of β_b range from 0.78 to 0.86, implying that both proxies of real marginal cost have an effect on inflation with a long delay as the dynamic cross-correlations between the two proxies and inflation show in the literature.[43] The highly persistent weighted averages of the output gap and the labor share seem to be important factors of inflation inertia. Taken all together, these results are consistent with the hybrid NKPC in which both inflation expectations and lagged inflation are necessary in describing inflation

[43] See Gali and Gertler (1999) for details.

dynamics.

The parameter estimate λ_1 associated with the output gap is between 0.06 and 0.08. In contrast to Sbordone (1998, 2002), Gali and Gertler (1999), and Woodford (2001), the estimated coefficients on the output gap are highly significant and positive, suggesting that the output gap plays a crucial role in driving inflation. The coefficient λ_2 is estimated to be around 0.04 or 0.05 with standard errors ranging from 0.011 to 0.017. It tells us that the labor share as well as the output gap drive inflation, as in the purely backward-looking framework.

4.4.2 A Substantial Change in the Role of Expectations: Graphical Analysis

This section examines the contribution of inflation expectations in determining inflation before and after 1980. Figure 4.3a displays the fitted values of the closed form solution of the backward-looking Phillips curve, equation (9). Figure 4.3b is obtained from a regression of equation (10) that is designed to identify the role of inflation expectations and lagged inflation.

Figure 4.3a. Inflation Explained by the Backward-looking Component

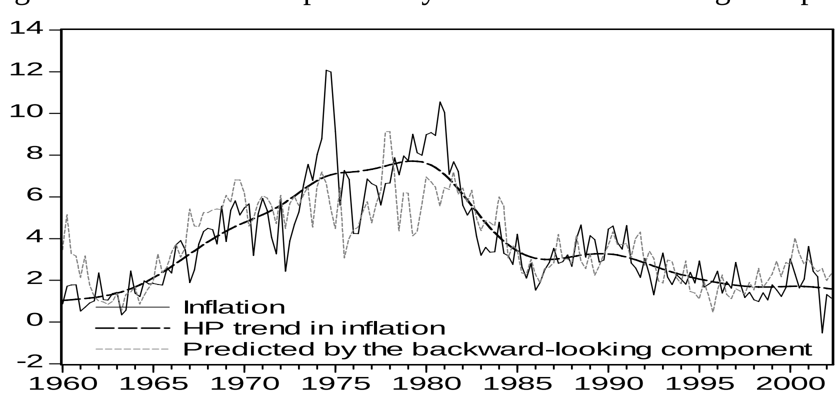
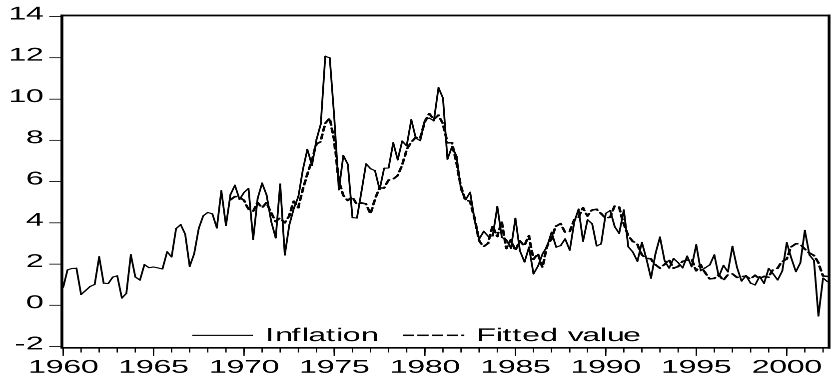


Figure 4.3b. Inflation and Fitted Value



Notes: Inflation expectations from the SPF and the CBO output gap are used.
Inflation expectations are available from 1968.

Figure 4.3a displays that inflation seems to be well-explained by the backward-looking Phillips curve except for the 1970s and the early 1980s. The backward-looking model tracks the rising inflation in the 1960s very well. In particular, a rise in the output gap is likely to contribute to an increase in inflation in that period because the labor share started to rise in the late 1960s. However, in the 1970s and early 1980s, considering that inflation predicted by current and past values of the output gap and the labor share remains stable in the 1970s and early 1980s, the backward-looking component fails to explain the rising and declining inflation, revealing that beliefs might have been crucial in determining inflation at that time. Since equation (10) suggests that inflation is determined by either the backward-looking component or inflation expectations, the failure of the backward-looking component to account for the variations of the inflation rate in the 1970s and the early 1980s implies that inflation expectations play an important role in these periods. As Figure 4.3b shows, the addition of inflation expectations to equation (9) makes a dramatic difference in predicting inflation in the 1970s and early

