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ESSAYS ON THE DYNAMICS OF NEW KEYNESIAN MODEL WITH SEARCH FRICTIONS

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ESSAIS SUR LA DYNAMIQUE DU MODÈLE NÉO KEYNÉSIEN AVEC APPARIEMENT ET RECHERCHE D'EMPLOI

THÈSE

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ABSTRACT

This thesis is composed of three chapters dealing with the dynamics of the New Keynesian model with search and matching. The main objective of the thesis is to reproduce the dynamics of inflation, labor market variables and output, following temporary shocks, without introducing ad-hoc components to the model. Moreover, the interest is also in reproducing the strong fluctuations in labor market variables observed in the U.S. data using a model with microeconomics foundations. The first chapter assesses the ability of the New Keynesian model with search frictions in the labor market to reproduce the dynamics of inflation, output and employment following a monetary shock when the indexation of prices to past inflation is absent from the model. The indexation of prices and wages has been widely criticized because it does not have microeconomics foundations. Despite these criticisms, authors continue to introduce it mechanically into their models. The central question is to know to what extent the performance of the model depends on the use of backward price indexation. Our results show that the success of this model is mainly related to the presence of this assumption and not to the endogenous mechanisms determined by the search frictions. Without price indexation, the model is unable to replicate the volatilities of key variables relative to that of output and the dynamics of inflation in response to a monetary shock. Without indexation, output, employment and vacations respond less to technological shocks and their responses are less persistent in comparison to results reproduced by the model with backward indexation. The second chapter contributes to the recent literature which aims at resolving the "Shimer puzzle". Shimer (2005) shows that standard search and matching models are not able to replicate the high volatilities of unemployment, vacancies, and labor market tightness variables observed in U.S. data. Evidence indicates that these variables are nearly 10 times more volatile than the standard model suggests. I develop a New Keynesian model with search frictions in the labor market that assumes a non-zero inflation rate in the steady state equilibrium. This introduces a new mechanism of interaction between the positive inflation rate and the investment shock that helps resolving this puzzle. In the third chapter, I assume that the firm uses intermediate input as an input in the production function. Wages are determined by the credible alternating offer bargaining (CAOB) à la Hall and Milgrom (2008). I show that the interaction between these two features generates strategic complementarity. This mechanism magnifies the effects of shocks on aggregate fluctuations, making this model more consistent with labor market and business

cycle fluctuations observed in U.S data. This amplifying effect can be seen as a complement to various forms of wage rigidity that help explaining inflation inertia and volatility of labor markets variables.

Keywords: New Keynesian model, positive trend inflation rate, unemployment volatility, roundabout production structure, investment shock, labor market frictions, indexation of prices to past inflation, real frictions.

RÉSUMÉ

Cette thèse est composée de trois chapitres qui portent sur la dynamique du modèle néo keynésien avec appariement et recherche d'emploi. L'objectif principal est de reproduire la dynamique de l'inflation, des variables du marché du travail ainsi que celle de l'output, suite à des chocs temporaires, sans recourir à des ingrédients ad-hoc. On s'intéresse aussi à reproduire les fortes fluctuations des variables liées au marché de travail observées sur données américaines en se basant sur des éléments qui ont des fondements microéconomiques. Le premier chapitre évalue la capacité du modèle néo keynésien avec frictions de recherche d'emploi à reproduire la dynamique de l'inflation, de l'output et de l'emploi suite à un choc monétaire lorsque l'hypothèse de l'indexation des prix à l'inflation passée est abandonnée. L'indexation des prix et des salaires a été largement critiquée parce qu'elle n'a pas de fondements microéconomiques. Malgré ces critiques, les auteurs continuent de l'introduire de façon automatique dans leurs modèles. La question centrale est de savoir dans quelle mesure la performance de ce genre de modèle est reliée à la présence de ce mécanisme de prix fortement critiqué ? Les résultats trouvés montrent que le succès de ce modèle peut être principalement liée à la présence de cette hypothèse ad-hoc plutôt qu'un mécanisme endogène déterminé par les frictions liées au marché de travail. Sans indexation des prix, le modèle est incapable de reproduire les volatilités des variables clés relatives à l'output ainsi que la dynamique de l'inflation en réponse à un choc monétaire. Sans indexation, l'output, l'emploi et les vacances répondent moins aux chocs technologiques et leurs réponses sont moins persistantes en comparaison aux résultats du modèle avec indexation. Le deuxième chapitre contribue à la littérature visant à résoudre "le puzzle de Shimer". Shimer (2005) montre que les modèles d'appariement et de recherche d'emploi standards ne sont pas capables de reproduire les volatilités élevées du chômage, du nombre des vacances et de la tension du marché de travail observées sur données américaines. Je développe un modèle néo keynésien avec frictions de recherche d'emploi qui est approximé autour d'un état stationnaire à taux d'inflation positif. Mes résultats proposent un nouveau mécanisme d'interaction entre le taux d'inflation positif et le choc à l'investissement qui aide à résoudre ce puzzle. Dans le troisième chapitre, je suppose que la firme utilise l'input intermédiaire comme intrant dans sa fonction de production. Les salaires sont déterminés par un "credible alternating offer bargaining (CAOB)" à la Hall et Milgrom (2008). Je montre que l'interaction entre ces deux ingrédients génère des complémentarités stratégiques qui amplifient les effets des chocs sur les fluctuations des variables du marché de travail ainsi que celles de la consommation et de l'inflation pour les rapprocher plus des données.

Mots clés : Modèle néo keynésien, taux d'inflation positif à l'état stationnaire, volatilité du chômage, boucle de production, choc à l'investissement, frictions de recherche d'emploi, indexation des prix à l'inflation passée, frictions réelles.

INTRODUCTION

Les modèles néo keynésiens avec rigidités nominales constituent un outil assez riche et populaire utilisé par les macroéconomistes pour l'analyse de la politique monétaire. Cependant, ces modèles ont été critiqués à cause des faiblesses suivantes.

Premièrement, ils sont incapables de générer une persistance élevée de l'output suite à un choc monétaire (Chari, Kehoe et McGrattan ; 2000). Deuxièmement, ces modèles éprouvent de la difficulté à reproduire la dynamique inflationniste à court terme en réponse à un choc monétaire (Gali et Gertler ; 1999). Pour pallier au problème de persistance, il faut supposer un degré de rigidité nominale des prix très élevé, lequel est contredit par les données microéconomiques sur la fréquence d'ajustement des prix. Troisièmement, plusieurs modèles néo keynésiens supposent que les prix et les salaires sont indexés au taux d'inflation passé (*backward indexation*), or cette indexation est sans fondements microéconomiques (Woodford ; 2007 et Chari, Kehoe and McGrattan ; 2009). Quatrièmement, la structure du marché de travail dans les modèles néo keynésiens ne permet pas d'analyser la dynamique du chômage qui constitue un indicateur important de la performance d'une économie.

Un courant de la littérature a récemment combiné les modèles néo keynésiens avec le modèle d'appariement et de recherche d'emploi à la Mortensen et Pissarides (1994) et Pissarides (2000) pour expliquer la dynamique de l'inflation et du chômage et la persistance de l'output. La spécification du marché de travail a des effets sur la magnitude et la persistance des chocs monétaires.

L'idée provient principalement de Merz (1995) et Andolfatto (1996). Ils introduisent le marché de travail avec appariement et recherche d'emploi dans des modèles du cycle réel (RBC) et trouvent que la spécification du marché de travail a des implications positives sur le mécanisme de propagation endogène des modèles RBC. Elle permet aussi d'améliorer la performance de ces modèles sur plusieurs dimensions, incluant par exemple les fluctuations importantes des heures par rapport aux salaires et la corrélation contemporaine faible entre les heures et la productivité. Toutefois, leurs études se basent sur des modèles non-monétaires avec une parfaite flexibilité des prix.

Plusieurs auteurs ont examiné le rôle des frictions liées à la recherche d'emploi dans les modèles néo keynésiens avec rigidités des prix. On cite par exemple les travaux de Walsh (2005) et Trigari (2009). Ils trouvent que l'introduction des frictions liées au marché d'emploi permet d'améliorer la capacité du modèle à reproduire la dynamique de l'output et de l'inflation suite à des chocs monétaires. Cependant, ces derniers utilisent l'indexation rétoactive des prix (Walsh ; 2005) et aussi des prix qui sont fixés selon une règle approximative d'usage "*rule-of-thumb*" (Trigari ; 2009). Ces mécanismes permettent d'améliorer la persistance des variables suite à un choc monétaire mais n'ont pas de fondements microéconomiques.

D'un côté, les modèles d'appariement et de recherche d'emploi du type Mortensen et Pissarides (1994) et Pissarides (2000) améliorent le mécanisme de propagation endogène du modèle néo keynésien. D'un autre côté ils souffrent d'un problème majeur. Ces modèles ne sont pas capables de reproduire les volatilités élevées du chômage, du nombre des vacances et de la tension du marché de travail observées sur données américaines. Ce problème a été soulevé par Shimer (2005), "le puzzle de Shimer". Le modèle d'appariement et de recherche d'emploi standard de Mortensen et Pissarides (1994) et Pissarides (2000) suppose que la recherche d'emploi est coûteuse pour les deux partenaires. La firme doit payer des frais liés à la recherche d'un travailleur et son recrutement. Pour les chercheurs d'emploi, ils doivent utiliser une part de leur temps qui autrement serait allouée au loisir à la recherche d'emploi, et ce, sans recevoir un salaire.

Lorsqu'il y a un match entre les deux parties, ils déterminent un salaire à travers la négociation à la Nash (1953). Cette manière de fixer les salaires conduit à un mouvement procyclique très important du salaire en réponse à un choc positif à la productivité. Étant flexible, le salaire fluctue beaucoup et absorbe une plus grande part de l'augmentation de la productivité, réduisant le surplus de la firme et son intention d'embaucher. Cela empêchera le chômage et les autres variables du marché de travail de fluctuer beaucoup suite à un choc à la productivité.

Plusieurs travaux ont essayé de résoudre "le puzzle de Shimer" en introduisant une rigidité au niveau des salaires. Gertler, Sala et Trigari (2008) introduisent la rigidité des salaires via la négociation à la Nash multi-périodique au moyen d'un arrangement à la Calvo décrite dans Gertler et Trigari (2009). Ils trouvent que leur modèle fournit des meilleurs résultats en comparaison avec un modèle d'appariement standard comportant des salaires flexibles. Le problème avec leur modèle c'est le recours systématique à la clause d'indexation au niveau des prix et des salaires.

Dans cette thèse, je m'intéresse à étudier la dynamique du modèle néo keynésien avec frictions de recherche d'emploi. Je soulève la question de la légitimité des ingrédients théoriques utilisés jusqu'à présent dans la littérature pour reproduire la persistance de l'output et du chômage et la dynamique de l'inflation en réponse à des chocs monétaires. Je cherche à développer un modèle qui permet de remédier au problème de volatilité des variables de marché de travail sans recourir à des composantes ad-hoc comme l'indexation. Je cherche aussi à analyser la dynamique des variables macroéconomiques en réponse à d'autres types de chocs comme les chocs neutres à la technologie et à l'investissement.

Dans un premier chapitre, j'évalue la capacité du modèle néo keynésien avec frictions de recherche d'emploi à reproduire la dynamique de l'inflation, de l'output et de l'emploi suite à un choc monétaire quand les prix ne sont pas indexés à l'inflation passée.. Je m'appuie sur le modèle utilisé dans Walsh (2005). Walsh (2005) examine le rôle des frictions du marché d'emploi sur la dynamique de l'inflation, de l'output et d'autres variables suite à un choc monétaire. Il trouve que les frictions du marché d'emploi augmentent la réponse de l'output et réduisent celle de l'inflation par rapport à un modèle néo keynésien standard, en réponse à un choc monétaire. Le problème dans le modèle de Walsh (2005) est le recours à l'indexation des prix au taux d'inflation passé.

La question clé est de savoir dans quelle mesure les résultats obtenus par Walsh (2005) et d'autres après lui sont reliés à la présence de la clause d'indexation fortement critiquée plutôt que sur un mécanisme endogène lié aux frictions de marché de travail ? Mes résultats confirment les critiques avancées par Woodford (2007) et Chari, Kehoe and McGrattan (2009) concernant le rôle de la clause d'indexation dans l'obtention des résultats qui sont compatibles avec les preuves empiriques. Woodford (2007) remet en question le réalisme du comportement de fixation des prix basé sur l'indexation dans les modèles d'équilibre général dynamique stochastique (DSGE). Selon lui, les modèles incluant l'indexation ne sont pas micro-fondés. Chari, Kehoe et McGrattan (2009) critiquent également l'utilisation des modèles néo keynésiens comme guide de l'analyse politique, car ces modèles sont basés sur un mécanisme d'indexation qui est en contradiction avec les données microéconomiques directes et n'a pas de fondements théoriques solides. Le modèle proposé dans ce chapitre est très différent des leurs.

Les résultats trouvés sont résumés de la façon suivante. Premièrement, sans indexation, la réponse de l'inflation à un choc monétaire est moins persistante, retourne rapidement à sa valeur d'avant choc et n'est pas en forme de bosse "hump-shaped". Deuxièmement, sans indexation, l'output, l'emploi et les vacances répondent moins aux chocs technologiques et leurs réponses sont moins persistantes en comparaison aux résultats du modèle avec indexation. Troisièmement, le modèle sans indexation échoue à reproduire les volatilités relatives de l'emploi, du taux de création d'emploi, du taux de destruction d'emploi et de l'inflation par rapport à l'output.

Ces résultats s'expliquent de la manière suivante : premièrement, l'indexation des prix à l'inflation passée change la forme de la courbe de Phillips néo keynésienne en lui ajoutant un terme d'inflation retardée qui permet de capter la persistance d'inflation. Deuxièmement, sans la clause d'indexation, la réponse de l'inflation est plus faible suite à un choc technologique car les firmes qui ne sont pas autorisées à réoptimiser leurs prix les gardent inchangés. L'augmentation de l'output suite à un choc technologique n'est pas alors suffisante pour aider le modèle à reproduire la volatilité de l'output observée sur les données américaines.

Dans le deuxième chapitre, je contribue à la littérature qui cherche à améliorer la capacité des modèles d'appariement et de recherche d'emploi à expliquer les volatilités élevées du chômage, des vacances et de la tension du marché de travail. Je propose un modèle néo Keynésien avec rigidités nominales des prix et frictions de recherche d'emploi. Les salaires sont fixés par la négociation à la Nash. Le modèle inclut des frictions réelles sous forme des coûts d'ajustement sur l'investissement et l'utilisation variable de capital comme dans Christiano, Eichenbaum et Evans (2005) et Gertler, Sala et Trigari (2008).

La majorité des modèles néo keynésiens développés dans la littérature sont approximés autour d'un état stationnaire à taux d'inflation nul. Cependant, les données d'après-guerre pour les pays développés montrent un taux d'inflation moyen positif. Ascari (2004) montre qu'il y a des changements de long terme et de court terme au niveau des propriétés des modèles à prix rigides quand le taux d'inflation tendancielle est positif. Par exemple, il montre que des niveaux très faibles d'inflation tendancielle impliquent des changements importants et irréalistes dans le niveau de l'output à l'état stationnaire.

Jusqu'à présent les quelques modèles existants qui ont exploré les effets d'un taux d'inflation tendancielle positif n'ont pas tenu compte de frictions liées au marché d'emploi. Dans ce chapitre, j'évalue l'effet d'un taux d'inflation positif à l'état stationnaire sur les volatilités des variables clés du marché d'emploi ainsi que sur la dynamique des variables macroéconomiques quand l'économie fait face à trois types de chocs : un choc monétaire, un choc neutre à la technologie et un choc à l'investissement.

Les résultats montrent que l'interaction entre le taux d'inflation positif et le choc à l'investissement aide à reproduire des volatilités des variables de marché d'emploi qui sont plus proches des données par rapport au modèle avec un taux d'inflation tendancielle nul à l'état stationnaire.

L'intuition est la suivante : la réaction de l'inflation en présence d'un taux d'inflation positif est plus importante suite à un choc à l'investissement positif que suite aux chocs monétaire et technologique. Avec un taux d'inflation positif, les firmes font plus attention aux conditions futures de l'économie plutôt qu'aux fluctuations à court terme. Cela se produit parce qu'elles savent qu'elles peuvent être bloquées avec le prix fixé à t et que l'inflation va donc éroder leurs profits au fil du temps. Elles vont donc exiger un markup sur le prix plus élevé avec un taux d'inflation positif pour éviter cette érosion de leurs prix et profits. Pour satisfaire la condition d'équilibre efficient et pour compenser la forte baisse de la consommation suite à un choc à l'investissement positif, les firmes augmentent le nombre des heures totales. En conséquence, le nombre de vacances augmentent et le chômage diminue. Cela a un impact important sur l'augmentation de la volatilité des variables lées au marché du travail.

Dans le troisième chapitre, je montre que l'interaction entre deux ingrédients clés de la littérature moderne génère des complémentarités stratégiques qui permet d'amplifier les effets des chocs sur les fluctuations des variables du marché de travail ainsi que sur la consommation et l'inflation pour les rapprocher plus des données américaines. Ces ingrédients sont la structure de production en boucle (Basu ; 1995) et les salaires qui sont déterminés par une négociation en alternance avec offre crédible "credible alternating offer bargaining (CAOB)" à la lumière de Hall et Milgrom (2008).

Basu (1995) utilise un modèle état-dépendant avec une structure de production plus complexe qui suppose que les firmes utilisent comme intrant en production un input intermédiaire. Utilisée dans un modèle avec prix rigides, cette structure de production dite en boucle ou "roundabout production" donne naissance à un mécanisme appelé le multiplicateur de rigidité de prix. Les effets de cette structure de production n'ont pas été explorés dans un modèle avec frictions au niveau du marché d'emploi

Un autre résultat important concernant la dynamique de l'output et du chômage en réponse à un choc monétaire. Dans le modèle avec CAOB et avec boucle de production, la réponse de l'output est plus forte et plus persistante par rapport à sa réponse dans le modèle standard (sans boucle de production). Le modèle avec boucle de production génère aussi des réponses du chômage et de l'output qui sont en forme de bosse suite à un choc monétaire. L'introduction d'une structure de production en boucle a aussi des effets sur la dynamique de l'inflation. L'inflation répond moins à un choc monétaire. L'examen des autocorrélations montre que la production en boucle améliore la persistance de l'inflation par rapport à ce qu'on trouve dans le modèle standard.

La boucle de production et les salaires CAOB ont des effets importants sur la pente de la courbe de Phillips néo keynésienne qui devient plus plate. Cela réduit alors la réponse de l'inflation aux fluctuations du coût marginal et améliore sa persistance. Le chômage fluctue plus parce que dans ce modèle la création de l'emploi est principalement liée aux heures par travailleur futures. Lorsque la firme prévoit une augmentation des heures par travailleur dans l'avenir, elle finit par afficher plus de postes vacants aujourd'hui afin d'éviter des coûts marginaux réels plus élevés. Cela permet d'avoir une dynamique du chômage et des variables liées au marché du travail plus proche des données.

Finalement, une boucle de production permet de générer une réponse de la consommation positive à l'impact suite à un choc d'investissement positif. Ce résultat est conforme aux preuves empiriques à savoir une corrélation contemporaine positive entre le taux de croissance de la consommation et de l'investissement. Le modèle sans boucle de production génère par contre une réponse négative de la consommation au choc positif d'investissement.

CHAPITRE I

THE DYNAMICS OF NEW KEYNESIAN SEARCH AND MATCHING MODELS : INTERNAL PROPAGATION MECHANISMS OR AD HOC COMPONENTS ?

Abstract

A number of authors have introduced backward indexing of prices (and wages) to past inflation in the New Keynesian model. Indexation has been the object of severe criticisms by neoclassical and New Keynesian economists for being counterfactual and for lacking microfoundations. What role exactly does this assumption play in shaping the dynamics of inflation, output and employment in a typical New Keynesian search and matching framework ? I address this issue by showing that the performance of this class of model is not related to the presence of search frictions alone as shown before, but to the presence of the indexation price hypothesis, which is of course at odds with direct microeconomics evidence. Without indexation, the inflation loses its typical hump-shaped pattern and a lot of its persistence. The model fails also to reproduce the standard deviations of key variables observed in U.S. data when the indexation is turned off. I further analyze the behavior of the model relative to the effects of a TFP shock on output, employment, vacancies and inflation. Without indexation, the response of nominal and real variables to a TFP shock is less pronounced and less persistent compared to their response in the model with indexation. Finally, I show that the inflation dynamics is sensitive to variations in the degree of nominal price rigidity and to the presence of search frictions in the model especially in the model with no backward price indexation.

Keywords : New Keynesian model ; search and matching model, price stickiness, backward indexation, monetary and TFP shocks.

1.1 Introduction

"An obvious source of doubts is the role of the automatic indexation of prices (as well as wages) to a lagged price index, introduced by Christiano, Eichenbaum, and Evans (2005)." Woodford (2007, p.204).

"The backward indexation of prices is a mechanical way to make the New Keynesian model match the persistence of inflation in the U.S. data. We show that this feature is flatly inconsistent with the micro data on prices." Chari,Kehoe and McGrattan (2009, p.245).

For several years, the challenge faced by macroeconomists has been to explain the short-run dynamics of inflation and the persistence of output fluctuations following a monetary shock. Gali and Gertler (1999) have shown that the standard New Keynesian model fails to explain inflation dynamics because the standard New Keynesian Phillips Curve (NKPC) is essentially a forward-looking relationship.

In the standard sticky-price model, the inertial behavior of inflation cannot be explained unless one assumes a very high degree of nominal price rigidity (or a lower frequency of price adjustments). This is contradicted by microeconomics data suggest a higher frequency of price adjustments. Bils and Klenow (2004) estimate the frequency of price changes for 350 categories of goods and find that half of prices last less than 4.3 months. Nakamura and Steinsson (2008) exclude sales and product substitutions and find a median duration of price rigidity of about 8 months.

Chari, Kehoe and McGrattan (2000) build a Dynamic Stochastic General Equilibrium (DSGE) with price rigidity and real frictions and show that staggered price contracts are not enough to replicate persistent output fluctuations following monetary shocks. To overcome these problems, some studies propose adding lagged inflation to the NKPC in order to increase the output persistence and provide intrinsic inflation inertia. Gali and Gertler (1999) modify the NKPC into a hybrid relationship assuming rule-of-thumb behavior by price-setters. Christiano Eichenbaum and Evans (2005) propose a version of the NKPC with indexation of nominal wages and prices to past inflation. Indexation is now routinely included in almost all New Keynesian models.

The introduction of backward indexation in New Keynesian models has two major effects. First, it produces higher inflation persistence due to the presence of lagged inflation into the NKPC. Second, with indexation, all firms including those not entitled to reoptimize their price due to a Calvo-type of signal will change prices every period. With a higher number of firms changing prices, price adjustment to aggregate disturbances is larger.

Woodford (2007) questions the realism of the price-setting behavior based on indexation in DSGE models. According to him, models including indexation lack a convincing mircrofoundations. Chari, Kehoe and McGrattan (2009) also criticize the use of New Keynesian models for the guidance of policy analysis because this mechanism is at odds with direct microeconomics evidence and does not have a solid theoretical foundation.

Despite criticisms addressed to the use of the backward indexation, most authors continue to introduce it systematically into their models.

I focus on the role played by backward price indexation to drive the dynamics of inflation, output and employment in a typical New Keynesian search and matching framework. I use a model similar to that proposed by Walsh (2005). I evaluate the respective contributions of the search frictions and the ad hoc indexation mechanisms on the findings obtained so far within this class of models.

Two fundamental questions are explored : To what extent the results obtained by Walsh (2005) and others after him are dependent on the use of the backward price indexation hypothesis attacked as much by neoclassical economists as New Keynesian? The performance of this model in explaining the dynamics of inflation, output and employment is-it related to the presence of search frictions or mainly to the union between search frictions and the backward indexation?

The effects of indexation on the model's main findings are quite important. I find that this hypothesis is responsible for much of the empirical success of the New Keynesian Search and Matching model. This is problematic since the performance of this model should be based on an endogenous mechanism such as search frictions and not on an ad-hoc hypothesis which does not hāve a solid theoretical foundation.