1980s. In contrast to the 1960s, the variations of inflation of the 1970s and early 1980s cannot be explained without people's beliefs about future inflation. Since the early 1980s, the backward-looking term appears to provide a good approximation of inflation dynamics again. This result allows us to doubt that the backward-looking component might be crucial factors in driving inflation when inflation remains stable. Benati (2008) and some authors argue that agents are purely forward-looking under stable regimes with well-anchored inflation expectations. However, Figure 4.3a shows that the purely backward-looking model provides a reasonable approximation of inflation dynamics under stable inflation regimes. In contrast to Benati (2008), results imply that the contribution of the backward-looking component might become crucial as inflation is stabilized. For example, in an extreme case that the economy has a constant inflation expectation (i.e., well-anchored inflation expectation), the contribution of current and past values of the output gap and the labor share could dominate beliefs in explaining the variations of inflation. We may define this regime as stable regime. On the other hand, in an economy with unstable inflation (i.e., hyper inflation in South America), beliefs about future inflation could obviously dominate fundamentals. Thus, the regime that beliefs dominate fundamentals may be defined as unstable regime.[44] In this respect, the role of beliefs and lagged inflation could be different across periods. This point of view is supported by estimation results, which are provided in a later sub-section. We report that

[44] We may have two regimes in inflation. The first regime (i.e., stable regime) could be the period that inflation could be well-approximated by the closed form solution of the backward-looking Phillips curve. The second regime (i.e., unstable regime) is related to the period that fundamentals itself fail to explain inflation. In this respect, the 1970s and the early 1980s are associated with unstable regime, in which beliefs play a crucial role in determining inflation. Other periods including 1960s could be defined as stable regime.

the estimates associated with inflation expectations significantly change across periods.

This chapter also raises questions about papers investigating inflation after controlling trend in inflation as in Cogley and Sargent (2006), Stock and Watson (2007) and Cogley and Sbordone (2008). Figure 4.3a displays that trend inflation could be approximated by inflation explained by fundamentals. Thus, their approaches could lead to misleading conclusions in that trend itself could be explained by output gap or labor income share. In particular, Cogley and Sbordone (2008)'s results obtained after controlling the low frequency components in inflation could be obtained after controlling the backward-looking components, thus mistakenly supporting the purely new Keynesian Phillips curve.

We can draw an implication about the source of inflation persistence from Figure 4.3a and 3b. While inflation persistence of the 1960s could be attributed to the backward-looking component, the inflation persistence of the 1970s is likely to be driven by inflation expectations since inflation explained by driving forces such as the output gap and the labor share remains stable over this period. Note that, in our modeling approach, only two sources of inflation persistence (inflation expectations and the closed form solution of the backward-looking Phillips curve) exist.

4.4.3 A Substantial Change in the Role of Expectations: Statistical Analysis

Figure 4.3a and 3b suggest that the contribution of inflation expectations toward explaining inflation dynamics was relatively more important in the 1970s and early 1980s than in any other period. We hence estimate the parameters of equation (10) across periods to detect any considerable change associated with inflation expectations. The sample period is divided, as in Clarida, Gali and Gertler (2000). Table 4.3 shows fundamental differences across periods in the effect of inflation expectations on current inflation.

Table 4.3. Panel A: Estimation Results of Equation (10): The SPF

Sample period	Output Gap	ϕ	β_b	λ_1	λ_2	R^2
1968Q4 ~ 1979Q4	CBO output gap	0.797 (0.025)	0.939 (0.008)	0.066 (0.004)	0.005 (0.006)	0.68
	Quadratically detrended output gap	0.826 (0.032)	0.945 (0.008)	0.088 (0.005)	-0.012 (0.006)	0.67
1982Q4 ~ 2002Q4	CBO output gap	0.413 (0.057)	0.766 (0.117)	0.038 (0.006)	0.070 (0.027)	0.57
	Quadratically detrended output gap	0.378 (0.056)	0.717 (0.124)	0.026 (0.004)	0.064 (0.027)	0.54

Notes: This table reports the GMM estimates of Eq. (10) using inflation expectations from the SPF. A Newey-West estimate of the covariance matrix was used. Standard errors are reported in parentheses.

Panel B: Estimation Results of Equation (10): The Green Book

Sample period	Output Gap	ϕ	β_b	λ_1	λ_2	R^2
1968Q4 ~ 1979Q4	CBO output gap	0.729 (0.032)	0.873 (0.015)	0.017 (0.005)	0.115 (0.014)	0.63
	Quadratically detrended output gap	0.730 (0.033)	0.882 (0.014)	0.024 (0.005)	0.102 (0.013)	0.64
1982Q4 ~ 2001Q4	CBO output gap	0.401 (0.057)	0.758 (0.093)	0.036 (0.005)	0.077 (0.023)	0.59
	Quadratically detrended output gap	0.367 (0.063)	0.727 (0.115)	0.036 (0.004)	0.078 (0.031)	0.58

Notes: This table reports the GMM estimates of Eq. (10) using inflation expectations from Green Book. A Newey-West estimate of the covariance matrix was used. Standard errors are reported in parentheses.

While the coefficient associated with inflation expectations is estimated to range from 0.73 to 0.83 before 1980, it dramatically decreases in the second sample period, ranging from 0.37 to 0.41. These estimates indicate substantial differences in the contribution of inflation expectations across periods as Figure 4.3a and 3b imply. Although OLS estimates are not reported here, the coefficients on inflation expectation are substantially different across subsamples, leading to the same conclusions as in Table 4.3. It implies that results are robust to estimation method. Results are supportive of the view that beliefs about future inflation may have bigger effects on inflation under unstable inflation regimes.