First, results show that indexation is responsible for the gradual and persistent responses of inflation following a monetary shock. With indexation, the inflation response to the monetary shock is hump-shaped. Without indexation, the inflation response is not hump-shaped anymore. The backward indexation makes the inflation response to the monetary shock more pronounced and more persistent in comparison to its response in the model without indexation. This occurs because the backward indexation changes the form of the NKPC by adding a lagged inflation term that helps the model reproducing more inflation persistence.

Second, in this literature, the focus has been on the propagation of monetary shocks, neglecting the effects of Total Factor Productivity shocks (TFP). I further analyze the behavior of the model relative to the effects of TFP shocks on output, employment, vacancies and inflation. Without indexation, the inflation response is more muted and less persistent. The sluggishness in the price level leads to a weaker expansion in aggregate demand. As a result, the increase in the output is smaller without backward indexation, firms post less vacancies and employment decreases in the short-run.

Third, with indexation, the model does relatively a good job reproducing the standard deviations of key variables observed in the U.S. data. When the backward indexation is turned off, the model fails along these dimensions. For example, the standard deviation of output is about 1.60 in the U.S. data. The model with price indexation generates almost the same volatility observed in data. Without indexation, the model reproduces only 58 percent of the empirical volatility of output. This occurs because the inflation response is more muted without indexation, the increase in the output following a technology shock is not enough to help the model reproducing the observed output volatility.

After showing results with the calibrated version of the model, I investigate how the inflation dynamics is affected by varying the degree of price rigidity and by the presence of search frictions. My main results are as follows :

First, the reduction of the degree of price stickiness increases the magnitude and the peak effect of the inflation response in both models with and without indexation. However, these effects are not the same in both models. Without indexation, the degree of price stickiness is the key parameter that helps capturing more inflation persistence. Inflation responds too much to the Calvo parameter changing when the indexation is turned off. For example, following a one standard deviation expansionary monetary shock, reducing the degree of price stickiness, changes the inflation maximum impact from 0.11 percent to 0.47 percent in the model with no indexation. However, the impact peak changes are only from 0.24 percent to 0.57 in the model with price indexation.

Second, New Keynesian model with search frictions requires less degree of price stickiness to generate inflation dynamics closer to the one generated in the standard New Keynesian model without search frictions. Introducing search frictions helps the inflation being more persistent and responding less to the monetary shock in comparison to what I found in the model without search frictions.

This paper is organized as follows. Section 1.2 describes the model. Section 1.3 presents the calibration. Section 1.4, describes the simulations results. Section 1.5 studies the inflation dynamics with different parameters values. Section 1.6 concludes.

1.2 The Model

The model is a variation of the Mortensen and Pissarides (1994) search and matching model with nominal price rigidities, following Walsh (2005). The economy is composed of households, wholesale firms, retail firms and a monetary authority. Wholesalers produce intermediate goods in a competitive market. Production requires that a wholesale firm and a worker be matched. Retailers buy intermediate goods from wholesalers, then repackage and sell them to households in a monopolistic competitive labor market. They set prices in the spirit of Calvo (1983). Following Walsh (2005) ; Gertler, Trigari and Sala (2008) ; Ravenna and Walsh (2008) and Blanchard and Gali (2010), I separate retailers from wholesalers. This separation follows the approach of Bernanke, Gertler and Gilchrist (1999) and is introduced to simplify the structure of the model since it avoids interactions between wage bargaining, matching decisions and the price set-up.

1.2.1 The households

I assume the presence of a continuum of households that are either employed or searching for a job. Unmatched households spend time in home production. To avoid complications from heterogeneity, I follow Merz (1995) and Andolfatto

(1996) and using perfect insurance market assumption. So, consumption is the same across households regardless of their labor income due to their situation in the job market.

The representative household consumes final goods and supplies labor. I assume that the labor supply is inelastic and is equal to unity. Household owns all firms and maximizes the following utility function

$$E_t \sum_{s=0}^{\infty} \beta^s \left[\frac{(c_{t+s}^T - h_c c_{t+s-1}^T)^{1-\sigma}}{1-\sigma} \right], \tag{1.1}$$

subject to the budget constraint

$$P_t Y_t + T_t + (1 + R_{t-1}) D_{t-1} \geq P_t c_t + D_t. \tag{1.2}$$

In equation (1.1), β is the subjective discount rate, h_c controls the degree of habit formation in preferences and σ is the intertemporal elasticity of substitution. I define $c_t^T = c_t + c_t^H$, where c_t^T is total consumption that incorporates the purchased composite consumption goods c_t and the home-produced consumption c_t^H that is equal to $-L$ if employed and to b if unemployed, where L is the worker's disutility of effort and b is the home production income when unemployed.

Equation (1.2) describes the sources of funds on the left hand side and the uses of funds on the right hand side. Y_t is the household's real income that includes wage income and firm profits, T_t is the monetary lump-sum transfers, D_t is the net nominal holdings of bonds at the period t and R_t is the gross nominal interest rate. The household allocates its income between the purchase of consumer goods c_t produced by retail firms and bonds D_t.

The aggregate consumption $c_t = \left(\int_0^1 c_{jt}^{\frac{\gamma-1}{\gamma}} dj \right)^{\frac{\gamma}{\gamma-1}}$, reflects the j variety of consumer goods produced by retail firms, where $\gamma \geq 0$ is the elasticity of substitution among differentiated goods produced by retailers. The aggregate retail price index $P_t = \left(\int_0^1 p_{jt}^{1-\gamma} dj\right)^{\frac{1}{1-\gamma}}$, where p_{jt} is the price for final goods j charged by retail firms at date t. This implies a demand function for good j defined as follows

$$c_{jt} = \left(\frac{p_{jt}}{P_t}\right)^{-\gamma} c_t. \tag{1.3}$$

The first-order condition for consumption and bond holdings satisfies

$$\lambda_t = \left(c_t^T - h_c c_{t-1}^T\right)^{-\sigma} - \beta h_c E_t \left(c_{t+1}^T - h_c c_t^T\right)^{-\sigma}, \tag{1.4}$$

$$\lambda_t = \beta(1 + R_t) E_t \lambda_{t+1} \frac{1}{\pi_{t+1}}, \tag{1.5}$$

where λ_t is the marginal utility of consumption and $\pi_{t+1} = \left(\frac{P_{t+1}}{P_t}\right)$ represents the gross inflation rate.

1.2.2 The firms

Production and hiring decisions take place in the wholesale sector, only pricing decisions take place in the retail sector. To simplify the analysis, the model ignores capital as an input in production.

The wholesale firms and the labor market

There is a representative wholesale firm hiring workers and producing homogenous goods. Wholesalers sell their output to retailers at the perfectly competitive price P_t^w. The output produced by wholesale firm i is given by

$$y_{it} = a_{it} z_t, \tag{1.6}$$

where z_t denotes the aggregate productivity that is common to all firms, while a specific job's productivity a_{it} is idiosyncratic. I assume that z_t is independently and identically distributed (i.i.d.) normal with mean disturbance equals to 1 and a_{it} follows i.i.d. lognormal distribution with zero mean and standard deviation σ_a.[1] The aggregate productivity shock follows the stochastic process,

$$\log z_t = \rho^z \log z_{t-1} + \varepsilon_t^z, \qquad 0 \leq \rho^z < 1, \tag{1.7}$$

where innovation ε_t^z, is a zero-mean i.i.d. random variable with known standard deviation σ_z.

Each period, a matching process occurs between a wholesale firm and a worker. Workers and firms are either searching or matched. Unmatched firm pays a cost κ for posting a vacancy. The unemployed worker takes time to find a job. These frictions in the wholesale sector create a surplus between the two parts because both of them do not enjoy the search, paying the vacancy costs or wasting their time. The match remains in effect if the expected gain is positive. The joint surplus is $S(a_{it}) = \left(\frac{a_{it} z_t}{\mu_t}\right) - L + J_t$, where $\mu_t = \frac{P_t}{P_t^w}$ is the retail's markup and J_t is the difference between the expected present value of a match that goes on in period $t+1$ and the alternative opportunities available to the firm and the worker, which is defined explicitly in equation (1.13).

Matches may end in two ways : either because of an exogenous separation, denoted by the probability ρ^x, or because of an endogenous separation given by

1. Den Hann, Ramey and Watson (2000) argue that this hypothesis simplifies the model analysis, eliminating the match-specific state variables in the case of non-separation.

the probability ρ_t^n. Let F be the cumulative distribution function of the match specific productivity shock. The endogenous separation occurs when the idiosyncratic productivity shock a_{it} is less than a specified level $\widetilde{a_t}$, where $\widetilde{a_t}$ is an endogenously determined critical value below which jobs with $a_{it} < \widetilde{a_t}$ are not profitable. With $S(a_{it}) = 0$, the critical value is equal to $\widetilde{a_t} = \frac{\mu_t}{z_t}(L - J_t)$. If z_t increases, production will increase according to equation (1.6). It also reduces $\widetilde{a_t}$, this leads more matches to produce since there are fewer endogenous separations. The effect of z_t on $\widetilde{a_t}$ amplifies the impact of the aggregate productivity shock on output, as emphasized by Den Haan, Ramey, and Watson (2000).

The aggregate endogenous separation rate is

$$\rho_t^n = \Pr(a_{it} < \widetilde{a_t}) = F(\widetilde{a_t}). \tag{1.8}$$

The total separation rate is defined as

$$\rho_t = \rho^x + (1 - \rho^x)\rho_t^n. \tag{1.9}$$

The number of new hires is given by the matching function in period t, $M(u_t, v_t) = \zeta u_t^{\xi} v_t^{1-\xi}$, where $\zeta \in [0,1]$ captures the efficiency of the matching process and ξ is the match elasticity. u_t is the number of job searchers and v_t is the number of vacancies posted by the wholesale firm. $U_t = 1 - N_t$ is the number of unmatched workers and N_t is the number of matched workers. Since I normalize the labor force size to 1, U_t and N_t are also the unemployment and employment rate, respectively.

Notice that the unemployment rate U_t is different from the number of job searchers u_t. The unemployment rate is the number of workers that are not matched with the firm, at the beginning of the period t. The number of job searchers is defined as $u_t = U_t + \rho_t N_t = 1 - (1-\rho_t)N_t$, because some of the matched workers separate and search for a new job in the same period.

Employment at $t+1$ is given by the number of matched workers surviving at t after total separation and the number of the new matches formulated at period t. It is described by the following dynamic equation

$$N_{t+1} = (1-\rho_t)N_t + M(u_t, v_t). \tag{1.10}$$

The job-finding rate is $p(\theta_t) = M(u_t, v_t)/u_t = M(1, \theta_t)$, where $\theta_t = \frac{v_t}{u_t}$ is aggregate labor market tightness. The probability that a firm finds a worker is $q(\theta_t) = M(u_t, v_t)/v_t = M(1/\theta_t, 1)$, this is the hiring rate.

The value of unemployment to the worker at period t is

$$S_t^w = b + E_t\Delta_{t,t+1}\left[p(\theta_t)(1-\rho^x)\int_{\widetilde{a_{t+1}}}^{\tilde{a}} \eta S(a_{it+1})f(a_{it})da_i + S_{t+1}^w\right]. \tag{1.11}$$

The value to the firm of an unfilled vacancy at period t is characterized by the following Bellman equation :

$$S_t^f = -\kappa + E_t\Delta_{t,t+1}\left[q(\theta_t)(1-\rho^x)\int_{\widetilde{a_{t+1}}}^{\tilde{a}} (1-\eta)S(a_{it+1})f(a_{it})da_i + S_{t+1}^f\right], \tag{1.12}$$

where $\Delta_{t,t+1} = \beta\left(\frac{\lambda_{t+1}}{\lambda_t}\right)$. I assume that the worker and the firm receive a share η and $(1-\eta)$ of the joint surplus, respectively.

Free entry condition implies that firm continues posting new vacancies as long as the net profit of a filled job exceeds the cost of posting a vacancy. Then in equilibrium, the value of a vacancy is $S_t^f = 0$. If the alternative opportunities available to the firm and the worker are zero and S_t^w, respectively, the value of J_t is

$$J_t = E_t \Delta_{t,t+1} \left[(1-\rho^x) \int_{\widetilde{a_{t+1}}}^{\tilde{a}} S(a_{it+1}) f(a_{it}) da_i + S_{t+1}^w \right] - S_t^w, \tag{1.13}$$

where $E_t \Delta_{t,t+1} \left[(1-\rho^x) \int_{\widetilde{a_{t+1}}}^{\tilde{a}} S(a_{it+1}) f(a_{it}) da_i + S_{t+1}^w \right]$ is the joint discounted value of an existing match for a worker and a firm who are already matched.

Following Den Haan, Ramey, and Watson (2000), I assume that firms repost immediately the unfilled vacancy when a match ends by exogenous separation since this vacancy has a positive expected surplus, while firms incurring endogenous separation do not. I define the job creation and job destruction rates as follows

$$cre_t = \frac{q(\theta_t)\left(v_t - \rho^x N_t\right)}{N_t}, \tag{1.14}$$

$$des_t = \rho_t - q(\theta_t)\rho^x. \tag{1.15}$$

Job creation is the difference between total matches formed in period t, $q(\theta_t)v_t$, and matches that are refilled within the period, $q(\theta_t)\rho^x N_t$. Job destruction is the difference between total separation, $\rho_t N_t$, and matches that are refilled within the period after an exogenous separation, $q(\theta_t)\rho^x N_t$.

The retail firms

Each retailer purchases intermediate goods from wholesale firms at the price P_t^w, and use them to produce a differentiated consumption good j with no costs. Retail firms are monopolistically competitive producers. They set prices according to Calvo (1983). That is, each period a fraction δ_p of retailers does not reset their price, while the remaining fraction $(1-\delta_p)$ does.

Let $V(c_{jt+s})$ be the total cost of production. Firm chooses the price p_{jt} to solve the following profit maximization problem

$$\max_{p_{jt}} E_t \sum_{s=0}^{\infty} \delta_p^s \Delta_{t,t+s} \left[p_{jt} \pi_{t,t+s-1}^{\gamma_p} c_{jt+s} - V(c_{jt+s}) \right], \tag{1.16}$$

subject to the demand schedule

$$c_{jt+s} = \left(\frac{p_{jt}\pi_{t,t+s-1}^{\gamma_p}}{P_{t+s}}\right)^{-\gamma} c_{t+s}. \tag{1.17}$$

In equation (1.16), $\Delta_{t,t+s} = \beta^s \left(\frac{\lambda_{t+s}}{\lambda_t}\right)$ is the stochastic discount rate. In equations (1.16) and (1.17), let $\pi_{t,t+s-1} = \pi_t \times \pi_{t+1} \times ...\pi_{t+s-1}$ be the cumulative gross inflation between t and $t+s-1$. Introducing $\pi_{t,t+s-1}^{\gamma_p}$ allows for indexation to past inflation, with $\gamma_p \in \{0,1\}$ being the coefficient determining the degree of price indexation.

The first order condition can be simplified and gives :

$$\frac{p_{jt}}{P_t} = \left(\frac{\gamma}{\gamma-1}\right) \left[\frac{E_t \sum_{s=0}^{\infty} (\delta_p\beta)^s \lambda_{t+s} P_{t+s} mc_{jt+s} \pi_{t,t+s-1}^{-\gamma_p(\gamma)} \left(\frac{P_{t+s}}{P_t}\right)^{\gamma} P_t^{\gamma-1} c_{t+s}}{E_t \sum_{s=0}^{\infty} (\delta_p\beta)^s \lambda_{t+s} P_{t+s} \pi_{t,t+s-1}^{-\gamma_p(1-\gamma)} \left(\frac{P_{t+s}}{P_t}\right)^{\gamma-1} P_t^{\gamma-1} c_{t+s}} \right], \tag{1.18}$$

where $mc_{jt+s} = \frac{V'(c_{jt+s})}{P_{t+s}}$ is the real marginal cost of production for retailers.

Now, in the above equation, let $\pi_{t+1,t+s} = \frac{P_{t+s}}{P_t}$. All firms allowed to adjust their price choose the same price p_t^*. The optimal pricing decision is given by [2]

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2. In a flexible price equilibrium, retailers charge the same price which is a constant markup $\left(\frac{\gamma}{\gamma-1}\right)$ over wholesale prices.

$$p_t^* = \left(\frac{\gamma}{\gamma-1}\right)\left[\frac{E_t\sum_{s=0}^{\infty}(\delta_p\beta)^s\lambda_{t+s}P_{t+s}c_{t+s}mc_{t+s}\left(\frac{\pi_{t,t+s-1}^{\gamma_p}}{\pi_{t+1,t+s}}\right)^{-\gamma}}{E_t\sum_{s=0}^{\infty}(\delta_p\beta)^s\lambda_{t+s}P_{t+s}c_{t+s}\left(\frac{\pi_{t,t+s-1}^{\gamma_p}}{\pi_{t+1,t+s}}\right)^{1-\gamma}}\right]. \quad (1.19)$$

The aggregate price index is

$$P_t^{(1-\gamma)} = (1-\delta_p)p_t^{*(1-\gamma)} + \delta_p(P_{t-1}\pi_{t-1}^{\gamma_p})^{(1-\gamma)}. \quad (1.20)$$

In Christiano, Eichenbaum and Evans (2005), firms that are not allowed to reoptimize their prices, index them to past inflation, $P_t = \pi_{t-1}P_{t-1}$. This induces a new source of inertia in the inflation rate since current inflation depends on lagged inflation.

If $\gamma_p = 1$, there is full price indexation and the aggregate rate of inflation is given by

$$\pi_t = \frac{\beta}{1+\beta}E_{t-1}\pi_{t+1} + \frac{1}{1+\beta}\pi_{t-1} + \frac{\omega}{1+\beta}E_{t-1}\widehat{\mu}_t. \quad (1.21)$$

If $\gamma_p = 0$ there is no price indexation and the aggregate rate of inflation is

$$\pi_t = \beta E_{t-1}\pi_{t+1} + \omega\widehat{\mu}_t, \quad (1.22)$$

where $\omega = \frac{(1-\delta_p\beta)(1-\delta_p)}{\delta_p}$.

Inflation persistence is measured by the autocorrelation of current inflation relative to past inflation. Without price indexation (equation 1.22), current inflation depends on expected future inflation. The model is then unable to reproduce the empirical inflation persistence unless assuming a very high value for δ_p. With backward indexation, a new term appears in the equation (1.21), $\frac{1}{1+\beta}\pi_{t-1}$. This helps the model better match the data.

1.2.3 Monetary policy

I assume that monetary policy is described by the following Taylor rule

$$R_t = R_{t-1}^{\rho_R} \pi_t^{\phi_\pi (1-\rho_R)} \varepsilon_t^R, \tag{1.23}$$

where $\rho_R \in (0,1)$ captures the degree of interest rate smoothing, ϕ_π is a non-negative policy rule coefficient and ε_t^R is an i.i.d. shock to monetary authority with zero mean and standard deviation σ_R.

1.3 Calibration

In this section, I describe the values assigned to all parameters used in the model. The calibration is based on Walsh (2005). I assume a quarterly frequency calibration. A summary of the calibrated parameters and the steady-state is presented in Table 1.1 and Table 1.2. First, I choose the preference parameters. I set the quarterly subjective discount factor β equals to 0.99. The coefficient of relative risk aversion σ is chosen to be 2. The internal habit formation h_c is equal to 0.78. The sum of the home production b and the worker's disutility of effort L is determined residually from the critical value $\widetilde{a}$, equations (1.11) and (1.13) at steady-state.

Second, I set the labor market parameters. I normalize the quarterly steady-state total separation rate $\rho = 0.1$ to be consistent with a monthly separation rate equal to 0.034 calculated by Shimer (2005) on U.S. data from 1951 to 2003. I set the probability of finding a worker $q_s = 0.7$ as in Den Han, Ramey and Watson

(2000). The steady-state job finding rate p_s is equal to 0.6 this is similar to the value used by Cooley and Quadrini (1999) and implies an average duration of unemployment of 1.67 quarters as reported by Cole and Rogerson (1999).

To calculate the steady-state exogenous separation rate ρ^x, I follow the approach used in Den Han, Ramey and Watson (2000). They use the quarterly plant-level data from U.S. manufacturing, from 1972Q2 to 1988Q4, and find a job creation rate equal to 0.052. Since job destruction must equal job creation in the steady-state, $des = \rho - q_s\rho^x = 0.052$, hence $\rho^x = 0.068$. I can then find the steady-state endogenous separation rate, $\rho^n = F(\widetilde{a}) = 0.034$. The average U.S. unemployment rate between 1951Q1 and 2012Q1 is about 6 percent, so I target a steady-state unemployment rate at 0.06 and find the steady-state pool of job seekers u_s equals 0.154. I choose the elasticity of matches to unemployment ξ to be 0.4 which is consistent with the estimates of Blanchard and Diamond (1989) and the calibration used by Cooley and Quadrini (1999). The firm's bargaining power η is equal to 0.5, this value is within the range of values used in the literature.[3] From steady state, the vacancy posting cost is equal to 0.06 while the efficiency parameter of the matching function is equal to 0.65. Following the approach used in Walsh (2005), I assume that $\widetilde{a}$ is log normally distributed, serially uncorrelated, with standard deviation σ_a equal to 0.13.

Third, I choose the New-Keynesian model parameters. Following Walsh (2005), I set the Calvo parameter, δ_p, equal to 0.85. However, I also look at the sensitivity of findings to a lower value of δ_p. The elasticity of substitution between differentiated goods γ is 11, which corresponds to a steady-state price markup

3. The worker's bargaining power $(1 - \eta)$ used in the literature varies from 0.4 in Merz (1995) to 0.72 in Shimer (2005).

of 10 percent under zero trend inflation. I set $\gamma_p = 0$ in the model with no price indexation and $\gamma_p = 1$ in the variant of the model with indexation to past inflation.

Finally, I set the monetary policy and shock parameters. The monetary policy is conducted by a Taylor rule in which : $\rho_R = 0.9$ is the parameter capturing the degree of interest rate smoothing and $\phi_\pi = 1.1$ is the coefficient on inflation. The standard deviation of the monetary shock, $\sigma_R = 0.002$, following Walsh (2005). For the aggregate productivity shock, I set $\rho_z = 0.95$ and $\sigma_z = 0.01$, this standard deviation is selected to match statistics from simulated data for empirical measures of the statistical univariate representation of the process for the logarithm of U.S. real GDP.

1.4 Simulation results

In this section, I study the contribution of backward indexation in the New Keynesian model with labor market search frictions. I use the model developed in Walsh (2005) as a reference and show that the performance of this model is widely attributed to the presence of the backward indexation hypothesis rather than the frictions in the labor market alone.

1.4.1 Impulse responses

In order to show graphically the effects of backward indexation on equilibrium dynamics, I compare the response of the economy to monetary and technology shocks in the model with and with no backward indexation.

Monetary Shocks

Figure 1.1 plots the impulse responses of output, inflation, nominal interest rate and vacancies to a one standard deviation expansionary monetary shock (i.e.

a negative shock to the Taylor rule). The dash-dot lines are the responses of each variable when $\gamma_p = 1$. This is the variant of the model where prices are fully indexed to lagged inflation, as in Walsh (2005). The impact response of inflation is positive, quite persistent and displays a hump-shaped response.

Backward indexation produces higher inflation persistence due to the presence of lagged inflation in the (NKPC), equation (1.21). In addition to that, price adjustment to aggregate disturbances becomes larger. This occurs because more firms adjust prices with indexation. Indeed, in the retail sector, there is a fraction $(1 - \delta_p)$ of firms allowed to re-optimize their prices following Calvo (1983). These firms choose the new price p_t^*. The remaining fraction δ_p, does not reset their price but are allowed to readjust prices to past aggregate inflation. So, in both cases firms change prices either by re-optimization or re-adjustment. This is reflected in the response of the inflation that is both more pronounced and more persistent following the expansionary monetary shock, as seen in Figure 1.1 (c) (dash-dot lines curve).

Output and employment rise by about 0.2 percent on impact of the monetary policy shock. Their responses are persistent and follow a hump-shaped pattern. Vacancies rise immediately following the monetary shock and return to their initial value after 10 quarters.