The lower estimates of the parameter on inflation expectations in the second sample period should not be interpreted as evidence that inflation persistence increases. Since observed inflation expectations from the SPF and Greenbook are highly persistent, beliefs itself could be a source of inflation persistence. The autocorrelation coefficient on inflation expectations from the Greenbook (SPF) is estimated to be 0.93 (0.97) for the full sample, showing that inflation expectations could be a source of the inflation persistence.[45] The parameter β_b is estimated to range from 0.87 to 0.95 before 1980 and from 0.72 to 0.77 after 1982. Estimates are a little higher in the first sample period. This evidence suggests that inflation persistence arising from the backward-looking component decreases in the second sample.

The estimate of λ_1 is highly significant for all cases, indicating that the output gap is an important driving force of inflation. On the other hand, the coefficient λ_2 associated with the labor share is not significant for the first sample when the SPF is used. This might be explained by the fact that the output gap and the labor share tended to move together in the 1970s. For the other cases, the coefficient on the labor share is highly

[45] Note that both the estimated HP filtered trend inflation and the predicted inflation in this chapter are within the 90 percent credible sets of trend inflation reported in Figure 2 of Cogley and Sbordone (2008).

significant, still supporting that labor income share is an important determinant of inflation.

In the 1970s, oil shocks had a huge impact to the economy. For robustness, this chapter adds changes in oil prices to the equation (10). Estimation is implemented by GMM again. We consider the following form of orthogonality condition,

$$E_t\left[\left(\pi_t - c - \phi\pi_{t+1} - \lambda_1\sum_{k=0}^{K}(\beta)^k y_{t-k} - \lambda_2\sum_{k=0}^{K}(\beta)^k ls_{t-k} - \beta^{K+1}\pi_{t-K-1} - B(L)\Delta p_t^{oil}\right)\tilde{Z}_t\right] = 0 \quad (11)$$

where $B(L) = a_1 L + a_2 L.^2 ... + a_4 L^4$. K is set to be 12 again. Instrument set is $\tilde{Z}_t$ = { Z_t , $\{\Delta p_{t-i}^{oil}\}_{i=1}^{4}$}. Changes in oil prices are considered only for the first sub-sample because B(1) is not significant in the second sample period, therefore adding oil prices does not alter our results.

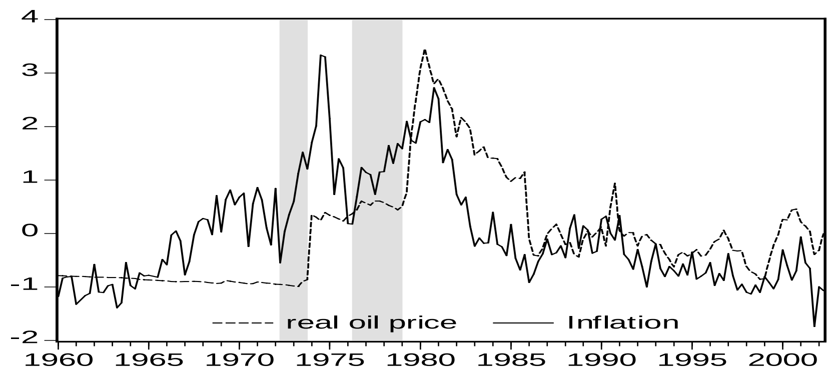
Table 4.4: Estimation Results of Equation (11)

$E_t\pi_{t+1}$	Output gap	ϕ	β_b	λ_1	λ_2	R^2	A(1)
SPF	CBO output gap	0.721 (0.019)	0.904 (0.009)	0.059 (0.003)	-0.000 (0.007)	0.81	0.023
	Quadratically detrended output gap	0.698 (0.017)	0.903 (0.008)	0.066 (0.003)	-0.011 (0.006)	0.81	0.024
Green-book	CBO output gap	0.762 (0.009)	0.829 (0.008)	0.075 (0.002)	-0.001 (0.005)	0.80	0.030
	Quadratically detrended output gap	0.787 (0.011)	0.820 (0.006)	0.073 (0.003)	-0.007 (0.004)	0.81	0.029

Notes: This table reports the GMM estimates of Eq. (11) using inflation expectations from the SPF. A Newey-West estimate of the covariance matrix was used. Standard errors are reported in parentheses. Estimates cover the sample period 1968Q4-1979Q4.

Considering changes in oil prices to explain inflation dynamics improves R^2 and the related coefficients continue to be highly significant, indicating that oil prices had an important contribution to higher inflation during the period under consideration. However, the estimates of ϕ are still highly significant and robust to adding oil prices to the estimation equation. The coefficient on inflation expectations ranges from 0.70 to 0.79 with small standard error, 0.01~0.02. These results suggest that inflation expectations still play a crucial role in driving inflation in the 1970s. Estimation results are robust to the output gap and inflation expectation measures. The conclusion that the contribution of beliefs to inflation could be different across periods seems to be robust.

Figure 4.4. Inflation and Oil Price



Notes: Each series is normalized. West Texas Intermediate is used. The means of quarterly prices are used.