Table 1.3 presents some evidence on the role played by the backward price indexation hypothesis in generating impulse responses following a monetary shock. The panel A and B show responses to the shock on impact in the model with backward indexation and in the model without backward indexation, respectively. The most important effect occurs with respect to inflation. Price indexation increases the maximum impact on inflation from 0.11 to 0.24 percent. This peak impact occurs 9 periods after the monetary shock rather than 1 period.

The solid lines in Figure 1.1 are the responses of each variable when $\gamma_p = 0$. The inflation response is less persistent following a monetary shock because there is no lagged inflation term in equation (1.22). Without indexation, prices are more rigid because firms which receive a signal of non-reoptimization δ_p keep the same price. Inflation responds weakly to monetary shock (solid line curve in Figure 1.1 (c)). The more sluggish price adjustment leads to a larger expansion in output. Firm posts more vacancies. As a result, the dynamic path of employment shows a larger increase in the model without backward indexation.

This result is shown in Table 1.3, when $\gamma_p = 0$, the output reaches a peak of 0.47 percent and this peak occurs 5 periods after the monetary shock. When $\gamma_p = 1$, the maximum impact is reduced to 0.43 percent that occurs 4 quarters following the shock.

Technology shocks

Figure 1.2 plots the impulse responses of output, inflation, nominal interest rate and vacancies to a one standard deviation technology shock, in both models with (dash-dot lines) and without (solid lines) backward indexation.

Again, the inflation response is more muted and less persistent in the model without backward indexation. The sluggishness in the price level leads to a weaker expansion in aggregate demand. As a result, the increase in the output is smaller without backward indexation. Indeed, when $\gamma_p = 0$, the output's peak response is about 0.2 percent in the ten quarter. However, when $\gamma_p = 1$, output increases and reaches a maximum of 0.7 percent after 16 quarters.

In both models, the increase in aggregate demand is not strong enough to compensate for the fact that wholesalers now need less labor to produce the same output. As a result, firms post less vacancies and employment decreases in the short-run, but increases after 2 and 5 quarters in the model with indexation and with no indexation, respectively.[4]

1.4.2 Comparative statistics

Table 1.4 generates standard deviations for selected variables relative to that of output. The first column presents the moments for variables computed with U.S. data. The second column shows moments for the variant of the model with indexation ($\gamma_p = 1$). The last column is for the model with no price indexation ($\gamma_p = 0$).[5]

When $\gamma_p = 1$, the model does a relatively good job in reproducing the statistical moments observed in U.S. data (except for the job creation rate).

When $\gamma_p = 0$, the model fails in matching the empirical volatility ratios for all selected variables. For example, the output volatility is reduced from 1.65 to 0.93 when the indexation is turned off.

As shown before, following a technology shock, the inflation response is more muted in the model without indexation than in the model with indexation. The increase in the output following this shock is not enough, without indexation, to help the model reproducing the observed output volatility. Hence, when $\gamma_p = 0$, the model reproduces only 58 percent of the output empirical volatility. In addition

4. Gali (1999) and Liu and Phaneuf (2007) showed that improvements in technology lead to a decline in hours in the short-run. Basu, Fernald and Kimball (2006) showed that a positive technology shock decreases total hours within the first year but increases them after 2 years.

5. The standard deviations calculated from U.S. data (first column) is taken from Cooley and Quadrini (1999) and Walsh (2005). Cooley and Quadrini (1999) use H.P detrended data from 1959Q1 through 1996Q4.

to that, the standard deviations of the labor market variables (employment, job creation rate and job destruction rate) and the inflation relative to output are too high in comparison to those observed in the U.S data. For example, the standard deviation of the job destruction rate relative to output rises from 4.25 to 7.21 when I cancel backward indexation from the model. This can be explained mainly, by the failure of the model matching the empirical output volatility.

1.5 The inflation dynamics

In this section, I study how the inflation dynamics is affected by the degree of nominal rigidity and by the presence of search frictions.

1.5.1 Varying the degree of nominal rigidity

In equations (1.21) and (1.22), the flexibility of inflation is largely determined by the response of inflation to the real marginal cost, which itself depends on the value of the composite parameter ω. If ω is small, the inflation responds weakly to a change in $\widehat{\mu}_t$, which means that inflation is not very flexible. A small value for ω is determined by a high fraction of unchanged prices δ_p.

In Figure 1.3, I investigate the effects of the Calvo parameter variation (δ_p) on the inflation response to a monetary shock (Panel A) and to a technology shock (Panel B). The left figures in Panel A and B show inflation responses with $\delta_p = 0.85$, while the figures on the right side correspond to $\delta_p = 0.6$.

In both models (with and without indexation), reducing the degree of price stickiness increases the magnitude and the peak effect of the inflation response. This also has a major effect on the period in which the maximum effect occurs when the model includes indexation (dash-dot lines). For example, reducing the degree of price stickiness, changes the peak effect from 9 quarters to 6 quarters (Panel A, dash-dot lines).

Varying the degree of nominal rigidity from 0.85 to 0.6, has more effects on inflation dynamics in the model with no indexation than in the model with indexation. Indeed, the inflation response to both shocks is nearly four times larger in the model with no indexation if I reduce δ_p from 0.85 to 0.6 (solid lines). However, this response is nearly two times larger in the model with indexation, if I reduce δ_p to 0.6 (dash-dot lines). This occurs because, without indexation, the degree of price stickiness is the key parameter that helps capturing more inflation persistence, see equation (1.22). However with backward indexation, inflation persistence is measured by the autocorrelation of the current inflation relative to past inflation, see equation (1.21).

Finally, with $\delta_p = 0.6$ the inflation response is more persistent in the model with no indexation than in the variant of the model with indexation.

1.5.2 Effects of search frictions

Figure 1.4 plots the impulse responses of inflation to monetary shock with two different models. Panel A plots the response of inflation in the New Keynesian model with search frictions in the labor market. Panel B plots the response of the inflation in the standard New Keynesian model without search frictions. In both panels, the solid line and the dash-dot line are respectively associated to the case without and with backward indexation. The left figures in Panel A and B show the inflation responses with the degree of nominal rigidity $\delta_p = 0.85$, those on the right side correspond to $\delta_p = 0.6$.

I start with the case of $\delta_p = 0.85$ and $\gamma_p = 1$. In Figure 1.4 (c), the inflation rises following the monetary shock reaches a peak of 0.86 after 5 quarters, then returns to its value after 14 quarters. In the model with search frictions (Figure 1.4 (a)), the response of inflation is smaller, more delayed and more persistent than in the standard New Keynesian model. The maximum impact occurs after 9 quarters and the response of inflation is still positive after 20 quarters.

With search frictions, the inflation responds less to the monetary shock and is more persistent in comparison to the response generated in the standard New Keynesian model.

Figure 1.4 (b) shows the response of the inflation in the New Keynesian model with search frictions when the degree of nominal rigidity is reduced to $\delta_p = 0.6$. With indexation, the peak increase in inflation is about 0.57 and occurs after 6 quarters.

If I compare the dash-dot lines in Figure 1.4 (b) and Figure 1.4 (c), one sees that the New Keynesian model with search frictions requires less degree of price stickiness to generate inflation dynamics closer to the one generated in the standard New Keynesian model.

In the standard New Keynesian model, the number of hours worked changes significantly following a monetary shock. This induces sizeable fluctuations in wages and real marginal costs (the labor supply elasticity is small). As a consequence, the response of the inflation to monetary shock is high and this is not in line with empirical evidence.

The introduction of search frictions in the labor market modifies the nature of the real marginal cost. Trigari (2009), shows that allowing for the extensive margin (number of employees) induces a significantly lower elasticity of marginal costs with respect to output. A smaller variation in real marginal cost reduces the volatility of the inflation and increases its persistence.

Now I describe results with $\gamma_p = 0$. In Figure 1.4 (c), the inflation increases sharply, reaches a peak of 0.75 after 1 quarter. As in the model with search frictions, the inflation loses the hump-shaped pattern when the indexation is turned off. If I compare inflation dynamics in Panel A and B with $\gamma_p = 0$, the introduction of search frictions helps the model capturing more inflation persistence with less degree of nominal rigidity. The introduction of backward indexation helps both models (the New Keynesian model with and with no search frictions) getting delayed inflation responses to monetary shock with hump-shaped pattern.

1.6 Conclusion

In this paper, I analyze the impact of backward price indexation on the short-term dynamic propagation in a New-Keynesian model with search frictions in the labor market. Despite criticisms against this hypothesis, the authors continue to introduce it systematically in their models. My results show that the performance of this class of model is not related to an endogenous mechanism but mainly to the presence of the indexation hypothesis, which is at odds with direct microeconomics evidence and does not have a solid theoretical foundation.

Without backward indexation, the model is not able to reproduce the output volatility observed in U.S. data as well as the empirical standard deviation of the labor market variables and inflation relative to output. The response of the inflation is less persistent following the monetary and technology shocks and loses the hump-shaped pattern. The responses of output, employment and vacancies following technology shocks are less pronounced and less persistent.

The inflation dynamics is also sensitive to the degree of price stickiness and the search frictions introduced in the model especially when the indexation backward is turned off.

In future research, I extend the analysis and assume that the model is log-linearized around a positive inflation steady state. Ascari (2004) emphasizes changes in the long-run and the short-run properties of sticky-price model when trend inflation is positive. I investigate the effects of positive trend inflation on inflation and labor market variables dynamics when the model does not introduce indexation to past inflation.

Table 1.1 Parameter values in the model with no price indexation

Parameter	value	Description
β	0.99	Subjective discount factor
σ	2	Coefficient of relative risk aversion
h_c	0.78	The internal habit formation parameter
ρ	0.1	Total separation rate
ξ	0.4	The matching function elasticity
η	0.5	The firm's bargaining power parameter
κ	0.06	Vacancy posting cost
δ_p	0.85	Probability of price non-reoptimization
γ	11	Elasticity of substitution among differentiated goods
γ_p	0	Indexation to past inflation
ζ	0.65	Efficiency parameter of the matching function
ρ_R	0.9	Degree of interest rate smoothing
ϕ_π	1.1	Taylor rule's coefficient on inflation
σ_R	0.002	Standard deviation of monetary shock
ρ_z	0.95	Autocorrelation coefficient of the aggregate productivity shock
σ_z	0.01	Standard deviation of the aggregate productivity shock
σ_a	0.13	Standard deviation of the idiosyncratic productivity shock

Table 1.2 Steady-state

Variable	Definition	Value
q_s	The probability of firm finding worker	0.7
p_s	The steady-state job finding rate	0.6
ρ^x	The exogenous separation rate	0.068
ρ^n	The endogenous separation rate	0.034
π	Steady-state inflation	1
U_s	Unemployment rate	0.06
u_s	The number of job seekers	0.154

Table 1.3 Effects of backward indexation on variables following a monetary shock

Variable	Impact		
	Total	Max	Period
Panel A : $\gamma_p = 1$			
Output	4.39	0.43	4
Inflation	3.88	0.24	9
Employment	2.86	0.28	3
Vacancies	5.11	1.87	0
Panel B : $\gamma_p = 0$			
Output	6.89	0.47	5
Inflation	1.21	0.11	1
Employment	4.48	0.31	4
Vacancies	8.41	1.99	0

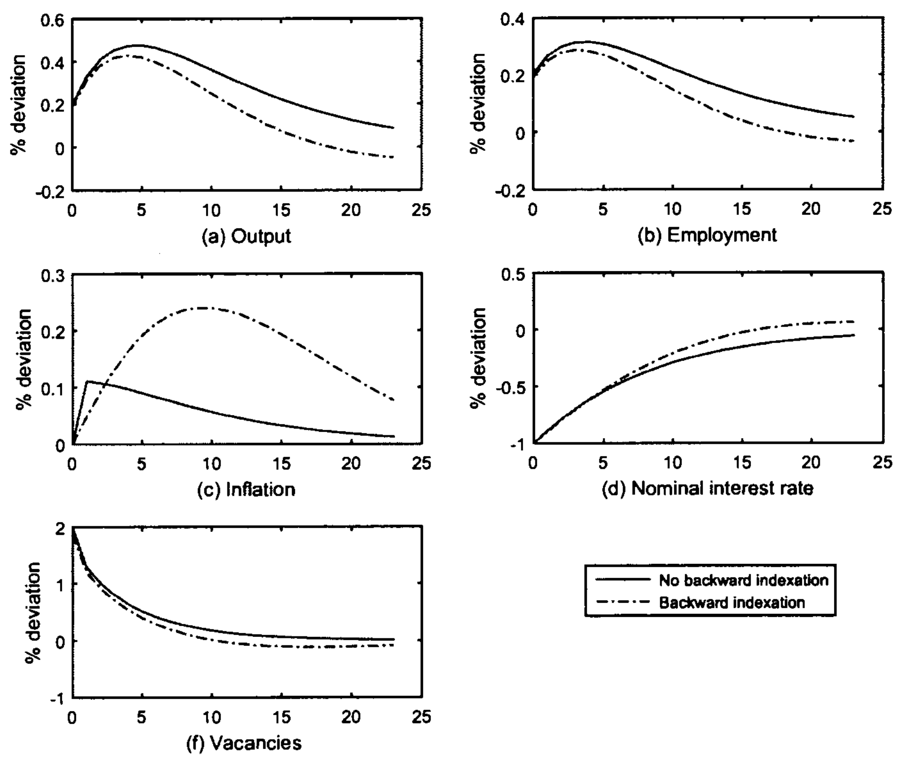
Note : This table shows the effects on selected variables following a monetary shock with and without price indexation. Panel A corresponds to results in the variant of the model with indexation. Panel B corresponds to results in the variant of the model with no indexation. The column labeled (Period) corresponds to number of quarters after shock in which maximum effect occurs.

Table 1.4 Relative standard deviations

	U.S. data	$\gamma_p = 1$	$\gamma_p = 0$
Output (σ_y)	1.60	1.65	0.93
Employment (σ_n/σ_y)	0.62	0.70	0.85
Job creation rate (σ_{jc}/σ_y)	2.89	3.90	5.68
Job destruction rate (σ_{jd}/σ_y)	4.26	4.25	7.21
Inflation (σ_π/σ_y)	0.35	0.43	0.53

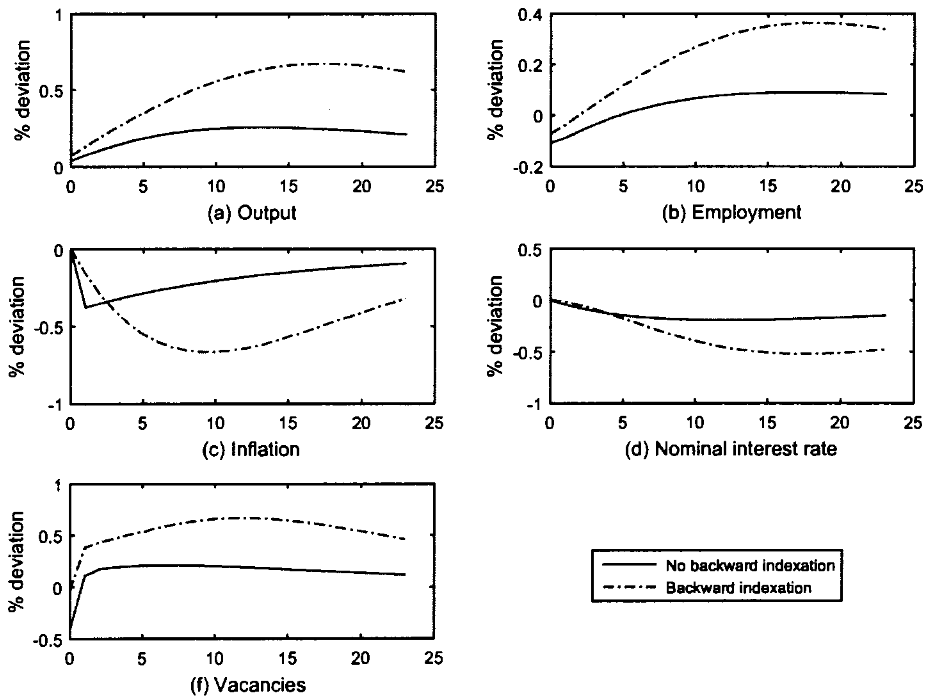
Note : This table calculated the standard deviations of employment, job creation rate, job destruction and inflation relative to that of output. The first column corresponds to the moments computed from the U.S. data. The second and the third column show the corresponding statistics respectively for the models with ($\gamma_p = 1$) and without ($\gamma_p = 0$) backward price indexation.

Figure 1.1 Impulse responses to a monetary shock



Note : This figure shows the impulse responses of output, employment, inflation, nominal interest rate and vacancies following an expansionary monetary shock. The dash-dot lines are responses in the model with price indexation to past inflation ($\gamma_p = 1$). The solid lines are responses in the model without price indexation ($\gamma_p = 0$).

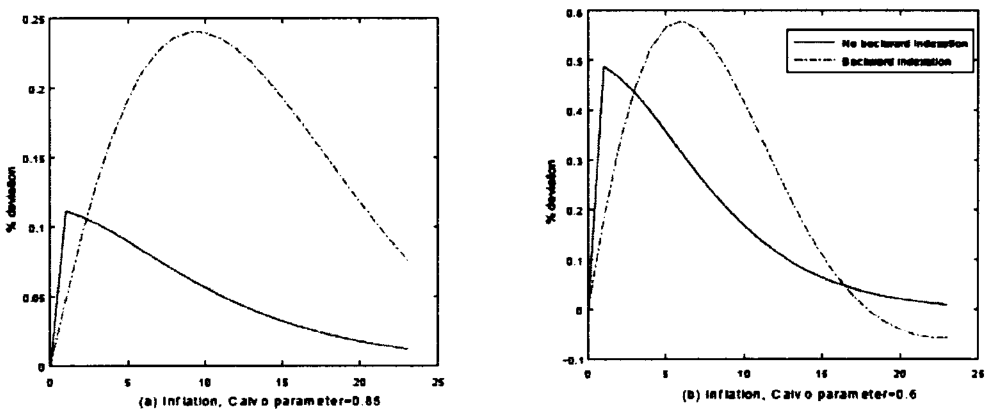
Figure 1.2 Impulse responses to a productivity shock



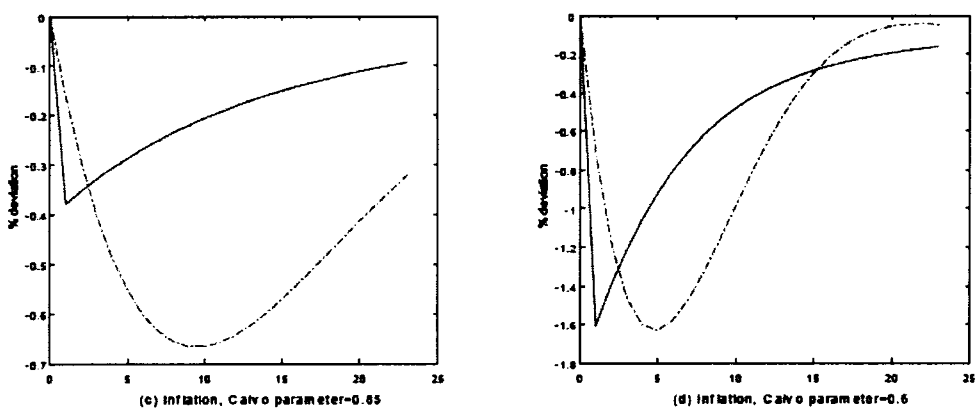
Note : This figure plots the impulse responses of output, employment, inflation, nominal interest rate and vacancies to one deviation productivity shock. The dash-dot lines are responses in the model with price indexation to the past inflation ($\gamma_p = 1$). The solid lines are responses in the model without price indexation to the past inflation ($\gamma_p = 0$) .

Figure 1.3 Effects of Calvo parameter on inflation

Panel A: following a positive monetary shock

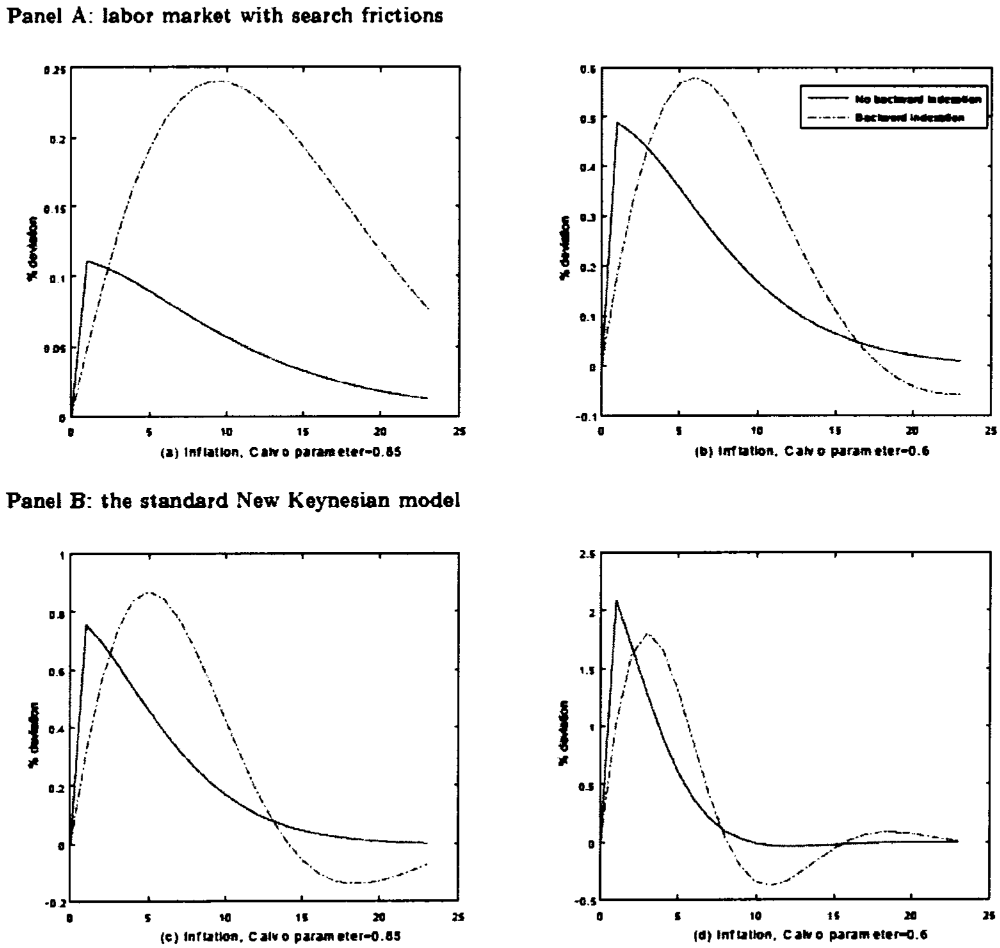


Panel B: following a positive technology shock



Note : This figure plots the impulse responses of inflation to a monetary shock (panel A) and to a technology shock (panel B). Figures (a) and (c) correspond to models with a Calvo parameter value $\delta_p = 0.85$. Figures (b) and (d) correspond to models with the Calvo parameter reduced to 0.6. The dash-dot line plots the inflation response in the model with price indexation to the past inflation ($\gamma_p = 1$). The solid line is the inflation response in the model without price indexation ($\gamma_p = 0$).

Figure 1.4 Effects of search frictions on inflation in response to monetary shock



Note : This figure plots the impulse responses of inflation to monetary shock with different values of Calvo parameter. The panel A plots responses of inflation in the New Keynesian model with search frictions. The panel B shows responses of inflation the standard New Keynesian model without search and matching. Figures (a) and (c) correspond to models with Calvo parameter $\delta_p = 0.85$. Figures (b) and (d) correspond to models with Calvo parameter reduced to 0.6. The dash-dot lines are variables responses in the model with price indexation to the past inflation ($\gamma_p = 1$). The solid lines are variables responses in the model without price indexation ($\gamma_p = 0$).