Figure 4.4 presents normalized real oil price and inflation. The shaded area represents the period of rising inflation before oil shocks in the 1970s. As De Long (1997) and Clarida et al (2000) argue, inflation began to rise before oil shocks occurred. Considering inflation started to increase from 1972 and 1976, rising inflation in the 1970s is likely to be initially caused by beliefs about future inflation rather than by oil shocks which occurred in 1973 and 1979. In this respect, oil shocks alone cannot explain rising inflation.[46]

[46] See Clarida, Gali and Gertler (2000) for more details.

4.5 Are Inflation Expectations Formed in a Model-consistent Way?

Rudd and Whelan (2006) conduct the following test to examine whether the forward-looking behavior in price-setting or the NKPC is supported by the data. They estimate the model using GMM with β restricted to be 1.

$$\pi_t = \mu_1 \sum_{k=0}^{\infty} (\beta)^k E_t mc_{t+k} + \mu_2 \pi_{t-1} \tag{12}$$

They find that μ_1 is not statistically significant and conclude that the NKPC is not supported by the data. In the light of our results showing highly significant coefficients on inflation expectations, Rudd and Whelan (2006)'s results might be interpreted as a test of whether inflation expectations are formulated in a model-consistent way. Rudd and Whelan (2006) also doubt that inflation expectations are determined in the way that the new Keynesian sticky price models predict, because empirical studies show "a significant degree of price stickiness" and "firms almost surely attempt to make some predictions about future inflation" when they reset their prices. Although the forward-looking behavior in price-setting is supported by empirical studies, the forward-looking Phillips curve is not supported by the test using equation (12). Hence, they think that a model-consistent inflation expectation predicted by the NKPC may be less reasonable. If inflation expectations are formulated other than what the NKPC implies, the test of the role of expectations based on the closed form solution of the NKPC could be interpreted as whether inflation expectations are formulated in a model-consistent way.

In this section, we examine whether the observed inflation expectations from the SPF could be replaced with model-consistent inflation expectations because the tests for the NKPC in the literature (e.g., Sbordone 2002 and Rudd and Whelan 2006) assume that inflation expectations are formulated in a model-consistent way.

Iterating the NKPC forward finitely gives us the following form of equation, which allows us to deal with the infinite number of variables to estimate.

$$\pi_{t+1} = \lambda \sum_{k=0}^{\infty} (\beta)^k E_{t+1} mc_{t+1+k} = \lambda \sum_{k=0}^{K} (\beta)^k E_{t+1} mc_{t+1+k} + (\beta)^{K+1} E_{t+1} \pi_{t+2+K} \tag{13}$$

Then, equation (13) yields the following form of inflation expectation:

$$E_t \pi_{t+1} = \lambda \sum_{k=0}^{K} (\beta)^k E_t mc_{t+1+k} + (\beta)^{K+1} E_t \pi_{t+2+K} \,. \tag{14}$$

The finite sum of expected future real marginal costs, the first term on the right hand side, is expected to approximate model-consistent inflation expectations, which are formulated in the manner that the new Keynesian sticky price models predict. [47] Since people's beliefs about future inflation are available from the SPF and Greenbook, we can examine whether model-consistent inflation expectations implied by the NKPC are equivalent to people's beliefs about future inflation. When agents form expectations in the way that new Keynesian theories imply, we expect that the estimated coefficient (ϕ) associated with inflation expectations from the SPF and Greenbook in equation (15) will be relatively smaller due to the addition of the approximation term of the model-consistent inflation expectations i.e. the last two terms of equation (15) . We assume that real marginal cost consists of the output gap and the labor share.

[47] $E_t \pi_{t+2+K}$ is not considered in the GMM estimation because the realized value of $E_t \pi_{t+2+K}$ will suffer from weak identification problems in the implementation of the GMM. For example, we cannot find appropriate instrument variables for $E_t \pi_{t+2+12}$ when K is set to be 12.

$$E_t\left[\begin{pmatrix} \pi_t - c - \phi\pi_{t+1} - \lambda_1 \sum_{k=0}^{K} (\beta_b)^k y_{t-k} - \lambda_2 \sum_{k=0}^{K} (\beta_b)^k ls_{t-k} \\ - \varphi\pi_{t-K-1} - \lambda_{1E} \sum_{k=0}^{K} (\beta)^k y_{t+1+k} - \lambda_{2E} \sum_{k=0}^{K} (\beta)^k ls_{t+1+k} \end{pmatrix} \hat{Z}_t\right] = 0 \qquad (15)$$

Equation (15) is estimated by GMM with β_b and β fixed, as in Rudd and Whelan (2006). We set β_b and β to be 0.9 and 0.99 respectively. We also set K equal to 12, as in Rudd and Whelan (2006). The instrumented variable set, $\hat{Z}_t$, includes $E_{t-1}\pi_{t+1}$, $E_{t-2}\pi_{t+1}$, $\sum_{k=0}^{12} (\beta_b)^k y_{t-k-1}$, $\sum_{k=0}^{12} (\beta_b)^k y_{t-k-2}$, $\sum_{k=0}^{12} (\beta_b)^k ls_{t-k-1}$, $\sum_{k=0}^{12} (\beta_b)^k ls_{t-k-2}$, π_{t-13}, 2 lags of output gaps and labor shares. The coefficient on π_{t-K-1} is not restricted to make estimation convenient.