CHAPITRE II

LABOR MARKET VOLATILITY, INVESTMENT SHOCKS AND TREND INFLATION

Abstract

The standard search and matching model is known for its failure to reproduce the U.S. cyclical movements of unemployment, vacancies and labor market tightness at the onset of a total factor productivity (TFP) shock (Shimer, 2005). Evidence indicates that these variables are nearly 10 times more volatile than the standard model suggests. I address these failures of the basic model by proposing a New Keynesian model with search frictions in the labor market that allows for an important interaction between modest trend inflation and investment shocks. This interaction has been overlooked so far in the literature. The distorting effects of positive trend inflation are much stronger when it interacts with the investment shock. With positive trend inflation, firms choose a higher price markup to prevent the erosion of their future relative price and profits by trend inflation. To satisfy the efficiency equilibrium condition and to compensate the sharp decline in consumption following a positive investment shock, total hours increase. As a consequence, firm posts more vacancies and unemployment decreases. This has an important impact on raising labor market volatility. Under a reasonable calibration, the model generates relative volatilities of labor market variables that are between 60 and 80 percent of their empirical values. The volatility of unemployment relative to productivity represents 83 percent of what is found in the data.

Keywords : Labor market fluctuations ; investment shocks ; New Keynesian model ; search and matching model ; trend inflation.

2.1 Introduction

The standard Diamond-Mortensen-Pissarides (DMP) search and matching model has difficulty generating labor market volatility. Shimer (2005) argues that the DMP model with period-by-period Nash wage bargaining is unable to reproduce the cyclical movement of unemployment and vacancies found in U.S. data following a labor productivity shock. In the data, the standard deviation of the labor market tightness (vacancy-unemployment ratio) is 20 times larger than the standard deviation of labor productivity. But in the DMP model, these volatilities are nearly the same. Shimer (2005) argues that this problem is connected to the way wages are treated in this type of model. Under period-by-period Nash bargaining, higher wages absorb most of the increase in the labor productivity, reducing firms' incentive to post vacancies. As a consequence, a labor productivity shock has little impact on labor market volatility.

Much of the literature has addressed this anomaly while proposing alternative solutions. A prominent example is Shimer (2005), who argues that introducing wage rigidity in new jobs helps amplify labor market fluctuations. Gertler and Trigari (2009) introduce staggered multiperiod wage contracting in the search and matching model. Each period, only a fraction of firms and workers receive a signal allowing them to reset their wages. Their wage is a generalization of the standard Nash bargaining solution. This produces spillover effects of aggregate wages introducing higher real wage stickiness. The model is then, able to capture unemployment and labor market volatility observed in the data. [1]

In this paper, I keep the standard Nash bargaining wage and I contribute

1. Other solutions to the volatility of the labor market problem include (i) assuming high labor supply elasticities in real business models (Chetty, Guren, Manoli and Weber 2013) ; and (ii) high replacement ratios (Hagedorn and Manovskii 2008).

to this literature by using a New Keynesian model with search frictions in the labor market. I assume a non-zero inflation rate in the steady state equilibrium. I then assess the ability of the model to account for the volatile behavior of unemployment, vacancies, labor market tightness and the firm's job finding when the economy is subject to three type of shocks : monetary shock, neutral technology shock, and investment shock.

My motivation is threefold. First, the introduction of search frictions in New Keynesian models has become a popular way to explain the joint fluctuations in output, inflation and labor market variables. Christiano, Eichenbaum and Trabandt (2016) estimate a Dynamic Stochastic General Equilibrium model (DSGE) in which the wage determination is not subject to exogenous wage rigidity. They show that their model succeeds in reproducing the business cycle properties of labor markets. My model does not contain the same wage specification as in Christiano, Eichenbaum and Trabandt (2016) since I keep the wage bargaining solution. By doing so, I do not mean to imply that wage rigidities may not play a role. My goal is to identify a new mechanism that contributes to resolve the volatility problem without using wage stickiness.

Second, the data in developed countries after the World War II show a low positive average inflation rate. All the New Keynesian model literature with search and matching, with the exception of Alves (2016), are log-linearized around a zero inflation steady state. Ascari (2004) emphasizes changes in the long-run and the short-run properties of sticky-price model when trend inflation is positive. Coibion and Gorodnichenko (2011) show that the Taylor principle cannot guarantee a determinate equilibrium when they allow for a positive trend inflation.

Third, and most importantly, investment shocks have been identified as an amplification mechanism in the volatility of labor market variables. Faccini and

Ortigueira (2010) and Toledo and Silva (2010) use a Real Business Cycles (RBC) model with search and matching. They show that investment shocks have a large impact on labor market fluctuations. Greenwood, Hercowitz, and Krusell (2000), Fisher (2006), and Justiniano and Primiceri (2008) find that these shocks are important in generating observed volatility of U.S. macroeconomic variables.

This paper is related to the literature that studies business cycle fluctuations in labor market variables. However, I assume a positive trend inflation. I evaluate the contribution of the interaction between an investment shock and a positive trend inflation to the volatility of labor market.

My framework shares similarities with the model of Alves (2016), which highlights the importance of a positive trend inflation in increasing fluctuations in the labor market without introducing wage rigidities.

My paper differs from that of Alves (2016) along the following dimensions. First, I use a model that realistically includes variable capital utilization and the costs of adjusting the flow of investment. In Alves (2016), there is no physical capital in the model. Second, I investigate the effects of positive trend inflation not only on labor market fluctuations but on equilibrium dynamics when the economy is driven by three different shocks (monetary, neutral technology and investment shocks). Alves (2016) considers that the economy is hit by preference, monetary and aggregate neutral technology shocks.

Third, I study the contribution of each shock in the volatility of the labor market variables and the impact of adding a positive trend inflation rate on the impulse responses of key variables following these shocks. Fourth, whereas Alves (2016) considers a model, in which firms making price decisions are subject to search frictions. I separate pricing decisions from hiring decisions to eliminate any source of amplification coming from other mechanisms unrelated to investment shock and trend inflation. According to Thomas (2011), the interaction between pricing and vacancy posting decisions creates real rigidities in prices that amplify fluctuations in the labor market.

The impulse responses generated by my model show that positive trend inflation increases the volatility and the persistence of labor market variables much more when it interacts with investment shock than with TFP and monetary shocks. When I compare the model (with positive trend inflation) with the data, I find that it outperforms the model with zero trend inflation in matching evidence on vacancies and unemployment. For example, the unemployment standard deviation observed in data for the 1951Q1 to 2008Q2 sample period is about 12.17 percent. The model with zero trend inflation is able to generate 69 percent of its empirical value. The model with positive trend inflation, is able to explain 83 percent of the observed volatility in unemployment.

When I analyze the standard deviation of key variables (unemployment, vacancies and labor market tightness) relative to output or to productivity, the interaction between trend inflation and the investment shock contributes largely to improve labor market fluctuations. For example, the positive trend model generates around 60 percent of the volatility of key variables relative to the output observed in U.S. data compared to 45 percent with the zero trend model. Similarly, volatilities of key variables, in absolute term and relative to the productivity (y/n) in the positive trend model, account for more than 80 percent of fluctuations observed in the U.S. data compared to 70 percent in the zero trend model.

The intuition is straightforward : the impact of the positive trend inflation rate on inflation response is more important when it interacts with positive investment shock than with TFP and monetary shocks. With positive trend inflation, firms are more forward-looking because they know that they may be stuck with the price set at t and that inflation will therefore erode their markup over time. As a result, firms ends choosing a higher price markup. Since investment is more profitable, households try to take advantage of this investment boom by saving more so they substitute consumption for investment. To satisfy the efficiency equilibrium condition and to compensate the sharp decline in consumption, total hours increase. As a consequence, firms post more vacancies and unemployment decreases. This has an important impact on raising labor market volatility.

Note that this paper is also connected to other frameworks that introduce investment technology shocks in search and matching models. Toledo and Silva (2010) investigate the impact of investment shocks on labor market fluctuations in a standard RBC model with search and matching with zero trend inflation. Their model generates about 80 percent of unemployment volatility observed in the U.S. data, in absolute terms. However it reproduces only 40 percent of vacancies volatility observed in the U.S. data. My model with positive trend inflation, accounts for 88 percent of the vacancies empirical value.

Faccini and Ortigueira (2010) study the implication of investment shocks in a business cycle model with search frictions and find that these shocks account for 40 percent of the observed volatility in U.S. labor productivity. Their model with three types of shocks (neutral, investment and job separation shocks) accounts for 43 percent, 78 percent and 45 percent of the observed volatility in unemployment, vacancies and labor market tightness, respectively. My model (with neutral, investment and monetary policy shocks) generates 82, 88 and 82 percent of the observed standard deviations in unemployment, vacancies and labor market tightness, respectively.

Both Toledo's and Silva's (2010), and Faccini's and Ortigueira's (2010) models differ from my model as I consider : a DSGE model with sticky prices, real frictions, endogenous monetary policy, and positive trend inflation.[2]

This paper is organized as follows. Sections 2.2 and 2.3 describe the model and the calibration, respectively. Section 2.4, presents impulse responses of the model following different shocks. Section 2.5 reproduces labor market statistics implied by my model and compares results with U.S. data. In this section, I discuss, quantitatively, the role of investment shock and positive trend inflation in reproducing labor market volatilities. Section 2.6 concludes.

2.2 The Model

In this section, I present a DSGE model with search and matching frictions in the labor market. The economy is composed of households, wholesale firms, retail firms and a monetary authority. Wholesalers produce intermediate goods in a competitive market, hire workers and negotiate wages according to Nash Bargaining. Retailers buy intermediate goods from wholesalers, repackage and sell them as final goods to households in a monopolistic competitive labor market. They set prices as in Calvo (1983). Following Walsh (2005), Ravenna and Walsh (2008), Gertler, Trigari and Sala (2008), Thomas (2008) and Blanchard and Gali (2010), I separate retailers from wholesalers to disentangle the two frictions in the model. I allow for variation in hours per employee at the intensive margin and

2. Other papers with investment shocks are Michelacci and Lopez-Salido (2007) and De Bock (2007). De Bock's (2007), results show a limited role for investment shocks in generating amplification in labor market variables compared to a standard RBC model. Michelacci and Lopez-Salido (2007) explore the effects of neutral technology and investment shocks on the labor market, especially in job destruction. They find that positive neutral technological shocks increase job destruction and reduce aggregate employment, while positive investment shocks reduce job destruction and are expansionary.

in employment at the extensive margin. The model includes two real frictions : investment adjustment costs and variables capital utilization. Finally, I add to this model a positive trend inflation rate in an economy characterized by three source of fluctuations : a monetary shock, a neutral technology shock and an investment shock. To develop this model, I follow Thomas (2008), Trigari (2009), Gertler, Trigari and Sala (2008) and Ascari, Phaneuf and Sims (2015).[3]

2.2.1 The labor market

The labor market is characterized by frictions in search and matching. Unemployed workers take time before finding a job and firms are subject to hiring costs. The number of new hires is given by the matching function in period t, $M(u_t, v_t) = \zeta u_t^{\epsilon} v_t^{1-\epsilon}$. u_t is the number of searching workers, v_t is the number of vacancies posted by firms, ζ is the match efficiency and ϵ is the match elasticity with respect to unemployment. I set the labor force equal to one, so u_t represents also the unemployment rate and $n_t = 1 - u_t$ is the employment rate. The probability that an unemployed worker finds a job is $p(\theta_t) = M(u_t, v_t)/u_t = M(1, \theta_t)$, where $\theta_t = \frac{v_t}{u_t}$ is a ratio denoting the labor market tightness. The probability that a firm finds a worker is $q(\theta_t) = M(u_t, v_t)/v_t = M(1/\theta_t, 1)$. Matches end according to the exogenous rate of job destruction, $\lambda \in (0, 1)$.

The evolution of the employment rate is given by

3. Ascari, Phaneuf and Sims (2015), evaluated the New Keynesian model's welfare cost of moderate trend inflation. Their model assessed the effects of positive trend inflation on the business cycle when the DSGE model is characterized by : (i) price and wage rigidities, (ii) roundabout production function, (iii) trend growth in investment-specific and neutral technology, and iv) shock to marginal efficiency of investment. However, their model abstracts from search frictions in the labor market.

$$n_{t+1} = (1-\lambda)n_t + p(\theta_t)(1-n_t). \tag{2.1}$$

2.2.2 Households

I assume the presence of continuum households that are either employed or searching for a job. Following Merz (1995), I use the perfect insurance market assumption, so consumption is the same across households regardless of their labor income due to their situation in the job market. The representative household chooses consumption c_t, investment I_t, nominal bonds B_{t+1}, physical capital K^p_{t+1}, and capital utilization Z_t to maximize the utility function

$$E_t \sum_{s=0}^{\infty} \beta^s \left(\frac{c_{t+s}^{1-\sigma}}{1-\sigma} - n_{t+s}b - \int_0^1 n_{it+s} \frac{h_{it+s}^{(1+\eta)}}{1+\eta} di \right), \tag{2.2}$$

where β is the subjective discount factor, σ is the intertemporal elasticity of substitution, b is the fixed work disutility (e.g. time lost in transport), η is the inverse Frisch elasticity of labor supply, n_{it} is the number of employed workers in firm $i \in [0,1]$ and h_{it} is the number of hours per employee in firm i.

Aggregate consumption is $c_t = \left(\int_0^1 c_{jt}^{\frac{\gamma-1}{\gamma}} di \right)^{\frac{\gamma}{\gamma-1}}$, where γ is the elasticity of substitution among differentiated goods j. The household's budget constraint is

$$\begin{aligned} & B_t + \int_0^1 n_{it} W_t(h_{it}) di + R_t^k Z_t K_t^p + \Pi_t + T_t \\ \geq \;\; & P_t(c_t + I_t + a(Z_t)K_t^p) + E_t D_{t,t+1} B_{t+1}, \end{aligned} \tag{2.3}$$

where $W_t(h_{it})$ is the nominal wage per employee as a function of hours h_{it}. Let T_t be lump sum transfers from government and Π_t be the nominal dividends received by households from firms. I allow households to own the capital stock, choose capital utilization Z_t to transform physical capital K_t^p into capital services, $K_t = Z_t K_t^p$, and rent it to firms at the nominal rental rate R_t^k. Aggregate price level P_t satisfies $P_t = \left(\int_0^1 P_{jt}^{1-\gamma} di\right)^{\frac{1}{1-\gamma}}$.

Households use their total income from labor, dividends, bonds, capital rent and lump sum transfers to consume, invest and purchase new nominal bonds whose date t discount price is $D_{t,t+1}$, such that $E_t D_{t,t+1} = \frac{1}{1+R_t}$, where R_t is the nominal interest rate at period t. Households spend part of their revenue to pay the cost of capital utilization per unit of physical capital $a(Z_t)$, I assume $a(1) = 0$, $a'(1) = 0$ and $a''(1) > 0$. In steady state, $Z = 1$. The resource cost of utilization is defined by following functional form :

$$a(Z_t) = \gamma_1(Z_t - 1) + \frac{\gamma_2}{2}(Z_t - 1)^2. \tag{2.4}$$

The physical capital accumulation process is

$$K_{t+1}^p = \varepsilon_t^I(1 - S(\frac{I_t}{I_{t-1}}))I_t + (1 - \delta)K_t^p, \tag{2.5}$$

where δ is the rate depreciation, ε_t^I is the investment shock and $S(\frac{I_t}{I_{t-1}})$ is the adjustment investment cost given by :

$$S(\frac{I_t}{I_{t-1}}) = \frac{s_1}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2. \tag{2.6}$$

Assuming $S(1) = 0, S'(1) = 0$, $S''(1) > 0$,and $s_1 \geq 0$ being a free parameter. This adjustment cost function is standard in the literature.

The exogenous investment shock ε_t^I is described by the following autoregressive process

$$\varepsilon_t^I = (\varepsilon_{t-1}^I)^{\rho_i} \exp(\mu_t^i). \tag{2.7}$$

The first order conditions with respect to c_t, B_{t+1}, Z_t , I_t and K_{t+1}^p are

$$\lambda_t^{AR} = U_c(c_t) = c_t^{-\sigma}, \tag{2.8}$$

$$\lambda_t^{AR} = \beta(1+R_t)E_t\lambda_{t+1}^{AR}\frac{1}{\pi_{t+1}}, \tag{2.9}$$

$$r_t^k = a_z(Z_t), \tag{2.10}$$

$$\begin{aligned} \lambda_t^{AR} &= \lambda_t^B \varepsilon_t^I \left[1 - S(\frac{I_t}{It-1}) - S'(\frac{I_t}{It-1})\frac{I_t}{It-1}\right] \\ &+\beta E_t \lambda_{t+1}^B \varepsilon_{t+1}^I S'(\frac{I_{t+1}}{It})(\frac{I_{t+1}}{It})^2, \end{aligned} \tag{2.11}$$

$$\lambda_t^B = E_t\lambda_{t+1}^B\beta(1-\delta) + E_t\lambda_{t+1}^{AR}\beta\left\{r_{t+1}^k Z_{t+1} - a(Z_{t+1})\right\}, \tag{2.12}$$

where λ_t^A, is the marginal utility of consumption, λ_t^B is the value of installed capital in consumption units and $\lambda_t^{AR} = P_t\lambda_t^A$. In equation (2.9), $\pi_{t+1} = \frac{P_{t+1}}{P_t}$. Furthermore, according to equations (2.10) and (2.12), $r_t^k = \frac{R_t^k}{P_t}$ and $r_{t+1}^k = \frac{R_{t+1}^k}{P_{t+1}}$, are the real rental capital rate for the period t and $t+1$, respectively.

2.2.3 The wholesale firms

The wholesale firm i rents the capital services K_{it} from households, hires n_{it} employees and uses technology to produce its homogenous intermediate goods

y_{it}. The production function is

$$y_{it} = A_t K_{it}^{\alpha} (n_{it} h_{it})^{1-\alpha}, \tag{2.13}$$

where A_t is the neutral technology shock that obeys the stochastic process,

$$A_t = (A_{t-1})^{\rho_a} \exp(\mu_t^a). \tag{2.14}$$

Since I separate pricing decisions from vacancies-posting decisions, only the wholesaler faces a frictional labor market. The firm posts vacancies and pays hiring costs χ in order to produce its intermediate goods that it sells to retail firms in a competitive environment at the real price mc_t. In equation (2.14) μ_t^a is an i.i.d shock.

The net value of employment for the firm is expressed as follows

$$F_{it} = mc_t A_t K_{it}^{\alpha} (n_{it} h_{it})^{(1-\alpha)} - w_{it}(h_{it}) n_{it} - \frac{\chi}{U_c(c_t)} v_{it} - r_t^k K_{it} + E_t \beta_{t,t+1} F_{it+1}, \tag{2.15}$$

where $w_{it}(h_{it}) = \frac{W_{it}(h_{it})}{P_t}$ is the real wage, $\frac{\chi}{U_c(c_t)}$ is the marginal cost of posting a vacancy and $\beta_{t,t+1} = \beta \frac{\lambda_{t+1}^{AR}}{\lambda_t^{AR}}$ is the firm's stochastic discount factor between t and $t+1$.

Each period, the wholesaler chooses the capital services stock K_{it} and the number of vacancies v_{it} to maximize (2.15) subject to

$$n_{it+1} = (1-\lambda) n_{it} + q(\theta_t) v_{it}. \tag{2.16}$$

The latter equation describes the evolution of employment in firm i. It shows that new employees go to work next period.

The corresponding first-order conditions are :

$[K_{it}]$:

$$r_t^k = \alpha mc_t A_t \left(\frac{n_{it}h_{it}}{K_{it}}\right)^{(1-\alpha)}. \tag{2.17}$$

$[v_{it}]$:

$$\frac{\chi}{U_c(c_t)} = q(\theta_t) E_t \beta_{t,t+1} \frac{\partial F_{it+1}}{\partial n_{it+1}}. \tag{2.18}$$

To simplify the analysis, I assume that capital is perfectly mobile across firms and that wholesalers face constant returns to scale in production. This implies that firms choose the same capital-labor ratio $\frac{K_{it}}{n_{it}h_{it}} = \frac{K_t}{n_t h_t}$. Equation (2.17) states that the real rental rate is equal to the marginal productivity of capital. Equation (2.18) describes the relation between the marginal cost of posting a vacancy, the probability of filling a vacancy and the value of the marginal worker in the next period $t+1$.

From equation (2.15), the value of an additional worker in firm i is

$$H_{it} = mc_t A_t (1-\alpha)(\frac{K_t}{n_t h_t})^{\alpha} h_{it} - w_t\,(h_{it}) + (1-\lambda)\beta_{t,t+1} E_t H_{it+1}, \tag{2.19}$$

where $H_{it} = \frac{\partial F_{it}}{\partial n_{it}}$ and $H_{it+1} = \frac{\partial F_{it+1}}{\partial n_{it+1}}$

From equations (2.18) and (2.19), the firm's hiring decision is given by

$$\frac{\chi}{q(\theta_t)} = \beta E_t [U_c(c_{t+1}) \{mc_{t+1} mpl_{t+1} h_{it+1} - w_{t+1}\,(h_{it+1})\} + (1-\lambda)\frac{\chi}{q(\theta_{t+1})}], \tag{2.20}$$

with $mpl_{it+1} = mpl_{t+1} = A_{t+1}(1-\alpha)(\frac{K_{t+1}}{n_{t+1}h_{t+1}})^{\alpha}$, being the marginal productivity of labor in the following period. It is the same across firms, since firms choose the same capital-labor ratio.

2.2.4 Workers

Before explaining how wage is determined in this model, I develop the worker's net value of employment at firm i, denoted by J_{it}. Let V_t be the household welfare, which can be rewritten in the following recursive form

$$V_t = \frac{c_t^{1-\sigma}}{1-\sigma} - n_t b - \int_0^1 n_{it} \frac{h_{it}^{(1+\eta)}}{1+\eta} di + \beta E_t V_{t+1}. \tag{2.21}$$

From equations (2.1), (2.3), (2.21) and with $n_t = \int_0^1 n_{it} di$, I can calculate $\frac{\partial V_t}{\partial n_{it}}$ which is the marginal contribution of a worker to household's welfare.[4] The worker's surplus in term of consumption goods is $J_{it} = \left(\frac{\partial V_t}{\partial n_{it}}\right) / U_c(c_t)$ and can be described by the following equation

$$\begin{aligned} J_{it} &= w(h_{it}) - \frac{b + \frac{h_{it}^{(1+\eta)}}{1+\eta}}{U_c(c_t)} - p(\theta_t)\beta_{t,t+1} \int_0^1 \frac{v_{It}}{v_t} E_t J_{I,t+1} dI \\ &\quad +(1-\lambda)\beta_{t,t+1} E_t J_{it+1}. \end{aligned} \tag{2.22}$$

2.2.5 Wage bargaining

I follow most of the labor search literature and assume that wage is determined by Nash bargaining between the wholesale firm and the worker. This is consistent with the approach laid out in Shimer (2005). However, I also want to investigate whether the model can generate larger fluctuations in the labor market without wage stickiness. Every period, firms and workers bargain over the joint surplus of their work relationship, $J_{it} + H_{it}$, and choose the wage that maximizes

4. $\frac{\partial V_t}{\partial n_{it}} = U_c(c_t)\frac{W_t(h_{it})}{P_t} - b - \frac{h_{it}^{(1+\eta)}}{1+\eta} - p(\theta_t)\beta_{t,t+1}\int_0^1 \frac{v_{It}}{v_t} E_t \frac{\partial V_{t+1}}{\partial n_{It+1}} dI + (1-\lambda)\beta_{t,t+1} E_t \frac{\partial V_{t+1}}{\partial n_{it+1}}$,
with $p(\theta_t)\frac{v_{IT}}{v_t}$: is the probability for an unemployed member to be match to firm $I \in [0,1]$.

the Nash product $w\left(h_{it}\right)=\arg\max\left\{H_{it}^{\xi}J_{it}^{1-\xi}\right\}$. The parameter ξ determines the bargaining power of the firm. The first order condition gives the surplus sharing rule

$$(1-\xi)H_{it}=\xi J_{it}. \tag{2.23}$$

Equations (2.19), (2.22) and (2.23) yield the wage equation

$$\begin{aligned} w(h_{it}) &= (1-\xi)[mc_t mpl_t h_{it}]+\xi[\frac{b}{U_c(c_t)}+\frac{\frac{h_{it}^{1+\eta}}{1+\eta}}{U_c(c_t)} \\ &\quad +p(\theta_t)\beta_{t,t+1}\int_0^1\frac{v_{IT}}{v_t}E_tJ_{It+1}dI]. \end{aligned} \tag{2.24}$$

Firms and workers choose hours per employee that maximize the joint surplus of their match. Hence, the first order condition with respect to h_{it} is $mc_t mpl_t=\frac{h_{it}^{\eta}}{U_c(c_t)}$. The marginal productivity of labor being the same across firms $mpl_{it}=mpl_t$, I use the last equation to replace h_{it} by h_t, so I can write the labor supply equation as follow

$$h_t=(mc_t mpl_t U_c(c_t))^{1/\eta}. \tag{2.25}$$

In equation (2.24), I can drop the subscript i since hours are equalized across firms. Using equation (2.18), (2.19), (2.23) and (2.24) the wage equation is [5]

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5. From equation (2.18) and (2.19), $\frac{\chi}{U_c(c_t)}=q(\theta_t)E_t\beta_{t,t+1}H_{it+1}$. From (2.23), I can write $J_{it}=\frac{(1-\xi)}{\xi}H_{it}\iff\int_0^1\frac{v_{IT}}{v_t}E_t\beta_{t,t+1}J_{It+1}dI=\frac{(1-\xi)}{\xi}\int_0^1\frac{v_{IT}}{v_t}E_t\beta_{t,t+1}H_{It+1}dI=\frac{(1-\xi)}{\xi}\frac{\chi}{Uc(c_t)}\frac{1}{q(\theta_t)}$

$$w(h_t) = (1-\xi)[mc_t mpl_t h_t + \frac{\chi}{U_c(c_t)}\theta_t] + \xi[\frac{b}{U_c(c_t)} + \frac{\frac{h_t^{1+\eta}}{1+\eta}}{U_c(c_t)}]. \qquad (2.26)$$

This equation expresses the real wage as a weighted average of the marginal revenue product, the marginal saving on vacancy-costs and the disutility of labor in term of consumption units.

From equation (2.26) and $mc_t mpl_t = \frac{h_t^{\eta}}{U_c(c_t)}$, equation (2.20), can be rewritten as

$$\frac{\chi}{q(\theta_t)} = \beta E_t[\xi\left(\frac{\eta}{1+\eta}h_{t+1}^{1+\eta} - b\right) - (1-\xi)\chi\theta_{t+1} + (1-\lambda)\frac{\chi}{q(\theta_{t+1})}]. \qquad (2.27)$$

which determines the firm's hiring decision.

2.2.6 Retailers

Firms in the retail sector buy intermediate goods from wholesalers at the real price mc_t, and then repackage and sell them as final goods to households under monopolistic competition. Prices at the retail level are set according to Calvo (1983) contracts. That is, in each period a fraction δ_p of retailers does not reset its price, while the remaining fraction $1-\delta_p$ does.

Let y_{jt} be the quantity of final goods sold by retailer j to the households at the nominal price P_{jt}. Aggregate output is $y_t = (\int_0^1 y_{jt}^{(\frac{\gamma-1}{\gamma})} dj)^{\frac{\gamma}{\gamma-1}}$. Firms that are allowed to reoptimize their price maximize their discounted expected future profits

$$\max_{P_{jt}} E_t \sum_{s=0}^{\infty} \delta_p^s \beta_{t,t+s}(P_{jt}\pi_{t,t+s-1}^{\gamma_p} y_{jt+s} - CT(y_{jt+s})), \qquad (2.28)$$

subject to the demand schedule

$$y_{jt+s} = (\frac{P_{jt}\pi_{t,t+s-1}^{\gamma_p}}{P_{t+s}})^{-\gamma} y_{t+s}, \tag{2.29}$$

where $CT(y_{jt+s})$ is the total cost of producing the final good and $\pi_{t,t+s-1} = \pi_t \times \pi_{t+1} \times ...\pi_{t+s-1}$ is the cumulative gross inflation between t and $t+s-1$. Introducing $\pi_{t,t+s-1}^{\gamma_p}$ in equation (2.28) would allow the possibility of indexing prices to past inflation, $\gamma_p \in (0,1)$ being the coefficient determining the degree of price indexation. However, in my model, there is no price indexation, so $\gamma_p = 0$.

The first order condition with respect to P_{jt} is given by

$$P_{jt} = \frac{\gamma}{\gamma-1} \frac{E_t \sum_{s=0}^{\infty} \delta_p^s \beta_{t,t+s} CT'(y_{jt+s}) \pi_{t,t+s-1}^{-\gamma_p(\gamma)} P_{t+s}^{\gamma} y_{t+s}}{E_t \sum_{s=0}^{\infty} \delta_p^s \beta_{t,t+s} \pi_{t,t+s-1}^{\gamma_p(1-\gamma)} P_{t+s}^{\gamma} y_{t+s}}, \tag{2.30}$$

where $\beta_{t,t+s} = \beta \frac{\lambda_{t+s}^{AR}}{\lambda_t^{AR}}$. This equation can be rewritten as

$$p_t^* = \frac{\gamma}{\gamma-1} \frac{E_t \sum_{s=0}^{\infty} (\delta_p \beta)^s \lambda_{t+s}^{AR} \frac{CT'(y_{jt+s})}{P_{t+s}} \pi_{t,t+s-1}^{-\gamma_p(\gamma)} \pi_{t+1,t+s}^{\gamma} y_{t+s}}{E_t \sum_{s=0}^{\infty} (\delta_p \beta)^s \lambda_{t+s}^{AR} \pi_{t,t+s-1}^{\gamma_p(1-\gamma)} \pi_{t+1,t+s}^{\gamma-1} y_{t+s}}, \tag{2.31}$$

where $\lambda_{t+s}^{AR} = P_{t+s}\lambda_{t+s}$, and $p_t^* = \frac{P_{jt}}{P_t}$.This last equation can also be written as[6]

$$p_t^* = \frac{\gamma}{\gamma-1} \frac{x_t^1}{x_t^2}, \tag{2.32}$$

where

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6. From equation (2.31), I can write $p_t^* = \frac{\gamma}{\gamma-1}\frac{x_t^1}{x_t^2}$, where $x_t^1 = \lambda_t^{AR} mc_t y_t + \delta_p \beta \pi_{t,t}^{-\gamma_p(\gamma)} \pi_{t+1,t+1}^{\gamma} x_{t+1}^1$. Since $\pi_{t,t} = \frac{P_t}{P_{t-1}} = \pi_t$ and $\pi_{t+1,t+1} = \frac{P_{t+1}}{P_t}$, I have $x_t^1 = \lambda_t^{AR} mc_t y_t + \delta_p \beta (\frac{\pi_t^{\gamma_p}}{\pi_{t+1}})^{-\gamma} x_{t+1}^1$.

$$x_t^1 = \lambda_t^{AR} mc_t y_t + \delta_p \beta (\frac{\pi_t^{\gamma_p}}{\pi_{t+1}})^{-\gamma} x_{t+1}^1, \tag{2.33}$$

$$x_t^2 = \lambda_t^{AR} y_t + \delta_p \beta (\frac{\pi_t^{\gamma_p}}{\pi_{t+1}})^{1-\gamma} x_{t+1}^2. \tag{2.34}$$

As reported by Ascari and Sbordone (2014), equation (2.31) contains expected future inflation rates in both the numerator and the denominator, that affect the relative weights on future variables. Firms need to worry about future inflation because the price fixed at t may be unchanged for several periods and the inflation will therefore erode their markup over time. As a result, firms use future expected inflation rates to discount future marginal costs. Firms become than more forward-looking, because they give more weight to future than to present economic conditions.

2.2.7 Monetary policy

I assume that the monetary policy is described by a Taylor rule stating that the nominal interest rate reacts to changes of inflation from steady state inflation and to output growth. The monetary policy rule is given by

$$\frac{(1+R_t)}{(1+R)} = [(\frac{\pi_t}{\pi})^{\phi_\pi} (\frac{y_t}{y_{t-1}})^{\phi_y}]^{1-\rho_R} [\frac{(1+R_{t-1})}{(1+R)}]^{\rho_R} \varepsilon_t^R, \tag{2.35}$$

where R is the steady-state nominal interest rate, $\rho_R \in (0,1)$ captures the degree of interest rate smoothing, ϕ_π and ϕ_y are non-negative policy rule coefficients and ε_t^R is an i.i.d. monetary policy shock.

2.2.8 Aggregation

The aggregate resource constraint is :

$$y_t = c_t + I_t + a(Z_t)K_t^p + \frac{\chi}{U_c(c_t)}v_t, \tag{2.36}$$

Given constant returns to scale in production, and since in equilibrium total supply from wholesalers must equal demand by retailers. I can write :

$\int_0^1 A_t(n_{it}h_{it})^{(1-\alpha)}K_{it}^{\alpha}di = \int_0^1(\frac{P_{jt}}{P_t})^{-\gamma}y_t dj$, so that $\int_0^1 A_t(n_{it}h_{it})\left(\frac{K_{it}}{n_{it}h_{it}}\right)^{\alpha}di = \int_0^1(\frac{P_{jt}}{P_t})^{-\gamma}y_t dj$.

With $n_t = \int_0^1 n_{it}di$, aggregate output can be written :

$$A_t(n_t h_t)^{(1-\alpha)}K_t^{\alpha} = s_t y_t, \tag{2.37}$$

where $s_t = \int_0^1(\frac{P_{jt}}{P_t})^{-\gamma}$ is a measure of price dispersion.

Given properties of Calvo (1983) price setting, aggregate inflation evolves according to :

$$1 = \delta_p(\frac{\pi_{t-1}^{\gamma_p}}{\pi_t})^{(1-\gamma)} + (1-\delta_p)p_t^{*(1-\gamma)}. \tag{2.38}$$

Recursively the price dispersion variable s_t can be written as :

$$s_t = (1-\delta_p)p_t^{*(-\gamma)} + \delta_p(\frac{\pi_{t-1}^{\gamma_p}}{\pi_t})^{-\gamma}s_{t-1}. \tag{2.39}$$

2.3 Calibration

In this section, I describe the values assigned to the parameters of the model. I assume a quarterly frequency calibration. Table 2.1 and Table 2.2 summarize parameter and steady state values.

Preference parameters

The quarterly subjective discount factor β is equal to 0.99, which implies a 4 percent annual steady-state real-interest rate. The intertemporal elasticity of substitution σ is set to 1 as in Blanchard and Gali (2007). The inverse Frisch elasticity of labor supply, η^{-1}, is also set to 1.

Labor market parameters

The value of quarterly job separation rate $\lambda = 0.1$ is consistent with a monthly separation rate equal to 0.034 in accordance with by Shimer (2005) and U.S. data from 1951 to 2003.[7] Accordingly, jobs last, on average, two years and six months. Following Toledo and Silva (2010), steady-state unemployment rate u_s is 0.11. This is a higher unemployment rate than typically used in most papers to include individuals who want to work and are searching for jobs while classified as inactive. Blanchard and Diamond (1990) use data from the Current Population Survey (CPS) that cover the period from 1968 to 1986. They calculate an average stock of unemployed workers of 11.2 million. From this number, there are 6.5 million of unemployed people and 4.7 million of people who are not in the labor force and "want a job".[8]

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7. This is also consistent with an average monthly separation rate of 3.4 percent as in the Job Openings and Labor Turnover Survey from 2001 to 2011.

8. Den Haan, Ramey, and Watson (2000) and Krause and Lubik (2007) set $u_s = 0.12$, Trigari (2009) estimates $u_s = 0.25$. Andolfatto (1996) sets the employment rate at $n_s = 0.54$.

The probability of finding a worker $q_s = 0.7$ follows Den Haan, Ramey and Watson (2000). The matching elasticity ϵ is 0.7. This choice is consistent with Shimer (2005) and matches the range of plausible values $\epsilon \in [0.5, 0.7]$ in Petrongolo and Pissarides (2001). The firm's bargaining power ξ, is equal to 0.7. I fix the steady state hours per employee h_s at 0.33 and the work disutility parameter $b = 0.4$. To calibrate the utility cost of posting a vacancy χ, I follow Andolfatto (1996) and Blanchard and Gali (2010) and set the steady-state ratio of vacancy posting utility cost to GDP, $d_s = \frac{\chi v_s}{y_s U_c(c_s)}$, to 1 percent. Hence, $\chi = \frac{y_s U_c(c_s)}{v_s} = 0.3575$. From steady-state, the efficiency parameter of the matching function, ζ is equal to 0.741.

New Keynesian model parameters

I set the Calvo parameter, δ_p, equal to 0.75, implying that firms keep their prices unchanged during 4 quarters. In the DSGE literature, there is some uncertainty about the duration of price contracts. Nakamura and Steinsson (2008) use data sets provided by the U.S. Bureau of Labor Statistics to calculate the duration of each price spell, and they find that prices remain unchanged for 7 to 9 months, in mean frequency, when product substitutions are included, and between 8 to 11 months when product substitution are excluded. Bils and Klenow (2004) estimate the frequency of price changes for 350 categories of goods and find that half of prices last less than 4.3 months in median. Trigari (2009) sets the probability Calvo equal to 0.85 that corresponds to an average duration of price rigidity of 6.5 quarters. Blanchard and Gali (2010) assume 4 quarters of price rigidity.

The elasticity of substitution between differentiated goods γ is 11, which correspond to a steady-state price markup of 10 percent when the inflation rate at steady state $\pi = 1$. There is no price indexation in the model, so $\gamma_p = 0$. The depreciation rate on physical capital δ is equal to 0.025. $\alpha = 0.33$ is the share parameter on capital service in the Cobb-Douglas production function. I choose the investment adjustment cost parameter $s_1 = 3$ following Christiano, Eichenbaum, and Evans (2005). γ_1 and γ_2, the coefficients in the utilization cost function, are set as follows : $\gamma_2 = 0.15$ as Justiniano, Primiceri, and Tambalotti (2010, 2011), and γ_1 is such that the capital utilization Z_t is equal to 1 at steady-state. The inflation rate at steady-state is $\pi = 1.0092$. To calculate the inflation rate at steady state, I use the annual seasonally adjusted Consumer Price Index for All Urban Consumers calculated by U.S. Bureau of Labor Statistics between 1951 to 2008. I find an annual inflation rate about 3.75 percent. This implies $\pi = (1.0375)^{0.25} = 1.0092$ at quarterly frequency.

Monetary policy and shock parameters

The monetary policy is conducted by a Taylor rule in which : $\rho_R = 0.8$ is the parameter capturing the degree of interest rate smoothing, $\phi_\pi = 1.5$ is the coefficient on inflation and $\phi_y = 0.125$ is the coefficient on output growth. The standard deviation of the monetary shock, σ_R is set at 0.0022 which is standard in the literature.

To calibrate the neutral technology shock, the AR(1) coefficient $\rho_a = 0.95$ and the standard deviation $\sigma_a = 0.0078$, as reported in Faccini and Ortigueira (2010). The investment shock follows an AR(1) process. With autocorrelation coefficient $\rho_i = 0.95$ and standard deviation $\sigma_i = 0.0578$, in accordance with the estimate in Justiano, Primiceri and Tambalotti (2010). In estimated DSGE models with an investment shock, this shock is customary found to be much larger than a TFP shock (e.g. see Justiano, Primiceri, 2008 ; Justiano, Primiceri and Tambalotti, 2011 ; Khan and Tsoukalas, 2012 ; Phaneuf and Victor, 2017).

2.4 Impulse responses

Three type of shocks affect labor market fluctuations and equilibrium dynamics under zero and positive trend inflation.

Figures 2.1, 2.2 and 2.3 present the impulse responses of the following variables to each shock : output, consumption, investment, hours per employee, inflation, real marginal cost, labor market tightness, vacancies, the marginal rate of substitution (MRS) between consumption and labor, capital utilization, unemployment, total hours, real wage, the marginal product of labor (MPL) and the price markup. The dotted lines show the impulse responses of key variables if trend inflation is set at 0 percent. The solid lines show the responses to shocks under a positive trend inflation of 3.75 percent.

2.4.1 Monetary policy shock

Figure 2.1 displays the response of selected variables following one percent positive shock to the nominal interest rate. The monetary shock decreases both output and inflation. However, the impact effect on inflation is smaller with positive trend inflation, while this impact on output is higher.

A positive trend inflation decreases the short-run price adjustments of firms allowed to change their price; consequently there is a smaller drop on impact in the inflation response to the interest rate. As reported by Ascari and Sbordone (2014), a higher trend inflation reduces the slope of the New Keynesian Phillips Curves. This is responsible for the smaller reaction of inflation following the monetary shocks.

The reaction of consumption, investment, capital utilization and hours per employee are slightly higher with positive trend inflation. As shown in equation

(2.27), the firm's hiring decision depends on fluctuations in expected hours per employees. Since the decrease of the output is larger, with a positive trend inflation, firms post less vacancies and the unemployment is larger. In conclusion, trend inflation tends to increase the volatility and the persistence of macroeconomic variables, especially for the labor market variables.

2.4.2 Neutral technology shock

Figure 2.2 plots impulse responses to a one percent positive neutral technology shock. A positive trend inflation reduces the impact effect of TFP shock on output and inflation. As described above, trend inflation slows down the price adjustment that slightly reduces the reaction of the inflation following this shock. The price level affects the demand schedules of firms which is then reflected in a smaller expansion of output on impact. As in Gali (1999), following a positive technology shock, a firm requires less labor input to produce, hence total hours decline in the short run. Since the adjustment in total hours occurs at both the intensive and the extensive margins, hours per employee react slightly more with moderate trend inflation. Hence firms post fewer vacancies and unemployment is substantially larger on impact. The labor market tightness is more volatile with positive trend inflation.

2.4.3 Investment shock

In this section, I study fluctuations in macroeconomics variables following an investment shock and assess the interaction between this shock and positive trend inflation to generate amplification.

In Figure 2.3, I report the effects of one percent positive investment shock. Under zero trend inflation, a positive investment shock implies that the price of new equipment falls, this stimulates investment and variable capital utilization. As a consequence, output increases persistently in a hump-shaped pattern. Since investment is more profitable, households try to take advantage of this investment boom by saving more so they substitute consumption for investment. As a result, consumption falls on impact, keeps decreasing for four quarters, and then starts increasing turning positive after 11 quarters.

The investment shock can be seen as an aggregate demand shock that raises the current demand for investment goods relative to supply, pushing output and inflation in the same direction, so inflation increases. These impulse responses are in line with the findings of Justiniano, Primiceri and Tambalotti (2010). To meet the increase in output demand, firms postulate more vacancies, total hours increase, unemployment falls consequently and labor market tightness rises.

Next I analyze the impulse responses under positive trend inflation. I use the efficiency equilibrium condition used in Justiniano, Primiceri and Tambalotti (2010) :

$$MPL(\underset{-}{H}) = \mu \; MRS(\underset{+}{c}, \underset{+}{H}). \tag{2.40}$$

This equation implies that under monopolistic competition in the goods market, the MPL is equal to the MRS between consumption and labor times a wedge μ. This wedge is the equilibrium markup of price over marginal cost. The MPL is decreasing in hours, the MRS is increasing in consumption and in hours. Equation (2.25) can be reformulate as follows

$$mpl_t \; mc_t = \frac{h_t^{\eta}}{U_c(c_t)}, \tag{2.41}$$

which can be expressed as an efficiency equilibrium condition of this form

$$mpl_t = \mu \; mrs_t, \tag{2.42}$$

where $mrs_t = \frac{h_t^{\eta}}{U_c(c_t)}$, and $\mu = \frac{1}{mc_t}$.

In Figure 2.3, a positive trend inflation increases the impact effect of investment shock on inflation and increases the price dispersion (not reported). Since firms are more forward-looking when trend inflation is non-zero, there is a stronger distortion effect on output. Households have to reduce their consumption by much more. Since prices are sticky, the price markup changes following the investment shock. With positive trend inflation, the investment shock sharply increases the price markup, total hours should increase to satisfy the efficiency equilibrium condition and to compensate the sharp decline in consumption that negatively affects the MRS (see equation 2.40). Since the adjustment in total hours occurs at both the intensive and the extensive margins, hours per employee and vacancies increase and unemployment decreases.

From these simulations, I conclude that the effect of trend inflation on the volatility of aggregate variables, especially labor market variables, depends on the type of shock. The interaction between trend inflation and the investment shock has more effect on labor market variables than the TFP or monetary policy shocks.

2.5 Matching moments

This section first assesses the model's ability to match various moments in the data as in Shimer (2005). Next, I compare unconditional moments predictions from versions of the model with and without positive trend inflation.

2.5.1 Labor market statistics in U.S. data

I use quarterly data for the 1951Q1 to 2008Q2 sample period to calculate a set of labor market statistics for the U.S. economy. The column labeled "U.S. data" in Table 2.3 displays statistics for unemployment (u), vacancies (v) and labor market tightness (θ). Following Shimer (2005), I use the seasonally adjusted unemployment level constructed by the U.S. Bureau of Labor Statistics (BLS) from the Current Population Survey (CPS) to measure unemployment (u). To measure vacancies (v), I use the help-wanted advertising index constructed by the Conference Board.[9] The labor market tightness variable (θ) is $\frac{v}{u}$. Production (y) is output in the non-farm business sector and the labor productivity (y/n) is output per person in the non-farm business sector provided by BLS. For labor productivity (y/H), I calculate total hours (H) as the product of average hours per employee (h) and total nonfarm payroll employment (n).

All variables are logged and detrended using the Hodrick-Prescott (HP) filter with a smoothing parameter of 1600. In the literature studying the ability of the search and matching model to reproduce some key characteristics of the labor market observed in U.S. data, Shimer (2005), Faccini and Ortigueira (2010) and Alves (2016) use an HP filter with a smoothing parameter of 10^5. I use a less smooth trend component, which corresponds to a smoothing parameter of 1600 (or HP filter with higher frequency) in order to study the business cycle fluctuations. Hornstein, Krusell and Violante (2007), Barnichon (2007), Thomas (2008) and Christiano, Eichenbaum and Trabandt (2016) use also HP filter with smoothing parameter 1600. I take the quarterly average of data available at a monthly frequency.

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9. For more details about the help-wanted advertising index, see Barnichon (2010).

2.5.2 Labor market statistics in the model

Shimer (2005) considers a standard version of the DMP model, in which wage are determined by Nash bargaining. Flexible wages absorb most of the labor productivity increase, this reduces the firm's surplus and then the incentive for posting more vacancies. As a result, the model fails to account for the large fluctuations in the labor market variables relative to the fluctuations in labor productivity (a result known as the "Shimer puzzle"). For example, the labor market tightness (v/u) generated by Shimer's model is less than 10 percent as volatile as in U.S. data (3.5 percent versus 38.2 percent).[10]

Using New Keynesian model and search frictions with a non-zero inflation rate in the steady state equilibrium, the objective is to analyze how positive trend inflation affects labor market volatility when wages are determined by Nash Bargaining.

Table 2.3 compares statistics generated from the U.S. data with statistics generated from versions of the model with and without positive trend inflation, respectively. The column labeled "positive trend model" reports the volatilities of labor market variables with trend inflation equals to 3.75 percent. The one labeled "zero trend model" shows the volatilities of labor market variables with zero trend inflation. The reported volatility statistics correspond to quarterly series detrended using the HP filter.

Panel (i) generates standard deviations in absolute terms, panel (ii) reports

10. These two values are taken from Shimer (2005), Table 1 and Table 3. Note that in this framework the author uses a HP filter with smoothing parameter 10^5. To calculate my statistics I use a smoothing parameter 1600; the result remain unaltered with a smoothing parameter of 10^5.

standard deviations of selected variables relative to that of output, while panels (iii) and (iv) report standard deviations of selected variables relative to that of labor productivity.

The key finding is that positive trend inflation amplifies the size of fluctuations in unemployment, vacancies and labor market tightness either in absolute or relative terms (relative to y and to (y/n)). For example, in the data, the standard deviation of the unemployment is 12.17 percent. The positive trend model generates an unemployment volatility of 10.03 percent compared to 8.41 percent in the zero trend model. The positive trend model explains 84 percent of the observed volatility in labor market tightness relative to labor productivity (y/n), while the zero trend model generates only 68 percent of this empirical value. With positive trend inflation, the model generates a contemporaneous correlation coefficient between u and v, representing the slope of the Beveridge curve, which is -0.7868 slightly below the U.S. data (-0.8732). With zero trend inflation this correlation is equal to -0.7806.

One can notice that the positive trend model is less successful in reproducing the standard deviation of labor market variables relative to productivity (y/H). However, this is connected to the persistence of the investment shock. Table 2.6 investigates this issue.

Tables 2.4, 2.5 and 2.6 show moments predicted by model versions under zero and positive trend, conditional on one or more types of shock.