Table 4.5: Panel A: Estimation Results of Equation (15): The SPF

$E_t\pi_{t+1}$	ϕ	λ_1	λ_2	φ	λ_{1E} .	λ_{2E}	R^2
	0.808	0.081	0.009	0.232	-0.002	-0.009	0.88
	(0.125)	(0.014)	(0.003)	(0.091)	(0.013)	(0.014)	
	0.849	0.073	0.008	0.230	0.006	-	0.88
	(0.080)	(0.006)	(0.002)	(0.066)	(0.009)		
SPF	0.815	0.082	0.009	0.267	-	-0.011	0.89
	(0.060)	(0.013)	(0.003)	(0.083)		(0.014)	
	0.791	0.073	0.007	0.267	-	-	0.88
	(0.056)	(0.006)	(0.002)	(0.061)			

Notes: This table reports the GMM estimates of Eq. (15) using inflation expectations from the SPF. A Newey-West estimate of the covariance matrix was used. Standard errors are reported in parentheses. Estimates cover the sample period 1968Q4-2002Q2.

Panel B: Estimation Results of Equation (15): The Green Book

$E_t\pi_{t+1}$	ϕ	λ_1	λ_2	φ	λ_{1E} .	λ_{2E}	R^2
	0.736	0.023	0.002	0.133	-0.003	0.018	0.85
	(0.141)	(0.007)	(0.002)	(0.088)	(0.017)	(0.014)	
Green	0.791	0.032	0.004	0.203	-0.001	-	0.86
-	(0.090)	(0.003)	(0.001)	(0.058)	(0.010)		
book	0.768	0.023	0.003	0.126	-	0.017	0.85
	(0.092)	(0.007)	(0.002)	(0.085)		(0.012)	
	0.799	0.054	0.008	0.187	-	-	0.87
	(0.080)	(0.006)	(0.002)	(0.062)			

Notes: This table reports the GMM estimates of Eq. (15) using inflation expectations from the Greenbook. A Newey-West estimate of the covariance matrix was used. Standard errors are reported in parentheses. Estimates cover the sample period 1968Q4-2001Q4.

The estimates of ϕ, λ_1, λ_2, φ, λ_{1E} and λ_{2E} are reported in Table 4.5. The over-identifying restrictions are satisfied by Hansen's J-test for all cases. Table 4.5 reports test results of whether people's beliefs about future inflation can be replaced with model-consistent inflation expectations. Results indicate that model-consistent inflation expectations are not supported by the data. While the estimates of ϕ are highly significant, the coefficients of λ_{1E} and λ_{2E} related to model-consistent expectations are not statistically significant for any case; therefore indicating that inflation expectations may not be formulated in a way that the new Keynesian theories imply.[48] When we interpret Rudd and Whelan (2006)'s results for equation (15) as a test of whether formulations of inflation expectations follow the way that new Keynesian theories suggest rather than whether the forward-looking behavior is important in inflation dynamics, the test results provided here are consistent with Rudd and Whelan (2006). Therefore, the typical tests for the forward-looking behavior in price-setting or the role of expectations under the assumption of the model-consistent inflation expectation in the literature might be reinvestigated.

4.6 Conclusion: Summary of Findings

The contributions of this chapter to the literature could be categorized into four parts. First, the tests for the forward-looking behavior or the role of inflation expectations in the literature have been carried out assuming that inflation expectations are predicted

[48] Our results remain the same when inflation expectations from the SPF are replaced with inflation expectations from Green Book.

in a model-consistent way. Although the assumption is crucial in testing the contribution of inflation expectations to inflation dynamics, it has not been tested. Our results show that the model-consistent inflation expectation is not supported by the data. That is, inflation expectations are not formed in the way that the Keynesian theories imply.

Second, to stave off the assumption that agents form expectations in a model-consistent way in examining the role of inflation expectations, we propose an alternative modeling approach to investigate whether both the role of inflation expectations and lagged inflation are necessary; the results support that inflation expectations as well as lagged inflation play a crucial role in explaining inflation dynamics. Our approach has an advantage to investigate the necessity of lagged inflation in tracking inflation dynamics in response to the spurious role of lagged inflation argued by Milani (2007) and Cogley and Sbordone (2008).

Third, using the proposed modeling approach allows us to find a substantial change in the contribution of inflation expectations to inflation dynamics. The rising inflation of the 1970s appears to be driven by expectations while that of the 1960s might have been mainly driven by current and past variables such as the output gap and the labor income share. These results allow us conclude that inflation persistence of the 1960s may result from the backward-looking component while that of 1970s arises from persistent beliefs.

Finally, the last finding of this chapter is that two proxies of real marginal cost provide a good description of inflation dynamics. The output gap and the labor income share appear to play their own role in driving inflation. We find a link between the output gap and the labor share in that the labor share appears to respond to economic activity with lags.

Chapter 5

Conclusion

This chapter investigates the existence of dual price (wage) stickiness with respect to the frequency and size of price (wage) adjustment and theoretical implications of dual stickiness to inflation and wage dynamics. I also propose an alternative NKPC modeling approach to investigate the contribution of inflation expectations and lagged inflation term to inflation dynamics.

The first essay shows that the presence of dual price stickiness is able to generate inflation persistence endogenously. The hybrid NKPC has been often criticized due to automatic indexation that is designed to directly incorporate a lagged inflation term into the Phillips curve to generate inflation persistence without microfoundations (Woodford 2007 and Chari, Kehoe, and McGrattan 2009). In response to the critique, I propose the dual price stickiness model that is able to generate inflation persistence in a forward-looking framework. The dual price stickiness model, in contrast to the NKPC, is satisfactorily able to explain the observed dynamic behavior between the output gap and inflation.

In the second essay, I develop a model of wage inflation dynamics in a maximizing framework featuring dual wage stickiness and rational expectations. The dual wage stickiness model is favored by U.S. data in terms of marginal likelihood as well as the ability to explain the dynamic correlation between wage inflation and output gap. Furthermore, estimation results are robust across periods and DSGE model specifications.

In the third essay, empirical results show that both inflation expectations and lagged inflation play a crucial role in explaining inflation dynamics. The findings indicate a substantial change in the contribution of inflation expectations to inflation dynamics. The rising inflation of the 1970s appears to be associated with expectations while that of the 1960s might have been related to current and past variables such as the output gap and the labor income share. The findings imply that both the output gap and the labor income share play their own role in driving inflation. My results also show that the model-consistent inflation expectation is not supported by the data. That is, inflation expectations are not formed in the way that the Keynesian theories imply.

Bibliography

Andolfatto, David; Hendry, Scott and Moran, Kevin, (2008), Are inflation expectations rational?, *Journal of Monetary Economics*, 2008, 55(2), pp. 406–422.

Angeloni, Ignazio; Aucremanne, Luc; Ehrmann, Michael; Gali, Jordi; Levin, Andrew; Smets, Frank, (2006), New Evidence on Inflation Persistence and Price Stickiness in the Euro Area: Implications for Macro Modeling, *Journal of the European Economic Association,* 4(2-3), pp. 562–574.

Basu, Susanto; Fernald, John G. and Shapiro, Matthew, (2001), Productivity Growth in the 1990s: Technology, Utilization, or Adjustment?, *Carnegie-Rochester Conference Series on Public Policy,* 55, pp. 117–165.

Benati, Luca, (2008), Investigating Inflation Persistence Across Monetary Regimes. *Quarterly Journal of Economics*, *123*(3), pp. 1005–1060.

Bils, Mark; Klenow, Peter J., (2004), Some Evidence on the Importance of Sticky Prices, *Journal of Political Economy*, 112(5), pp. 947–985.

Boivin, J., Giannoni, M., (2006), Has Monetary Policy Become More Effective?, *Review of Economics and Statistics*, 88(3), pp. 445–462.

Carlton, Dennis, (1986), The Rigidity of Prices, *American Economic Review*, 76(4), pp. 637–658.

Calvo, Guillermo A., (1983), Staggered Prices in a Utility-Maximizing Framework, *Journal of Monetary Economics*, 12(3), pp. 383–98.

Chari, V. V., Kehoe, Patrick J. and McGrattan, Ellen R., (2009), New Keynesian Models: Not Yet Useful for Policy Analysis, *American Economic Journal: Macroeconomics*, 1(1), pp. 242–266.

Christiano, Lawrence J.; Eichenbaum, Martin and Evans, Charles L., (2005), Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy, *Journal of Political Economy*, 113(1), pp. 1–45.

Clarida, Richard; Gali, Jordi and Gertler, Mark, (2000), Monetary Policy Rule and Macroeconomic Stability: Evidence and Some Theory, *Quarterly Journal of Economics*, 115 (1), pp. 147–80.

Cogley, Tim, and Sargent, Tomas J., (2005), Drifts and Volatilities: Monetary Policies and Outcomes in the Post WWII U.S., *Review of Economic Dynamics*, 8, pp. 262–302.

Cogley, Tim, and Sbordone, Argia., (2008), Trend Inflation, Indexation and Inflation Persistence in the New Keynesian Phillips Curve" *American Economic Review*, 98(5), pp. 2101–2126.

Dellas, Harris, (2006a), Monetary Shocks and Inflation Dynamics in the New Keynesian Model, *Journal of Money, Credit and Banking*, 38(2), pp. 543-551.

Dellas, Harris, (2006b), Inflation inertia in the New Keynesian model. Mimeo, University of Bern.

DeLong, J. Bradford, (1997), America's Only Peacetime Inflation: the 1970's, Reducing Inflation, NBER Studies in Business Cycles, Vol. 30.

Elliott, G.; Rothenberg, T.J. and Stock, J.H., (1996), Efficient Tests for an Autoregressive Unit Root, *Econometrica*, 64, pp. 813–836.

Erceg, Christopher J. ; Henderson, Dale W. and Levin, Andrew T., (2000), Optimal Monetary Policy with Staggered Wage and Price Contracts, *Journal of Monetary Economics*, 46, pp.281–313

Erceg, Christopher J. and Levin, Andrew T., (2003), Imperfect Credibility and Inflation Persistence, *Journal of Monetary Economics*, 50(4), pp.915–944.

Fabiani, S.; Druant, M.; Hernando, I.; Kwapil, C.; Landau, B.; Loupias, C.; Martins, F.; Mathä, T.; Sabbatini, R.; Stahl, H. and Stockman, A., (2004), The Pricing Behavior of Firms in the Euro Area: New Survey Evidence, mimeo.