Panel (i) in Table 2.4 reports U.S. statistics. Panel (ii) is a version of the model where fluctuations are driven only by neutral technology shocks. For both cases of zero and positive trend inflation, the standard deviations of u, v and θ are reported. With zero trend inflation, the neutral technology shock accounts for only 8.7 percent of the observed volatility in vacancies and about 7 percent of the volatility of unemployment and labor market tightness. Under positive trend inflation, there is a slight improvement in this values. Neutral technology shocks do not generate strong enough labor market fluctuations.

Panel (iii), reports the results of a model driven by two shocks, namely to both monetary policy and neutral technology. Without trend inflation the unemployment volatility is only 1.41 percent which is far from the observed volatility (12.17 percent). Adding the trend inflation increases somewhat the unemployment volatility, which is then 2.40 percent. Combining both monetary policy and neutral technology shocks does not help matching moments in the data.

Panel (iv) isolates the effects of only the investment shock. With zero trend inflation, the model reproduce about 62 percent of the unemployment volatility observed in data. With positive trend inflation, the investment shock accounts for 73 percent of this latter volatility. Hence, the interaction between the investment shocks and positive trend inflation helps the model to generate higher volatilities of unemployment, vacancies and labor market tightness.

The intuition is straightforward : as shown in Figure 2.3, the impact of the positive trend inflation rate on inflation response is more important following the investment shock. With positive trend inflation, firms are more forward-looking because they know that they may be stuck with the price set at t and that inflation will therefore erode their markup over time. As a result, firms choose a higher price markup. To satisfy the efficiency equilibrium condition given by equation (2.40) and to compensate the sharp decline in consumption that negatively affects the MRS, total hours increase. As a consequence, firms post more vacancies and unemployment decreases. This has an important impact on raising labor market volatility.

The importance of investment shocks in explaining the labor market volatility was explored in Faccini and Ortigueira (2010). However, it was never explored when the model includes positive trend inflation. Faccini and Ortigueira (2010) model's with three types of shocks (neutral, investment and job separation shocks) accounts for 43 percent, 78 percent and 45 percent of the observed volatility in unemployment, vacancies and labor market tightness, respectively. Panel (v) in Table 2.4 shows that my model with positive trend inflation and all shocks (monetary, neutral technology and investment shocks) generates 82, 88 and 82 percent of the observed standard deviations in unemployment, vacancies and labor market tightness, respectively. This success is mainly explained by the interaction between the investment shocks and the positive trend inflation which acts as as amplification mechanism.

Now, I test the sensitivity of the model to a somewhat lower persistence in the investment shock, by lowering the value of the AR(1) parameter of the investment shock to 0.8.[11]Panel (vi) presents the results of this exercise with all shocks in the model. Again, adding the positive trend inflation rate in the model helps reproducing higher labor market volatility. However, the variable's volatility change (from zero to positive trend) is greater with a less persistent investment shock, even if the level of volatility remains lower.

Table 2.5 conveys information about the standard deviations of u, v and θ and relative to that of output. Table 2.6 reports standard deviation of key variables relative to two measures of productivity, i.e. (y/n) and (y/H).

Panel (i) reports moments in U.S. data. Panels (ii) to (iv) report the relative volatilities conditional on the type of shocks. With only neutral technology shock, the relative volatilities of the variables with respect to those of output and labor

11. In the literature, the autocorrelation coefficient of investment shock ranges between 0.7 and 0.95.

productivity are very low compared to the data. For example, with positive trend inflation, the unemployment volatility relative to that of output generated by the model represents 19.5 percent of the observed value (see Table 2.5). When adding the monetary policy shock to the model this result improves only slightly. Adding the investment shocks (panel (v)), helps the model to match better the relative volatilities. For example, the model with positive trend yields about 60 percent of the observed unemployment volatility relative to that of output (Table 2.5).

Panel (v) in Table 2.6 shows that the model with zero trend inflation explains better the standard deviation of the variables relative to productivity (y/H) than the positive trend model (when $\rho_i = 0.95$). However, this result is sensitive to the value of the investment autocorrelation coefficient. A less persistent investment shock in the model with three shocks, i.e. $\rho_i = 0.8$, increases the standard deviation of variables relative to productivity (y/H) in the model with positive trend inflation to better match the data.

2.6 Conclusion

I have proposed a New Keynesian model with varying capacity utilization, investment adjustment costs and nominal price rigidity that allows for search and matching in the labor market. My model has emphasized the role of investment shocks interacting with moderate positive trend inflation as a key mechanism generating labor market volatility.

While monetary policy and neutral technology shocks have a small impact on fluctuations, investment shocks generate substantial labor market volatility in this type of framework, especially from unemployment, vacancies and labor market tightness. The interaction between positive trend inflation and an investment shocks amplifies the effects of this shock on labor market fluctuations. The model allows us to explore, for the first time in the literature, the effect of investment shock in a DSGE model with search friction when trend inflation is positive.

Table 2.1 Parameter values

Parameter	value	Description
β	0.99	Discount factor
σ	1	Intertemporal elasticity of substitution
η	1	Frisch elasticity of labor supply
λ	0.1	Job separation rate
ϵ	0.7	Matching function elasticity
ξ	0.7	Firm's bargaining power
b	0.4	Fixed work disutility parameter
χ	0.3575	Vacancy posting cost
δ_p	0.75	Probability of price non-reoptimization
γ	11	Elasticity of substitution among differentiated goods
γ_p	0	Indexation to past inflation
δ	0.025	Depreciation rate
α	0.33	Share parameter of capital services
s_1	3	Investment adjustment cost
γ_2	0.15	Coefficient in the utilization cost function
ζ	0.741	Efficiency parameter of the matching function
ρ_R	0.8	Degree of interest rate smoothing
ϕ_π	1.5	Taylor rule coefficient on inflation
ϕ_y	0.125	Taylor rule coefficient on output growth
σ_R	0.0022	Standard deviation of monetary shock
ρ_a	0.95	Autocorrelation coefficient of neutral technology shock
σ_a	0.0078	Standard deviation of neutral technology shock
ρ_i	0.95	Autocorrelation coefficient of investment shock
σ_i	0.0578	Standard deviation of investment shock

Table 2.2 Steady-state

Variable	Definition	Value
h_s	Hours per worker	0.33
π	Steady-state inflation	$(1.0375)^{0.25}$
u_s	Unemployment rate	0.11
n_s	Employment	0.89
Z_s	Capital utilization	1
$d_s = \frac{\chi v_s}{y_s U_c(c_s)}$	Ratio of vacancy posting utility cost to GDP	0.01
q_s	Probability of firm finding worker	0.7

Table 2.3 Moments for model with and without positive trend inflation

		U.S. data	$\pi = 1.0092$	$\pi = 1$
(i) Standard deviation	u	0.1217	0.1003	0.0841
	v	0.1389	0.1234	0.1056
	θ	0.2550	0.2116	0.1792
(ii) Std. dev. relative to that of output	u	5.9070	3.4136	2.6076
	v	6.7427	4.1977	3.2743
	θ	12.378	7.1989	5.5544
(iii) Std. dev. relative to that of (y/n)	u	9.4341	7.8917	6.3373
	v	10.7674	9.7044	7.9574
	θ	19.7674	16.6425	13.4987
(iv) Std. dev. relative to that of (y/H)	u	11.5904	4.8175	5.9537
	v	13.2285	5.9240	7.4758
	θ	24.2857	10.1594	12.6816
(v) Cross-Correlation of u and v		-0.8732	-0.7868	-0.7806

Note : This table compares moments generated from the models with positive and zero trend inflation with statistics generated from U.S. data. The column labeled "U.S. data" presents statistics for the 1951Q1 to 2008Q2 sample period . Data sources are described in section 2.5. All variables are reported in logs as deviations from an HP trend with smoothing parameter 1600 when trend inflation is positive ($\pi = 1.0092$) and zero ($\pi = 1$). u v, θ denote the unemployment rate, vacancies and the labor market tightness. Panel (i) presents the standard deviation in absolute terms. Panels (ii) (iii) and (iv) present the standard deviation relative to those of output (y), productivity (y/n) and (y/H), respectively. In the last panel, the negative correlation of the percentage deviation of u and v from trend is the slope of the Beveridge curve.

Table 2.4 Volatility effects of trend inflation, shock sources (1)

		volatilities statistics		
Specification	$\bar{\pi}$	$\sigma(u)$	$\sigma(v)$	$\sigma(\theta)$
(i) Data	-	0.1217	0.1389	0.2550
(ii) Only technology shock	1.0000	0.0092	0.0122	0.020
	1.0092	0.0112	0.0166	0.026
(iii) Monetary + technology shocks	1.0000	0.0141	0.0245	0.0358
	1.0092	0.0240	0.0411	0.0604
(iv) Only investment shock	1.0000	0.0764	0.0967	0.1632
	1.0092	0.0894	0.1086	0.1874
(v) All shocks	1.0000	0.0841	0.1056	0.1792
	1.0092	0.1003	0.1234	0.2116
(vi) All shocks, less persistent investment shock	1.0000	0.0666	0.0915	0.1482
	1.0092	0.0932	0.1255	0.2052

Note : This table presents moments generated from the model with steady state inflation given either by 3.75 percent and 0 percent. All variables are in log levels and HP-filtered with smoothing parameter 1600. u, v, θ denote the unemployment rate, vacancies and the labor market tightness ; $\sigma(.)$ is the standard deviation of these variables. In panel (i), volatilities are generated from U.S. data for the 1951Q1 to 2008Q2 sample period. Panels (ii) and (iii) show volatilities generated by the model when the shock calibration is different. For example, in panel (ii), the economy is subject to the neutral technology shock, with the standard deviation of the monetary and the investment shocks being set to zero. In Panel (iii), a new source of fluctuation is added as the monetary shock. Panel (iv) reports statistics generated by the model when there is only investment shock. In Panel (v), all shocks are activated. In the last panel, the investment shock has a lower persistent autocorrelation coefficient, namely ρ_i=0.8 instead of 0.95.

Table 2.5 Volatility effects of trend inflation, shock sources (2)

		standard deviations relative to output		
Specification	$\bar{\pi}$	$\frac{\sigma(u)}{\sigma(y)}$	$\frac{\sigma(v)}{\sigma(y)}$	$\frac{\sigma(\theta)}{\sigma(y)}$
(i) Data	-	5.9070	6.7427	12.3780
(ii) Only technology shock	1.0000	0.8837	1.1679	1.9268
	1.0092	1.1537	1.6977	2.6588
(iii) Monetary + technology shocks	1.0000	1.0836	1.8819	2.7487
	1.0092	1.7711	3.025	4.4500
(iv) Only investment shock	1.0000	2.9184	3.6914	6.2342
	1.0092	3.8914	4.7286	8.1580
(v)All shocks	1.0000	2.6076	3.2743	5.5544
	1.0092	3.4136	4.1977	7.1989
(vi) All shocks, less persistent investment shock	1.0000	2.3591	3.2390	5.2452
	1.0092	3.0256	4.0733	6.6600

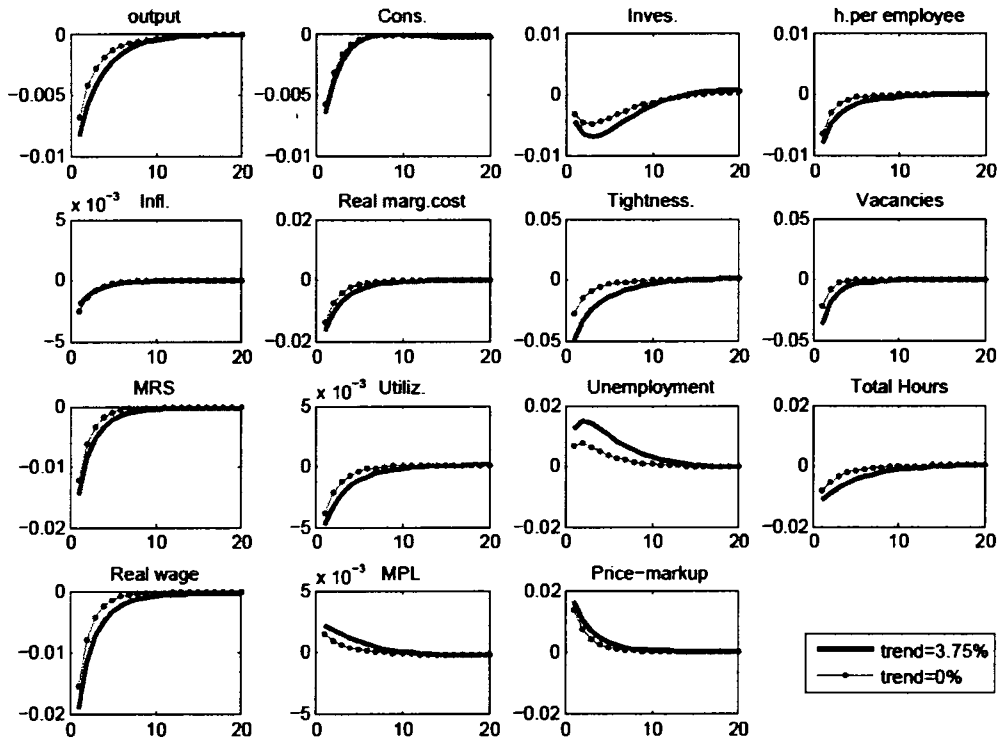
Note : This table presents standard deviations relative to that of output (y) from the model for both annualized trend inflation rate of 3.75 percent and 0 percent. All variables are in log levels and HP-filtered with smoothing parameter 1600. u, v, θ denote the unemployment rate, vacancies and the labor market tightness; $\sigma(.)$ is the standard deviation of these variables. In panel (i), volatilities are those of U.S. data for the 1951Q1 to 2008Q2 sample period, panel (ii) shows statistics generated by the model when there only one shock (neutral technology shock), while the standard deviations of the monetary and the investment shocks are set to zero. Panel (iii) shows volatilities for the model with both monetary and neutral technology shocks. Panel (iv) reports statistics for the model with the investment shock alone. Panel (v) is the model with all shocks being activated. In Panel (vi), the investment shock has a lower persistent autocorrelation coefficient, with ρ_i =0.8 instead of 0.95.

Table 2.6 Volatility effects of trend inflation, shock sources (3)

		Std. dev. relative to (y/n)			Std. dev. relative to (y/H)		
Specification	$\bar{\pi}$	$\frac{\sigma(u)}{\sigma(y/n)}$	$\frac{\sigma(v)}{\sigma(y/n)}$	$\frac{\sigma(\theta)}{\sigma(y/n)}$	$\frac{\sigma(u)}{\sigma(y/H)}$	$\frac{\sigma(v)}{\sigma(y/H)}$	$\frac{\sigma(\theta)}{\sigma(y/H)}$
(i) Data	-	9.4341	10.7674	19.7674	11.5904	13.2285	24.2857
(ii) Only technology shock	1.0000	0.9960	1.3163	2.1716	0.8571	1.1328	1.8689
	1.0092	1.1736	1.7270	2.7047	0.9323	1.3720	2.1487
(iii) Monetary + technology shocks	1.0000	1.3128	2.2799	3.3300	1.2443	2.1610	3.1563
	1.0092	2.1207	3.6220	5.3282	1.75978	3.0055	4.4214
(iv) Only investment shock	1.0000	9.9852	12.6300	21.3301	7.7838	9.8456	16.6277
	1.0092	12.184	14.8054	25.5428	5.4898	6.6709	11.5089
(v)All shocks	1.0000	6.3373	7.9574	13.4987	5.9537	7.4758	12.6816
	1.0092	7.8917	9.7044	16.6425	4.8175	5.9240	10.1594
(vi) All shocks less persi. shock	1.0000	5.1701	7.0982	11.4949	5.1575	7.0810	11.4670
	1.0092	7.8567	10.5771	17.2940	5.0705	6.8262	11.1611

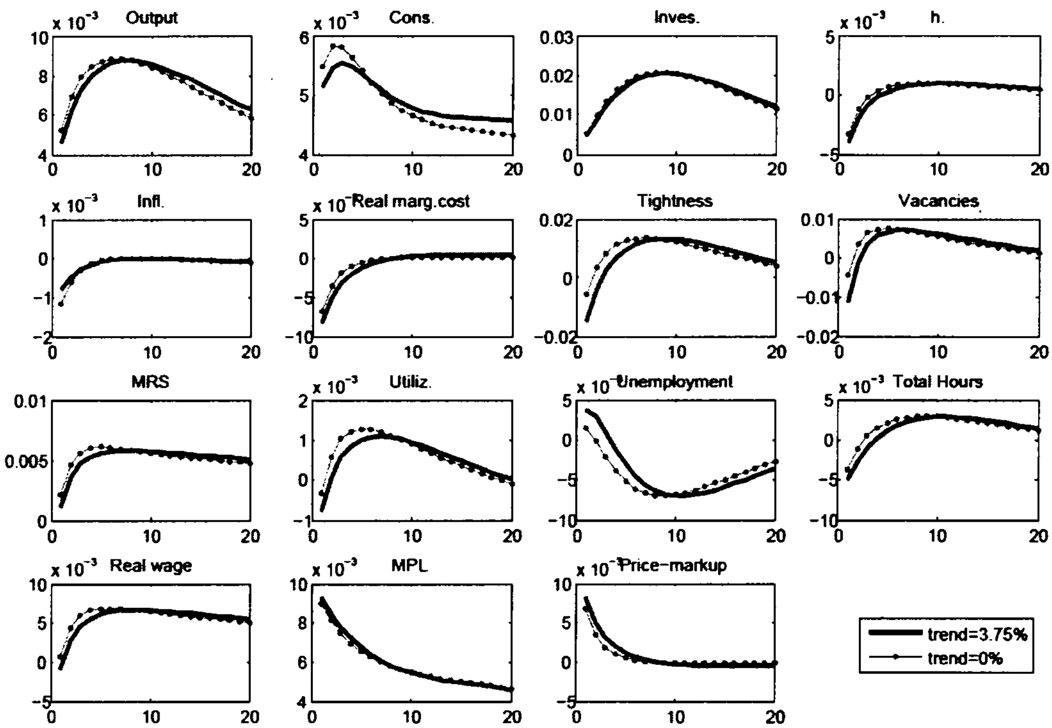
Note : This table presents standard deviations relative to those of (y/n) and (y/H) from the model with both levels of annualized trend inflation set at 3.75 percent and 0 percent. All variables are in log levels and HP-filtered with smoothing parameter 1600. u, v, θ denote the unemployment rate, vacancies and the labor market tightness; $\sigma(.)$is the standard deviation of these variables. In panel (i), volatilities are those for U.S. data for the 1951Q1 to 2008Q2 sample period. Panel (ii) shows statistics for the model with the neutral technology shock alone, while the standard deviations of the monetary and the investment shocks are set to zero. Panel (iii) shows volatilities for the model with monetary and neutral technology shocks. Panel (iv) reports statistics for the model with only an investment shock. Panel (v) is the model with all shocks being activated. In Panel (vi), the investment shock has a lower persistent autocorrelation coefficient, with ρ_i =0.8 instead of 0.95.

Figure 2.1 Impulse responses to a monetary shock



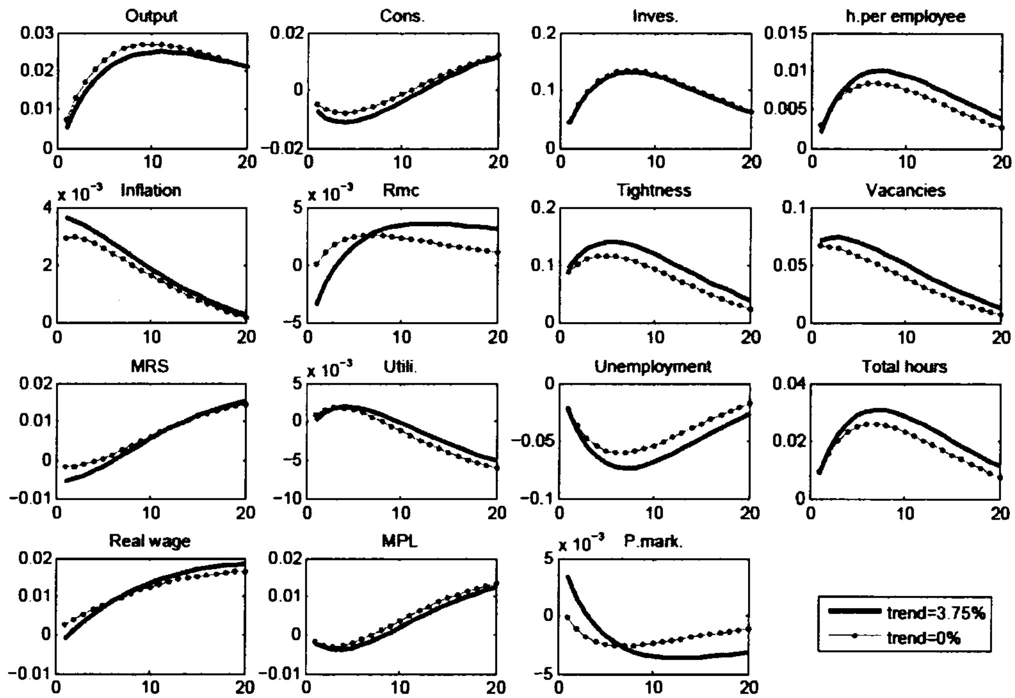
Note : This figure shows the impulse responses of key variables following a monetary shock with a 3.75 percent (solid line) and a 0 percent (dotted line) inflation trend rate.

Figure 2.2 Impulse responses to a neutral technology shock



Note : This figure shows the impulse responses of key variables following a positive neutral technology shock with a 3.75 percent (solid line) and a 0 percent (dotted line) inflation trend rate.

Figure 2.3 Impulse responses to investment shock



Note : This figure plots the impulse responses of key variables to an investment shock with a 3.75 percent (solid line) and a 0 percent (dotted line) inflation trend rate.

CHAPITRE III

INVESTMENT SHOCKS, PRODUCTION NETWORKING AND UNEMPLOYMENT

Abstract

I develop a New Keynesian model with firm networking. Real wages are determined by credible alternating offer bargaining. I provide evidence of the quantitative importance of the roundabout production structure on the transmission of monetary, neutral technology and investment shocks, when the labor market is characterized by frictions. The interaction between firm networking and credible bargaining wage generates strategic complementarity. This mechanism magnifies the effects of shocks on aggregate fluctuations, making this model more consistent with labor market and business cycle fluctuations. This amplifying effect can be seen as a complement to various forms of wage rigidity that help explaining inflation inertia and volatility of labor markets variables observed in U.S. data.

JEL classification : E24, E31, E32, J64.

Keywords : Firm networking; New Keynesian model; search and matching model, credible alternating offer bargaining.

3.1 Introduction

I propose a search and matching model that emphasizes an important interaction between production networking and a credible wage-setting device. I show that these features substantially magnify the effects of shocks on aggregate fluctuations, making this class of models more consistent with observed labor market fluctuations. The mechanism can be described as follows.

Firm networking introduces strategic complementarity among price setters. The share of intermediate input affects the real marginal cost of wholesale firms and hence production and hiring decisions. In turn, this affects the real marginal cost of retailers, and their optimal real price. Smaller variations in marginal costs cause smaller adjustments in prices. This effect is reflected in a flatter slope of the New Keynesian Phillips curve (NKPC).

The credible bargaining is another source of strategic complementarity. Take the case a firm consider a reduction in its nominal price, given the price of other firms. This increases its production demand. In this search and matching framework, employment is predetermined. The marginal cost is equal to the real marginal wage. The real marginal wage is flexible and increases with hours worked. The anticipated rise in the marginal real cost leads the firm to choose a smaller price reduction than the one initially chosen. This raises the persistence of the inflation on the one hand and increases unemployment fluctuations on the other hand.

Inflation persistence occurs because inflation becomes weakly sensitive to changes in the marginal cost. Unemployment fluctuations occur because hours per worker are the driving force for job creation. When the firm expects lager increases in hours per worker in the future, it ends up posting more vacancies today to avoid higher real marginal costs.

As many other New Keynesian models with search and matching, this model exploits the distinction between wholesale and retail firms (Walsh, 2005 ; Thomas, 2008 ; Trigari, 2009). In this setup, production and firm networking take place at the wholesale firms level. Firm networking captures the fact that a typical firm sells about half of its output to other firms and materials purchases from other firms account for roughly half of the firm's input costs. Therefore, wholesale firms in this model use intermediate inputs in addition to capital services and labor to produce goods. Retail firms buy a composite good from wholesalers which they differentiate and transform into final goods. They also set prices in a staggered fashion based on a Calvo's price-setting.

The interconnection between firm networking at the wholesale firms level and sticky prices at the retail firms level induces a multiplier for price stickiness with the potential of magnifying the effects of shocks on aggregate fluctuations. Combined with a credible wage-setting device, this mechanism helps the search and matching model to generate predictions about the volatility of consumption, unemployment, vacancies, employment, the vacancies-to-unemployment ratio and inflation that are significantly closer to the data than does a model without firm networking. In that sense, it offers a potentially new explanation of the volatility observed in the labor market and in the economy more generally.

The use of firm networking is not new in Dynamic Stochastic General Equilibrium (DSGE) models. Following the original insight of Basu (1995), it has been included in macroeconomic models by Huang, Liu and Phaneuf (2004), Dotsey and King (2006) and Nakamura and Steinsson (2010), among others. These models have been used to study the transmission of monetary policy shocks and the importance of monetary non-neutrality. Little work has been done on the significance of firm networking for the transmission and amplification of non-monetary shocks. Two notable exceptions, however, are Ascari, Phaneuf and Sims (2015,

2016) who look at the effects of total factor productivity (TFP) shocks, shocks to the marginal efficiency of investment and monetary policy shocks in a DSGE model with firm networking. Their model abstracts, however, from search and matching.

My model shares common features with the framework proposed by Gertler, Sala and Trigari (2008), including sticky prices, consumer habit formation, variable capital utilization and investment adjustment costs. However, it differs from their framework along the following dimensions.

First, unlike theirs, my model does not allow staggered Nash wage bargaining. Instead, real wage rigidity stems from a credible alternating offer bargaining (CAOB) process (Hall and Milgrom, 2008). To set the wage, employers and workers alternate in making a wage offer. Wage rigidity is then endogenous. Leaving the negotiation and choosing the outside option is not a credible threat in the bargaining problem. The threat point of the bargaining in the model with CAOB is the value of delay and not the outside options as in the standard Nash bargaining. As a result, the real wage is less responsive to labor market conditions.

Second, as explained above, wholesale firms are interconnected through networking, meaning that they use material inputs to produce. I look at the interaction between firm networking and credible wage and its effects on labor market volatility and business cycle fluctuations more generally.

I find that without firm networking (standard model), the volatilities of key labor market variables are larger than in the U.S. data. For example, the volatility of unemployment in data is about 6.51 percent, while the standard model predicts it to be 8.45 percent, i.e. 30 percent higher than its actual value. When augmenting the model to include firm networking (baseline model), the volatility of unemployment implied by the model matches that in the data.

Another result pertains to inflation dynamics. The baseline model explains about 76 percent of the actual volatility of inflation. By contrast, the standard model generates a value of inflation volatility (0.0085) higher than observed in the data (0.0060). In addition, the presence of firm networking helps the model producing stronger inflation persistence. For example, at a lag of 5 quarters, the baseline model reproduces 53 percent of the inflation autocorrelation, while the standard model accounts for only 12 percent of this autocorrelation.

When I compare the standard deviation of shocks in models with and without firm networking, I find that firm networking magnifies the effects of shocks on aggregate fluctuations to match the actual size of output growth volatility. For example, to match the actual size of output growth volatility, the baseline model delivers a standard deviation of the neutral technology shock which is 2.32 times smaller than implied by the standard model. The standard deviation of the investment shock is 1.14 smaller with a roundabout production structure. The effect of the monetary shocks is also magnified by the presence of the intermediate input with a standard deviation which is 1.4 smaller than in the standard model.

Finally, the presence of firm networking helps accounting for the positive response of consumption in response to an investment shock[1]. It helps also to account for hump-shaped responses of unemployment and vacancies following a monetary shock.

The paper is organized as follows. Section 3.2 describes the baseline model

1. Ascari, Phaneuf and Sims (2016), add a roundabout production structure and a real per capita output growth from trend growth in investment-specific and neutral technologies in New Keynesian model. They show that these ingredients help the model to generate an initial response of consumption which is positive following an investment shock. Their model do not include search frictions in the labor market.

with CAOB and firm networking. Section 3.3, presents the calibration. Section 3.4 and 3.5 discuss the characteristics of U.S. data and the simulation results, respectively. The concluding remarks are the object of section 3.6.

3.2 Model

The economy is composed of households, firms and a monetary authority. I assume there are both wholesale firms and retailers. [2] Wholesalers produce goods and make hiring decisions. Retailers buy goods from wholesaler which they differentiate and transform into retailer goods. Then, they sell goods to households. They set prices in a staggered fashion as in Calvo (1983). Fluctuations in labor input result from variation at the extensive (employment) and the intensive (hours) margins. Finally, I assume three sources of aggregate uncertainty : a monetary policy shock, a neutral technology shock and an investment shock.

3.2.1 The labor market

In the Mortensen-Pissarides model, the labor market is subject to search frictions. Firms and unemployed workers do not meet instantaneously. The matching process takes time and is costly. Firms post vacancies and have to pay hiring costs. Workers take time to find an acceptable job. Let u_t be the number of unemployed workers who are searching for a job, and v_t the number of vacancies

2. The separation between retail and wholesale sectors is used in the literature to disentangle the two frictions in the model. Hence firms that set prices are not subject to search frictions. This assumption simplifies the analysis because that separates forward-looking vacancy-posting and pricing decisions. See for example Walsh (2005), Thomas (2008), Gertler, Trigari and Sala (2008), Ravenna and Walsh (2008), Blanchard and Gali (2010) and Christiano, Eichenbaum and Trabandt (2016).

posted by firms. The labor force is normalized to one, u_t is the unemployment rate and $n_t = 1 - u_t$ is the employment rate. A match occurs when a vacancy is filled by an unemployed worker. The process is summarized by a matching function $M(u_t, v_t) = \zeta v_t^{\epsilon} u_t^{1-\epsilon}$ that exhibits constant returns to scale. Let $\theta_t = \frac{v_t}{u_t}$ be the labor market tightness at time t. The unemployed worker will find a job with probability $p(\theta_t) = M(u_t, v_t)/u_t = M(1, \theta_t)$. Similarly, the probability for a firm to fill a vacancy job may be expressed as $q(\theta_t) = M(u_t, v_t)/v_t = M(1/\theta_t, 1)$. The job-finding rate $p(\theta_t)$ is increasing in θ. An increase in θ gives more opportunities for an unemployed worker to find a job, since vacant jobs are more abundant relative to job-seekers. Inversely, $q(\theta_t)$ is decreasing in θ and a tighter labor market reduces the probability for a firm to fill a vacancy job.

The law of motion for the employment can be written as

$$n_{t+1} = (1 - \lambda)n_t + p(\theta_t)(1 - n_t), \tag{3.1}$$

where $\lambda \in (0, 1)$ is the exogenous rate of job destruction.

3.2.2 Households

The economy is populated by a continuum of households on the unit interval. Households are either employed or unemployed. The representative household is seen as a large family. I follow Merz (1995) and Andolfatto (1996) in assuming that members in each family pool their incomes to insure a perfect consumption for all members. This implies that consumption is the same for each person, regardless of his labor income due to his situation in the job market.

The household utility is given by

$$E_t \sum_{s=0}^{\infty} \beta^s \left\{ \ln(c_t - h_c c_{t-1}) - \int_0^1 n_{it+s} \frac{h_{it+s}^{(1+\eta)}}{1+\eta} di \right\}, \tag{3.2}$$

where β is the subjective discount factor, η is the inverse Frisch elasticity of labor supply, n_{it} is the number of employed workers in firm $i \in [0,1]$, h_c controls the degree of habit formation in preferences and h_{it} is the number of hours per employee in firm i (the wholesaler). The aggregate consumption is $c_t = \left(\int_0^1 c_{jt}^{\frac{\gamma-1}{\gamma}} dj \right)^{\frac{\gamma}{\gamma-1}}$, where γ is the elasticity of substitution between differentiated goods in the retailing firm j.

The household's budget constraint is given by

$$\begin{aligned} & B_t + \int_0^1 n_{it} W_t(h_{it}) di + (1 - n_t) b + R_t^k Z_t K_t^p + \Pi_t + T_t \\ \geq \;& P_t(c_t + I_t + a(Z_t) K_t^p) + E_t D_{t,t+1} B_{t+1}. \end{aligned} \tag{3.3}$$

During period t, the representative household receives labor income $W_t(h_{it})$, i.e. the nominal wage as a function of hours h_{it}. Unemployed members receive nominal unemployment benefits b. The representative household enters period t with the stock of nominal bonds B_t and the physical capital K_t^p. The household chooses the capital utilization rate Z_t to transform the physical capital K_t^p into capital services, $K_t = Z_t K_t^p$, and rents it to firms at the nominal rental rate R_t^k. In additions, he receives dividends Π_t remitted by firms. T_t represents nets lump-sum transfers from the government.

These resources are used to buy consumption and investment goods. I_t denotes investment goods.

The aggregate price level is $P_t^{1-\gamma} = (\int_0^1 P_{jt}^{1-\gamma} dj)^{1/(1-\gamma)}$. The household uses her income resources to purchase new risk-free bonds that yield a return in $t+1$ at the costs $D_{t,t+1}$. Let $D_{t,t+1} = \frac{1}{1+R_t}$ which is known at time t, with R_t being the nominal interest rate at period t. The household faces cost, in units of investment goods, of the capital utilization rate, $a(Z_t)$. I assume $a(1) = 0$, $a'(1) = 0$ and $a''(1) > 0$, while at the steady-state, $Z = 1$. The cost associated with setting capacity utilization has the following functional form :

$$a(Z_t) = \gamma_1(Z_t - 1) + \frac{\gamma_2}{2}(Z_t - 1)^2. \tag{3.4}$$

The physical capital K_t^p evolves according to

$$K_{t+1}^p = \varepsilon_t^I(1 - S(\frac{I_t}{I_{t-1}}))I_t + (1 - \delta)K_t^p, \tag{3.5}$$

where δ is the rate depreciation, ε_t^I is the investment shock. $S(\frac{I_t}{I_{t-1}})$ is the increasing and convex adjustment investment cost given by :

$$S(\frac{I_t}{I_{t-1}}) = \frac{s_1}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2, \tag{3.6}$$

where $S(1) = 0, S'(1) = 0$ and $S''(1) > 0$ and $s_1 \geq 0$ is a free parameter.

The exogenous investment shock ε_t^I is assumed to follow an autoregressive process such that

$$\varepsilon_t^I = (\varepsilon_{t-1}^I)^{\rho_i} \exp(\mu_t^i), \tag{3.7}$$

where μ_t^i is i.i.d $N(0, \sigma_i^2)$.

The representative household chooses consumption c_t, investment I_t, nominal bonds B_{t+1}, physical capital K_{t+1}^p, and capital utilization Z_t to maximize the sum of expected utility (3.2) subject to the constraints (3.3) and (3.5).

The first order conditions with respect to c_t, B_{t+1}, Z_t , I_t and K_{t+1}^p are

$$\lambda_t^{AR} = U_c(c_{t-1}, c_t) = \frac{1}{c_t - h_c c_{t-1}} - E_t \frac{\beta h_c}{c_{t+1} - h_c c_t}, \tag{3.8}$$

$$\lambda_t^{AR} = \beta(1 + R_t) E_t \lambda_{t+1}^{AR} \frac{1}{\pi_{t+1}}, \tag{3.9}$$

$$r_t^k = a_z(Z_t), \tag{3.10}$$

$$\begin{aligned} \lambda_t^{AR} &= \lambda_t^B \varepsilon_t^I \left[1 - S(\frac{I_t}{It-1}) - S'(\frac{I_t}{It-1})\frac{I_t}{It-1}\right] \\ &\quad + \beta E_t \lambda_{t+1}^B \varepsilon_{t+1}^I S'(\frac{I_{t+1}}{It}) \left[\frac{I_{t+1}}{It}\right]^2, \end{aligned} \tag{3.11}$$

$$\lambda_t^B = E_t \lambda_{t+1}^B \beta(1 - \delta) + E_t \lambda_{t+1}^{AR} \beta \left[r_{t+1}^k Z_{t+1} - a(Z_{t+1})\right], \tag{3.12}$$

where $\lambda_t^{AR} = P_t \lambda_t^A$, λ_t^A is the Lagrange multiplier associated with the budget constraint and is interpreted as the marginal utility of consumption, λ_t^B is the Lagrange multiplier associated with the investment adjustment constraint and is interpreted as the value of installed capital measured in consumption units. In equation (3.9), $\pi_{t+1} = \frac{P_{t+1}}{P_t}$, is gross inflation. In equation (3.10), $r_t^k = \frac{R_t^k}{P_t}$ is the real rental capital rate.

3.2.3 The wholesale firms

The economy includes a continuum of wholesale firms i. At period t, firm i rents the capital service K_{it} from households, hires n_{it} employees, buy intermediate input Γ_{it}, and uses technology to produce a wholesale good X_{it} according to the following production function :

$$X_{it} = \max\left\{A_t \Gamma_{it}^{\phi}\left(K_{it}^{\alpha}\left[n_{it}h_{it}\right]^{1-\alpha}\right)^{1-\phi} - F, 0\right\}, \tag{3.13}$$

where $\phi \epsilon [0, 1]$ is the intermediate input share and F is a fixed cost chosen such that profits are zero in steady state, so entry and exit of firms can be ignored. A_t is the neutral technology shock that obeys the stochastic process :

$$A_t = (A_{t-1})^{\rho_a} \exp(\mu_t^a), \tag{3.14}$$

where μ_t^a is i.i.d. $N(0, \sigma_a^2)$.

Since I separate pricing decisions from posting-vacancies decisions, the wholesaler faces a labor market characterized by search frictions. Firm i posts vacancies and pays hiring costs χ in order to produce the differentiated wholesale good X_{it} that it sells to retail firms at the flexible price P_{it}. The firms' discounted value of future real profits is expressed as follows

$$F_{it} = \frac{P_{it}}{P_t} X_{it}^d - w_{it}(h_{it}) n_{it} - \Gamma_{it} - \frac{\chi}{U_c(c_{t-1}, c_t)} v_{it} - r_t^k K_{it} + E_t \beta_{t,t+1} F_{it+1}. \tag{3.15}$$

Here X_{it}^d is the demand for the good produced by wholesaler i, $w_{it}(h_{it}) = \frac{W_{it}(h_{it})}{P_t}$ is the real wage, $\frac{\chi}{U_c(c_{t-1}, c_t)}$ is the marginal cost of posting a vacancy and $\beta_{t,t+1} = \beta \frac{\lambda_{t+1}^{AR}}{\lambda_t^{AR}}$ is the firm's stochastic discount factor between t and $t+1$.

The demand for the good of the i^{th} wholesaler is

$$X_{it}^d = \left(\frac{P_{it}}{P_t}\right)^{-\varrho} X_t, \tag{3.16}$$

where ϱ denotes the elasticity of substitution between differentiated wholesale goods.

After choosing its price, the wholesaler commits to satisfy demand. This implies that the following condition holds at all times :

$$(\frac{P_{it}}{P_t})^{-\varrho}X_t = A_t\Gamma_{it}^{\phi}\left(K_{it}^{\alpha}\left[n_{it}h_{it}\right]^{1-\alpha}\right)^{1-\phi} - F. \tag{3.17}$$

Due to search frictions on the labor market, new hires become productive in the next period. The employment law of motion at the firm level is given by :

$$n_{it+1} = (1-\lambda)n_{it} + q(\theta_t)v_{it}. \tag{3.18}$$

Each period, the wholesaler chooses the capital service K_{it}, the intermediate input Γ_{it}, the number of vacancies v_{it}, hours h_{it}, workers number n_{it+1} and flexible nominal price P_{it} that maximizes

$$E_0\sum_{t=0}^{\infty}\beta_{0,t}\left\{\begin{array}{c} (\frac{P_{it}}{P_t})^{1-\varrho}X_t - w_{it}\left(h_{it}\right)n_{it} - \Gamma_{it} - \frac{\chi}{U_c(c_{t-1},c_t)}v_{it} - r_t^k K_{it} \\ +mc_t\left[\left(A_t\Gamma_{it}^{\phi}\left(K_{it}^{\alpha}\left[n_{it}h_{it}\right]^{1-\alpha}\right)^{1-\phi} - F\right) - (\frac{P_{it}}{P_t})^{-\varrho}X_t\right] \\ +\vartheta_{it}\left[(1-\lambda)n_{it} + q(\theta_t)v_{it} - n_{it+1}\right] \end{array}\right\},$$

where mc_t and ϑ_{it} are the Lagrange multipliers with respect to (3.17) and (3.18), respectively. mc_t is interpreted as the real marginal cost.

First-order conditions are given by :

$[\partial K_{it}]$:

$$r_t^k = \alpha(1-\phi)mc_tA_t\Gamma_{it}^{\phi}\left(K_{it}^{\alpha}\left[n_{it}h_{it}\right]^{1-\alpha}\right)^{-\phi}K_{it}^{\alpha-1}\left[n_{it}h_{it}\right]^{1-\alpha}, \tag{3.19}$$

$[\partial v_{it}]$:

$$\frac{\chi}{U_c(c_{t-1},c_t)} = q(\theta_t)\vartheta_{it}, \tag{3.20}$$

$[\partial \Gamma_{it}]$:

$$\phi mc_t A_t \Gamma_{it}^{\phi-1} \left(K_{it}^{\alpha} \left[n_{it} h_{it}\right]^{1-\alpha}\right)^{1-\phi} = 1, \tag{3.21}$$

$[\partial n_{it+1}]$:

$$\vartheta_{it} = E_t \beta_{t,t+1} \left[\begin{array}{c} (1-\alpha)(1-\phi) mc_{t+1} A_{t+1} \Gamma_{it+1}^{\phi} \left(K_{it+1}^{\alpha} \left[n_{it+1} h_{it+1}\right]^{1-\alpha}\right)^{-\phi} \\ K_{it+1}^{\alpha} \left[n_{it+1} h_{it+1}\right]^{-\alpha} h_{it+1} \\ -w_{it+1}\left(h_{it+1}\right) + (1-\lambda)\vartheta_{it+1} \end{array} \right], \tag{3.22}$$

$[\partial h_{it}]$:

$$mc_t = \frac{w'_{it}\left(h_{it}\right)}{(1-\alpha)(1-\phi) A_t \Gamma_{it}^{\phi} \left(K_{it}^{\alpha} \left[n_{it} h_{it}\right]^{1-\alpha}\right)^{-\phi} K_{it}^{\alpha} \left[n_{it} h_{it}\right]^{-\alpha}}, \tag{3.23}$$

$[\partial P_{it}]$:

$$p_t^w = \frac{\varrho}{\varrho - 1} mc_t. \tag{3.24}$$

In equation (3.23), $w'(h_{it})$ denotes the real marginal wage. In equation (3.24), as prices are flexible in the wholesale sector, firms set prices to be equal to their desired or frictionless markup over marginal cost. All wholesaler firms behave the same way, so they all set the same real price p_t^w.

To simplify, I assume that capital is perfectly mobile across firms and that wholesalers have constant return to scale in production. This imply that firms choose the same capital-labor ratio $\frac{K_{it}}{n_{it} h_{it}} = \frac{K_t}{n_t h_t}$ and the same capital-input ratio $\frac{\Gamma_{it}}{K_{it}} = \frac{\Gamma_t}{K_t}$.

From equations (3.20) and (3.22) the firm's hiring decision is given by

$$\frac{\chi}{q(\theta_t)} = \beta E_t U_c(c_t, c_{t+1}) \{mc_{t+1} mpl_{t+1} h_{it+1} - w_{it+1}(h_{it+1})\} + \beta E_t (1-\lambda) \frac{\chi}{q(\theta_{t+1})}, \quad (3.25)$$

where $mpl_{t+1} = (1-\alpha)(1-\phi) A_{t+1} \left(\frac{\Gamma_{t+1}}{K_{t+1}}\right)^{\phi} \left(\frac{K_{t+1}}{n_{t+1}h_{t+1}}\right)^{\phi(1-\alpha)+\alpha}$, is the marginal productivity of labor in the next period which is the same across firms, since firms choose the same capital-labor ratio.

3.2.4 Workers

I define the worker's surplus from employment. Let M_{it}^w denotes the worker's value of a match in firm i at period t and let U_t^w be the unemployment value. M_{it}^w and U_t^w are given by

$$M_{it}^w = w_t(h_{it}) - \frac{h_{it}^{(1+\eta)}}{(1+\eta)U_c(c_{t-1}, c_t)} + E_t \beta_{t,t+1} \left\{(1-\lambda) M_{it+1}^w + \lambda U_{t+1}^w\right\}, \quad (3.26)$$

$$U_t^w = \frac{b}{U_c(c_{t-1}, c_t)} + E_t \beta_{t,t+1} \left\{p(\theta_t) M_{it+1}^w + (1-p(\theta_t)) U_{t+1}^w\right\}, \quad (3.27)$$

where $\frac{h_{it}^{(1+\eta)}}{(1+\eta)U_c(c_{t-1},c_t)}$ is the marginal disutility of labor expressed in consumption units and $\frac{b}{U_c(c_{t-1},c_t)}$ is the unemployment benefits in consumption units. According to equation (3.27), the unemployment value depends on the unemployment benefits and the probability of being employed versus unemployed in the next period.

3.2.5 The alternating-offer wage bargain

I follow Hall and Milgrom (2008) and assume that credible alternating offer bargaining (CAOB) takes place in determining wage. At the beginning of the period, the firm starts the negotiation by making a wage offer. The worker has three options : (i) to accept the wage offer made by the firm, (ii) to reject the offer and to make a counter-offer, (iii) or to give up bargaining and to choose the outside option. The firm also has the possibility to choose one of the three options to respond to the new proposal made by the worker. Leaving the negotiation by either party gives an outside-option payoff of zero to the firm and U_t^w to the worker.

When the responding party makes a counter-proposal, both bargainers receive the non-agreement payoff for that period prevailing before the agreement is reached. The worker receives the benefit b and the firm incurs the cost z while bargaining continues. z is the cost of delaying bargaining by one day. In such environment, the party that rejects the proposal have to continue bargaining because that option has a strictly higher payoff than choosing the outside option. Therefore, the outside options are not credible and the credible threat points are the payoffs obtained during the non-agreement period. Consequently, it is optimal for each bargainer to make an acceptable proposal.

To develop the real wage expression, I use the result of Binmore, Rubinstein and Wolinsky (1986). When the length of a single bargaining period is small, the solution of the CAOB converges to the solution found by Nash (1953) with the credible threat points. These credible threat points are the benefit b for the worker and the cost z for the firm.

Every period, firms and workers bargain over the joint surplus of their work relationship for the current period. The current surplus for the worker is

$S_{it}^{w} = w_t(h_{it}) - \frac{h_{it}^{(1+\eta)}}{(1+\eta)U_c(c_{t-1},c_t)} - \frac{b}{U_c(c_{t-1},c_t)}$. The current surplus of the firm is $S_{it}^{f} = mc_t mpl_t h_{it} - w_t\left(h_{it}\right) + \frac{z}{U_c(c_{t-1},c_t)}$. Let ξ be the bargaining power of the firm. The bargainers choose the real wage that satisfies the following surplus-sharing rule :

$$(1-\xi)S_{it}^{f} = \xi S_{it}^{w}. \tag{3.28}$$

The real wage equation is

$$w(h_{it}) = (1-\xi)[mc_t mpl_t h_{it} + \frac{z}{U_c(c_{t-1},c_t)}] + \xi[\frac{b}{U_c(c_{t-1},c_t)} + \frac{\frac{h_{it}^{1+\eta}}{1+\eta}}{U_c(c_{t-1},c_t)}]. \tag{3.29}$$

From equation (3.29), the real marginal wage is

$$w'(h_{it}) = (1-\xi)mc_t mpl_t + \xi\frac{h_{it}^{\eta}}{U_c(c_{t-1},c_t)}. \tag{3.30}$$

Replacing $w'(h_{it})$ in equation (3.23), I get $mc_t = \frac{h_{it}^{\eta}}{mpl_t U_c(c_{t-1},c_t)}$. I can drop the subscript i since hours are equalized across firms and I can replace h_{it} by h_t. I can express the real marginal cost as

$$mc_t = \frac{h_t^{\eta}}{mpl_t U_c(c_{t-1},c_t)}, \tag{3.31}$$

which leads to the following real wage equation

$$w(h_t) = (1-\xi)[mc_t mpl_t h_t + \frac{z}{U_c(c_{t-1},c_t)}] + \xi[\frac{b}{U_c(c_{t-1},c_t)} + \frac{\frac{h_t^{1+\eta}}{1+\eta}}{U_c(c_{t-1},c_t)}]. \tag{3.32}$$

From equation (3.31), the firm's hiring decision, equation (3.25), is finally given by

$$\frac{\chi}{q(\theta_t)} = \beta\xi E_t \frac{\eta}{1+\eta} h_{t+1}^{\eta+1} - \beta(1-\xi)z - \beta b\xi + \beta E_t(1-\lambda)\frac{\chi}{q(\theta_{t+1})}. \qquad (3.33)$$

3.2.6 Comparison between the credible and the Nash wage determination

In the original Mortensen-Pissarides (MP) model with Nash wage bargaining, the worker has two choices : accept the proposal made by the firm or choose the outside option. When the match occurs, each party receives a given fraction ξ and $(1-\xi)$ of the prospective joint surplus. Leaving the negotiation by either party gives an outside-option payoff for each one.