Fischer, Stanley, (1977), Long-term Contracts, Rational Expectations, and the Optimal Money Supply Rule, *Journal of Political Econom*y, 85, pp. 191-205.

Fuhrer, Jeffery C. and Moore, George R., (1995), Inflation Persistence, *Quarterly Journal of Economics*, 110(1), pp. 127–59.

Gadzinski, Grégory and Orlandi, Fabrice, (2004), Inflation Persistence in the European Union, the Euro Area and the United States, ECB Working papers.

Gali, Jordi, (1999), Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?, *American Economic Review*, 89(1) , 249–271.

Gali, Jordi and Gertler, Mark., (1999), Inflation Dynamics: A Structural Econometric Analysis, *Journal of Monetary Economics*, 44(2), pp. 195–222.

Gali, J.; Gertler, M., Lopez-Salido, D., (2005), Robustness of the Estimates of the Hybrid New Keynesian Phillips Curve, *Journal of Monetary Economics*, 52 (6), pp. 1107–1118.

Huang, Kevin X. D.; Liu, Zheng and Phaneuf, Louis, (2004), Why Does the Cyclical

Behavior of Real Wages Change Over Time?, *American Economic Review*, 94(4), pp. 836–856.

Ireland, Peter N., (2004), Technology Shocks in the New Keynesian Model, *Review of Economics and Statistics*, 2004, 86(4), pp. 923–936.

Jeffreys, H., (1961), Theory of Probability (3rd Edition), Oxford University Press.

Justiniano, Alejandro and Primiceri, Giorgio, (2008), The Time Varying Volatility of Macroeconomic Fluctuations, *American Economic Review*, 98(3), pp. 604–641.

Kashyap, Anil K., (1995), Sticky Prices: New Evidence from Retail Catalogs. *Quarterly Journal of Economics*, 110(1), pp. 245–274.

Kim, Chang-Jin and Nelson, Charles, (2006), Estimation of a Forward-Looking Monetary Policy Rule: A Time-Varying Parameter Model using Ex-Post Data, *Journal of Monetary Economics*, 53(8), pp. 1969–1966.

Kim, Jinill, (2000), Constructing and Estimating a Realistic Optimizing Model of Monetary Policy, *Journal of Monetary Economics*, 45, pp. 329–359.

Kozicki, Sharon and Tinsley, P.A., (2002), Dynamic Specifications in Optimizing Trend-Deviation Macro Models, *Journal of Economic Dynamics & Control*, 26, pp. 1585-1611

Kollmann, Robert, (1996), The Exchange Rate in a Dynamic-Optimizing Current Account Model with Nominal Rigidities: a Quantitative Investigation, Universite de Montreal}, mimeo.

Kurmann, Andre., (2003), Quantifying the Uncertainty About the Fit of a New Keynesian Pricing Model: Extended Version, Universite du Quebec a Montreal, CIRPEE

Working Paper 03–44.

Kurmann, Andre., (2005), Quantifying the Uncertainty About the Fit of a New Keynesian Pricing Model, *Journal of Monetary Economics*, 52, pp 1119–1134.

Kwiatkowski, Denis; Phillips, Peter C. B.; Schmidt, Peter and Shin, Yongcheol, (1992), Testing the Null Hypothesis of Stationary Against the Alternative of a Unit Root," *Journal of Econometrics,* 54, pp159–178.

Liu, Zheng and Phaneuf, Louis, (2007), Technology Shocks and Labor Market Dynamics: Some Evidence and Theory, *Journal of Monetary Economics*, 54(8), pp. 2534–2553.

Mankiw, N. Gregory. and Reis, Richardo, (2002), Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve, *Quarterly Journal of Economics*, 117(4), pp.1295–1328.

Matheron, Julien and Maury, Tristan-Pierre, (2004), Supply-side refinements and the New Keynesian Phillips Curve." *Economic Letters*, 82, pp 391–396.

Milani, Fabio., (2007), Expectations, Learning and Macroeconomic Persistence." *Journal of Monetary Economics*, 54, pp. 2065–2082.

Lucas, Robert E., Jr., (1972), Econometric Testing of the Natural Rate Hypothesis, in O. Eckstein, ed., *The Econometrics of Price Determination*, Washington: Board of Governors of the Federal Reserve System.

Lucas, Robert E., Jr., (1973), Some International Evidence on Output-Inflation Tradeoffs, *American Economic Review*, 63, June, pp. 326-334.

Nakamura, Emi and Steinsson, J., (2008), Five Facts About Prices: A Reevaluation of

Menu Cost Models, *Quarterly Journal of Economics*, 123(4), 1415–1464.

Nelson, Edward, (1998a), A Framework for Analyzing Alternative Models of Nominal Rigidities, manuscript, Carnegie Mellon University.

Nelson, Edward, (1998b), Sluggish Inflation and Optimizing Models of the Business Cycle, *Journal of Monetary Economics*, 42, 303-322.

Rabanala, Pau and Rubio-Ramirez, Juan F., (2005), Comparing New Keynesian Models of the Business Cycle: A Bayesian Approach, *Journal of Monetary Economics*, 52, pp. 1151–1166.

Reis, Ricardo, (2006), Inattentive producers, *Review of Economic Studies*, 73, pp. 793-821.

Roberts, John M., (1992), Evidence on Price Adjustment Costs in U.S. Manufacturing Industry, *Economic Inquiry*, 30(3), pp. 399–417.

Roberts, John M., (1995), New Keynesian Economics and the Phillips Curve, *Journal of Money, Credit and Banking*, 27, pp. 975–84.

Roberts, John M., (1997), Is inflation sticky?, *Journal of Monetary Economics*, 39, pp. 173–196.

Roberts, John M., (2005), How Well Does the New Keynesian Sticky-Price Model Fit the Data?, *Contributions to Macroeconomics*, 5(1), pp. 1206–1206.

Rotemberg, Julio J., (1982), Sticky Prices in the United States, *Journal of Political Economy*, 90(6), pp. 1187–1211.

Rotemberg, Julio J. and Woodford, Michael, (1997), An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy, in Ben S. Bernanke and

Julio J. Rotemberg, eds., *NBER Macroeconomics Annual*. Cambridge, MA: MIT Press, 1997, pp. 297–346.

Rudd, Jeremy and Whelan, Karl, (2005a), New Tests of the New-Keynesian Phillips Curve. *Journal of Monetary Economics*, *52*(6), pp. 1167–1181.

Rudd, Jeremy and Whelan, Karl, (2005b), Does Labor's Share Drive Inflation? *Journal of Money, Credit and Banking*, 37(2), pp. 297–312.

Rudd, Jeremy, and Karl Whelan, (2006), Can Rational Expectations Sticky-Price Models Explain Inflation Dynamics?, *American Economic Review*, 96, pp. 303–20.

Rudd, Jeremy, and Karl Whelan, (2007), Modeling Inflation Dynamics: A Critical Review of Recent Research" *Journal of Money, Credit and Banking*, Vol. 39, No. 1, pp. 155–170.

Sargent, T.J., Williams, N., Zha T., (2006), Shocks and Government Beliefs: The Rise and Fall of American Inflation, *American Economic Review*, 96(4), pages 1193–1224.

Sbordone, Argia M., (1998), Prices and Unit Labor Costs: Testing Models of Pricing." Princeton University, mimeo.

Sbordone, Argia M., (2005), Do Expected Future Marginal Costs Drive Inflation Dynamics?, *Journal of Monetary Economics*, 52 (6), pp. 1183–1197.

Sbordone, Argia M., (2007), Inflation Persistence: Alternative Interpretations and Policy Implications, *Journal of Monetary Economics*, 54, pp. 1311–1339.

Schorfheide, Frank, (2008), DSGE Model-Based Estimation of the New Keynesian Phillips Curve, University of Pennsylvania, mimeo.

Smets, Frank and Wouters, Rafael, (2003), Dynamic Stochastic General Equilibrium

Model of the Euro Area, *Journal of the European Economic Association*, 1(5), pp. 1123–1175.

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

Steinsson, Jon, (2003), Optimal Monetary Policy in an Economy with Inflation Persistence, *Journal of Monetary Economics,* 50(7), pp. 1425-1456.

Stock, J. H. and Watson, Mark W., (2003), Has the Business Cycle Changed? Evidence and Explanations, FRB Kansas City Symposium, Jackson Hole, Wyoming.

Stock, James H. and Watson, Mark W., (2007), Why Has U.S. Inflation Become Harder to Forecast?, *Journal of Money, Credit and Banking,* Vol. 39, No. 1, pp. 3–33.

Taylor, J.B., (1979), Staggered Wage Setting in a Macro Model," *American Economic Review, Papers and Proceedings,* 69 (2), pp. 108-113.

Taylor, J.B., (1980), Aggregate Dynamics and Staggered Contracts, *Journal of Political Economy,* 88, pp. 1–22.

Taylor, J.B., (1993), Discretion Versus Policy Rules in Practice, *Carnegie-Rochester Conference Series on Public Policy*, 39, pp. 195–214.

Taylor, J.B., (1999), Staggered Price and Wage Setting in Macroeconomics, *Handbook of Macroeconomics,* 1, pp. 1009–1050.

Walsh, Carl E., (2003), Monetary Theory and Policy, *The MIT Press*, 2003.

Woodford, Michael, (2001), The Taylor Rule and Optimal Monetary Policy, *American Economic Review,* 2001, 91, pp. 232–237.

Woodford, Michael, (2003), Interest and Prices: Foundations of a Theory of Monetary

Policy, Princeton University Press.

Woodford, Michael, (2007), Interpreting Inflation Persistence: Comments on the Conference on Quantitative Evidence on Price Determination.” *Journal of Money, Credit and Banking*, 39, pp. 203–211.

Yun, Tack, (1996), Nominal Price Rigidty, Money Supply Endogeneity, and Business Cycles, *Journal of Monetary Economics*, 37, pp. 345–370.

Zbaracki, Mark J.; Ritson, Mark; Levy, Daniel; Dutta, Shantanu and Bergen, Mark, (2004), Managerial and Customer Costs of Price Adjustment: Direct Evidence From Industerial Markets, *Review of Economics and Statistics*, 86(2), pp. 514–533.