The main difference with the CAOB model is the threat points. For the worker, the threat point is the unemployment value U_t^w. Because of the free entry condition on the labor market, the expected profit for firms from opening new vacancies is zero. The firm's threat point U_t^f is then zero. Let $J_{it}^w = M_{it}^w - U_t^w$ be the job-seeker's surplus and $J_{it}^f = H_{it} - U_t^f$ be the firm's surplus. H_{it} is the value of the marginal worker for the firm i at the period t which is given by $H_{it} = mc_t mpl_t h_{it} - w_t(h_{it}) + E_t\beta_{t,t+1}(1-\lambda)H_{it+1}$.

Every period, firms and workers bargain over the joint surplus of their work relationship, $J_{it}^f + J_{it}^w$, and choose the wage that maximizes the Nash product $w^N(h_{it}) = \arg\max\left\{(J_{it}^f)^{\xi}(J_{it}^w)^{1-\xi}\right\}$.

The first order condition gives the surplus sharing rule $(1-\xi)J_{it}^f = \xi J_{it}^w$. After some derivations, the real wage under Nash Bargaining can be expressed as

$$w^N(h_t) = (1-\xi)[mc_t mpl_t h_t + \frac{\chi}{U_c(c_t,c_{t-1})}\theta_t] + \xi[\frac{b}{U_c(c_t,c_{t-1})} + \frac{\frac{h_t^{1+\eta}}{1+\eta}}{U_c(c_t,c_{t-1})}]. \quad (3.34)$$

Under credible alternating offer bargaining, the real wage $w(h_t)$ given by equation (3.32) is

$$w(h_t) = (1-\xi)[mc_t mpl_t h_t + \frac{z}{U_c(c_t, c_{t+1})}] + \xi[\frac{b}{U_c(c_t, c_{t+1})} + \frac{\frac{h_t^{1+\eta}}{1+\eta}}{U_c(c_t, c_{t+1})}]. \quad (3.35)$$

The comparison between equation (3.34) and (3.35), shows that the CAOB wage is more rigid than the Nash wage since there is no θ_t in the equation (3.35). When firms post vacancies, the labor market tightness $\theta_t = v_t/u_t$ increases. The recruiting rate $q(\theta_t)$, will decrease. Following a positive productivity shock, if real wage is sticky, the firm surplus will rise, that will affect the employer's recruiting effort and then unemployment will decrease. Wages being flexible, the firm's surplus will be unchanged and will not affect the employer's recruiting effort, so there will not be fluctuations in unemployment.

3.2.7 Retailers

There is a continuum of monopolistically competitive retailers j. These firms buy the composite goods $\int_0^1 \left(X_{it}^{\frac{\varrho-1}{\varrho}} di \right)^{\frac{\varrho}{\varrho-1}}$ from wholesalers at the real price p_t^w. They then differentiate and transform them into retailer goods without costs and re-sell them to the households. Final goods are produced using a constant return to scale technology :

$$X_t = \int_0^1 \left(X_{jt}^{\frac{\gamma-1}{\gamma}} dj \right)^{\frac{\gamma}{\gamma-1}}. \quad (3.36)$$

Due to imperfect substitutability across goods, the demand curve for goods in retail firms is :

$$X_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\gamma} X_t, \tag{3.37}$$

and the aggregate price is :

$$P_t^{1-\gamma} = \int_0^1 P_{jt}^{1-\gamma} dj. \tag{3.38}$$

Prices at the retail level are set according to Calvo-contract. That is, each period a fraction δ_p of retailers does not reset their price, while the fraction $1-\delta_p$ of firms reoptimize their price. When given the opportunity to reset its price, the retailers maximizes the discounted expected flow of future profits subject to the demand schedule (37) :

$$\max_{P_{jt}} E_t \sum_{s=0}^{\infty} \delta_p^s \beta_{t,t+s} \left[\left(\frac{P_{jt}}{P_{t+s}}\right)^{1-\gamma} X_{t+s} - \left(\frac{P_{jt}}{P_{t+s}}\right)^{-\gamma} p_{t+s}^w X_{t+s} \right]. \tag{3.39}$$

The optimal pricing decision is then given by

$$E_t \sum_{s=0}^{\infty} \delta_p^s \beta_{t,t+s} P_{t+s}^{\gamma} X_{t+s} \left(\frac{P_t^*}{P_{t+s}} - \frac{\gamma}{\gamma-1} p_{t+s}^w \right) = 0.$$

Where P_t^* is the optimal price chosen by all retailers allowed to reset their price in a given period. The optimal real price p_t^* can be expressed recursively as

$$p_t^* = \frac{\gamma}{\gamma-1} \left(\frac{\varrho}{\varrho-1}\right) \frac{x_t^1}{x_t^2}, \tag{3.40}$$

with

$$x_t^1 = \lambda_t^{AR} mc_t X_t + \delta_p \beta \pi_{t+1}^{\gamma} x_{t+1}^1, \tag{3.41}$$

$$x_t^2 = \lambda_t^{AR} X_t + \delta_p \beta \pi_{t+1}^{\gamma-1} x_{t+1}^2. \tag{3.42}$$

3.2.8 Monetary policy

I assume that the monetary policy is described by a Taylor rule stating that the nominal interest rate reacts to changes of inflation from steady state inflation and to output growth. The monetary policy rule is given by

$$\frac{(1+R_t)}{(1+R)} = [(\frac{\pi_t}{\pi})^{\phi_\pi}(\frac{y_t}{y_{t-1}})^{\phi_y}]^{1-\rho_R}[\frac{(1+R_{t-1})}{(1+R)}]^{\rho_R}\varepsilon_t^R, \tag{3.43}$$

where R is the steady-state nominal interest rate, $\rho_R \in (0,1)$ captures the degree of interest rate smoothing, ϕ_π and ϕ_y are non-negative policy rule coefficients and ε_t^R is an i.i.d. monetary policy shock.

3.2.9 Aggregation

In equilibrium, total supply of the wholesale goods, must equal total demand from retail firms $\int_0^1 X_{jt}dj$. Using equation (3.37), I can express the aggregate output as :

$$s_t X_t = A_t \Gamma_t^{\phi}\left(K_t^{\alpha}\left[n_t h_t\right]^{1-\alpha}\right)^{1-\phi} - F, \tag{3.44}$$

where $s_t = \int_0^1 (\frac{P_{jt}}{P_t})^{-\gamma}$ is a measure of price dispersion. From Calvo (1983), aggregate inflation evolves according to :

$$1 = \delta_p \pi_t^{(\gamma-1)} + (1-\delta_p)p_t^{*(1-\gamma)}. \tag{3.45}$$

Recursively the price dispersion variable s_t can be written as :

$$s_t = (1 - \delta_p) p_t^{*(-\gamma)} + \delta_p \pi_t^{\gamma} s_{t-1}. \tag{3.46}$$

I can express the aggregate net output y_t as the difference between the gross output and the intermediate output :

$$y_t = X_t - \Gamma_t. \tag{3.47}$$

Finally, I close the model by the aggregate resource constraint :

$$y_t = c_t + I_t + a(Z_t) K_t^p + \frac{\chi}{U_c(c_t, c_{t+1})} v_t. \tag{3.48}$$

3.3 Calibration

In this section, I describe the values assigned to the parameters of the baseline model. Calibration is on a quarterly basis. Table 3.1 and Table 3.2 summarize the parameter and steady state values of the baseline economy.

The preferences parameters

The quarterly subjective discount factor β is equal to 0.99, which implies a 4 percent annual steady-state real interest rate. The internal habit formation $h_c = 0.7$. The Frisch elasticity of labor supply, η is set to 1.

The labor market parameters

I set the quarterly job separation rate $\lambda = 0.1$ to be consistent with a monthly separation rate equal to 0.034 calculated by Shimer (2005) for U.S. data from 1951 to 2003.[3] This implies that jobs last for two years and six months, on average. I follow Toledo and Silva (2010) and target a steady-state unemployment rate u_s at 0.11. I choose a higher unemployment rate than typically used in most papers to include individuals who want to work and are searching for jobs while classified as inactive.[4]

I set the probability of finding a worker $q_s = 0.7$ following Den Haan, Ramey and Watson (2000), and Cooley and Quadrini (1999). The matching elasticity ϵ is 0.5. This choice matches the range of plausible values $\epsilon \in [0.5, 0.7]$ in Petrongolo and Pissarides (2001). The firm's bargaining power ξ, is equal to 0.6. I fix the steady state hours per employee h_s at 0.33 and the unemployment benefits $b = 0.4$ as in Shimer (2005). At steady-state, the job finding rate is $p(\theta) = M(u, v)/u = \zeta\theta^{\epsilon}$, which implies an efficiency parameter of the matching function ζ equal to 0.774.

To calibrate the utility cost of posting a vacancy χ, I follow Andolfatto (1996) and Blanchard and Gali (2010) and set the steady-state ratio of vacancy posting utility cost to GDP, $d_s = \frac{\chi v_s}{y_s U_c(c_s)}$, equal to 1 percent, so that $\chi = 0.1$. Given the value of χ, the hiring decision at the steady state under the CAOB wage is solved for $z = 0.066$. The resulting value of z is 0.066 days of worker productivity per day of delay. That means that if a worker produces for 200$ per day, then $z = 0.066$ implies a cost of 13.2$ to make the counteroffer.

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3. Also consistent with an average monthly separation rate of 3.4 percent as in the Job Openings and Labor Turnover Survey from 2001 to 2011.

4. Blanchard and Diamond (1990) calculate an average stock of unemployed workers of 11.2 million between 1968-1986. Den Haan, Ramey and Watson (2000) and Krause and Lubik (2007) set $u_s = 0.12$; Trigari (2009) estimates $u_s = 0.25$. Andolfatto (1996) sets the employment rate at $n_s = 0.54$.

The New Keynesian model parameters

I set the Calvo parameter, δ_p, equal to 0.66, implying that firms keep their prices unchanged for 3 quarters on average. In the DSGE literature, there is some uncertainty about the duration of price contracts. Nakamura and Steinsson (2008) use data sets provided by the Bureau of Labor Statistics to calculate the duration of each price spell and find that prices remain unchanged for 7 to 9 months, in mean frequency, when product substitution are included, and between 8 to 11 months, when product substitution are excluded. Bils and Klenow (2004) estimate the frequency of price changes for 350 categories of goods and find that half of prices last a median duration less than 4.3 months. Trigari (2009) sets the probability Calvo equal to 0.85, that corresponds to a 6.5 quarters average duration of price rigidity. Finally, Blanchard and Gali (2010) assume 4 quarters of price rigidity.

The elasticity of substitution between differentiated goods for both wholesale firms ϱ and retail firms γ is set to 6 (Liu and Phaneuf, 2007). The depreciation rate on physical capital δ is equal to 0.025. $\alpha = 0.33$ is the share parameter on capital service in the Cobb-Douglas production function. I choose the investment adjustment cost parameter $s_1 = 3$ following estimation provided by Christiano, Eichenbaum, and Evans (2005). γ_1 and γ_2, the coefficients in the utilization cost function are set as follows : $\gamma_2 = 0.15$ as in Justiniano, Primiceri, and Tambalotti (2010) and γ_1 is such that the capital utilization Z is equal to 1 in the steady-state. The calibration of the intermediate input share ϕ comes from the definition presented by Nakamura and Steinsson (2010). The weighted average cost share of intermediate inputs ϕ is equal to the weighted average revenue share times the markup. My calibration of ϱ implies a price markup equal to 1.2. The revenue share of intermediate inputs in U.S private sector using the Consumer Price Index expenditure is about 51 percent in 2002. Hence, I set the intermediate input share ϕ equal to 0.61.

The monetary policy parameters

The monetary policy is conducted by a Taylor rule in which : $\rho_R = 0.8$ is the parameter capturing the degree of interest rate smoothing, $\phi_\pi = 1.5$ is the coefficient on inflation and $\phi_y = 0.125$ is the coefficient on output growth.

The shock parameters

To calculate standard deviations of the three shocks, I impose that the model matches the standard deviation of output growth observed in U.S. data (0.0122), assigning to each type of shock a percentage contribution to the forecast error variance of output growth based on some consensus in the literature.

Estimations from Getler, Sala and Trigari (2008), show that the investment shock explains about 54.8 percent of the variance decomposition of the growth rate of output. The technology shock explains about 16.7 percent, followed by the monetary shock with 11.1 percent. The contribution of the other shocks to the variance of output is about 17.4 percent.

In Justiniano, Primiceri and Tambalotti (2010), the investment shock accounts for 50 percent of fluctuations in output. The contribution of the neutral technology shock to the variance of output is about 25 percent. The monetary shock explains about 5 percent of the variance of output. The contribution of the other shocks to the variance of the output is about 20 percent.

For the calibration of the standard deviations of all three shocks, I consider that the investment shock accounts for 50 percent of the variance of the output growth, the neutral technology shock 35 percent and the monetary shock 15 percent. I call this case Split (1).[5] Table 3.3 presents the size of shocks generated

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5. In Table 3.5 and Table 3.6, I present statistics with two other splits of the relative size

under Split (1) for two versions of the model. The column labeled "Standard" is for the model without firm networking (the standard model). The column labeled "Baseline" is for the model with firm networking (the baseline model). Hence with the baseline model, I get $\sigma_a = 0.0050$ for the standard deviation of the neutral technology shock, $\sigma_r = 0.0037$ for the standard deviation of the monetary shock and $\sigma_i = 0.0437$ for the investment shock.

Estimations of DSGE models show that the neutral technology shock is quite persistent. I set the autocorrelation coefficient of this shock at 0.95. I set the autoregressive parameter of the investment shock at 0.7, (Justiniano, Primiceri and Tambalotti, 2010).

3.4 Data

I use quarterly data from 1951Q1 to 2008Q2 to calculate a set of business cycle statistics for the U.S. economy. Following Shimer (2005), I use seasonally adjusted unemployment level constructed by the U.S Bureau of Labor Statistics (BLS) from the Current Population Survey (CPS) for unemployment (u). To measure vacancies (v), I use the help-wanted advertising index constructed by the Conference Board as a proxy.[6]The labor market tightness (θ) is $\frac{v}{u}$. The employment (n) is defined as all employees (total nonfarm payrolls) from the BLS. Output (y) is defined as output in the non-farm business sector. I use seasonally adjusted data on gross domestic product implicit price deflator to calculate quar-

of shocks.

6. This standard proxy for vacancies is measured as the number of help-wanted advertisements in 51 major newspapers. For more details about this measure, see Abraham (1987).

terly inflation (π). Consumption (c) is the real personal consumption expenditures and investment (i) is the real gross private domestic investment. All of them from the Bureau of Economic Analysis. I take quarterly average of data available at a monthly frequency.

3.5 Simulation results

In this section, I present the simulation results from different versions of the model. The first subsection compares some statistics generated from quarterly U.S. data to statistics generated from the baseline model (with firm networking) and form the standard model (without firm networking). In this subsection, I use the CAOB wage. The second subsection, reports results for the version of the model with Nash wage bargaining. The third subsection generates inflation persistence in the baseline and the standard models as well as impulse responses of key variables following monetary, neutral technology and investment shocks.

3.5.1 Model with CAOB wage

To assess the empirical relevance of the baseline model and evaluate the effect of firm networking on the dynamics of the model with search frictions in the labor market, I present some business cycle moments implied by the model and compare them to their counterparts in the data.

Table 3.4 displays statistics for selected variables in first differences. The column labeled "Data" presents moments generated from quarterly data from 1951Q1 to 2008Q2. The column labeled "Standard" shows statistics for the model without firm networking (the standard model). The column labeled "Baseline" reports statistics for the model with firm networking (the baseline model).

By construction, all variants of the model reproduce the same standard deviation of the output growth as observed in data. The baseline model reproduces 78 percent and 83 percent of the observed volatility of consumption growth and investment growth, respectively. In the standard model, the variances of consumption growth and investment growth are about 66 percent and 86 percent of their actual values.

The standard model overestimates the volatility of inflation by 41 percent, that of unemployment by 30 percent and that of the labor market tightness by 20 percent. The baseline model does reasonably well reproducing the unemployment and the labor market tightness volatility. It also generates 76 percent of the standard deviation of the inflation observed in U.S. data.

For most variables, the baseline model outperforms the standard model replicating the relative volatility of key variables to that of output growth. For example, the baseline model reproduces 76 percent of the variability of inflation relative to the volatility of output growth observed in data, while the standard model overestimates this value by 42 percent.

The roundabout production acts as a mechanism reducing the sensitivity of inflation relative to real marginal costs, which means that the NKPC is flatter. The credible bargaining wage displays real wage rigidity with respect to labor market conditions. However, it is flexible with respect to the marginal disutility of labor. This flexibility with respect to hours per employee induces strategic complementarity between firms that helps generating more inflation inertia. Moreover, from equation (3.33), the job creation is driven by expected hours per worker. If the firm expects an increase in future hours per employee, it chooses to post more vacancies today to avoid increasing in the real marginal wage and than in its real marginal costs. The rigidity in the cost of an additional employee and the flexibility in the cost of an additional hour increases the firm's incentive to hire. That explains fluctuations in unemployment and labor market variables.

Firm networking has an important impact on the transmission of monetary, neutral technology and investment shocks. If one compares the standard deviation of the neutral technology shock σ_a, the investment shock σ_i and the monetary shock σ_r of different models in Table 3.3, one sees that the presence of firm networking reinforces the ability of the model to generate fluctuations with a much smaller size of shocks in comparison to the standard model. The standard deviation of the investment shock σ_i is 1.14 times smaller when there is firm networking in the model. The effect of the monetary shock is magnified by the presence of firm networking with a standard deviation σ_r which is 1.4 times smaller than in the standard model. The standard deviation of the neutral technology shock σ_a is 2.32 times smaller with the baseline model than with the standard model.

One notices the sizeable effects of firm networking on the neutral technology shocks since it is twice smaller than in the standard model. That is since the neutral technology shock affects the production function in two instances relative to the standard model. First, the neutral technology shock has an effect on the production function (the direct effect). Second, in the baseline model, there is another effect as the neutral technology shock filters through the intermediate input that comes from other firms (the indirect effect).

In Table 3.4, the correlation of the labor market variables with output growth implied by the standard model is more attractive and closer to the data than the one implied by the baseline model. However, the performance of the baseline model along this dimension is explained by the contribution of the investment shock to the variance of the output growth.

I test the robustness of these results to different percentage contributions of the shocks to variance decomposition of output growth.

First, I increase the importance of investment shock and assume that this shock accounts for 60 percent of the variance of output growth, while 25 percent is due to the neutral technology shock and 15 percent is due to the monetary shock, which is labeled Split (2). This split is consistent with most estimated models, in which investment shocks explain between 50 and 60 percent of the variance of output growth.

Finally, Split (3) is defined in the case in which the neutral technology shock is the most important, accounting for 75 percent of the variance of the output growth, while the monetary shock accounts for 25 percent. This is in line with some papers in the literature that do not include investment shocks in their models.

Table 3.5 calculates the standard deviation of three shocks under Split (2) and Split (3). Whatever the contribution of the investment and of the neutral technology shocks in the variance of output growth, the presence of intermediate inputs reinforces the ability of the model to generate fluctuations with smaller size of shocks $(\sigma_a, \sigma_i, \sigma_r)$ in comparison with the standard model.

Table 3.6 replicates Table 3.4 presenting the moments for Splits (2) and (3). With Split (2), the contribution of the investment shock to the variance of output growth is higher than with Split (1). This increases mainly from the failure of the standard model in matching the variance of the labor market variables observed in data. For example, the standard model overestimates the volatility of unemployment by 30 percent in Split (1), and by 37 percent in Split (2). However, the baseline model does not overestimate the volatility of any variable and explains about 91 percent of the observed volatility of unemployment. The correlation of the labor market variables with output growth in the baseline model, increases in

Split (2) compared to Split (1). For example, in Split (1), the baseline model explains 29 percent of the correlation of labor market tightness with output growth, while it explains about 53 percent with Split (2).

In Split (3), there is no investment shock in the model. The baseline model generates almost the same standard deviation in inflation as observed in data. It reproduces nearly 70 percent of the inflation correlation with output growth observed in data. However, it fails in matching the correlation of other variables with output growth.

3.5.2 Model with Nash wage bargaining

In this subsection, I test the effect of firm networking when wages are determined by Nash bargaining. It is well known in the literature that the credible wage bargaining introduces some real wage stickiness in the model. This improves the ability of the search and matching model to reproduce the empirical fluctuations in unemployment in response to labor productivity shocks. Here, I would like to know whether there is an interaction between the roundabout production structure and the real wage rigidity, and if the model with firm networking loses some of its ability to generate sizeable fluctuations with a small size of shocks when wages are flexible (Nash bargaining).

Tables 3.7 and 3.8 report the size of shocks and moments in models with CAOB and with Nash wages, with Split (1). The panel labeled "CAOB wage" replicates results for the baseline model and the standard model, with credible alternating offer bargaining. The panel labeled "Nash wage", shows results with Nash wage bargaining for both models with firm networking "FN, Nash" and without firm networking "No FN, Nash".

In Table 3.8, the "No FN, Nash" model is not able to reproduce unemployment fluctuations that are consistent with the data. The unemployment standard deviation in the "No FN, Nash" model is nearly 27 percent of its empirical value. The unemployment standard deviation relative to output growth implied by the same model is about 21 percent of its empirical value.

The "FN, Nash" model also fails along these dimensions. It explains only 20 percent of the standard deviation of the unemployment found in data. One sees that introducing firm networking in the model does not improve unemployment and labor market tightness volatility relative to the "No FN, Nash" model. However, Table 3.7 shows that the "No FN, Nash", requires standard deviations of shocks that are up to 2.54 times higher than those in the "FN, Nash" model to match the actual volatility of output growth. Firm networking is still the key behind the magnifying effects of shocks in the model. However, it requires introducing real wage stickiness (via the CAOB) to match unemployment and labor market tightness fluctuations with a much smaller size of shocks in comparative to the model without firms networking.

3.5.3 Inflation persistence and impulse responses

Table 3.9 presents inflation autocorrelations from a one to five quarter lags for different model. The introduction of firm networking enhances inflation persistence. At the one-quarter lag, the baseline model generates nearly the same inflation autocorrelation that is observed in data. Only 80 percent of this statistics was accounted for in the standard model. At lag 5, the baseline model reproduces 55 percent of the inflation autocorrelation. However, the standard model reproduces barely 11 percent of this statistic.

In order to show graphically the effects of firm networking on equilibrium dynamics, I compare the response of the economy to monetary, neutral technology and investment shocks in the standard and baseline model.

Figures 3.1, 3.2 and 3.3 display impulse responses of selected variables following a monetary policy shock, a neutral technology shock and an investment shock, respectively. The solid lines in each figure plot responses of variables in the model with firm networking and CAOB "Baseline". The dashed lines correspond to the impulse response functions of the model with CAOB, but without firm networking ("Standard").

Figure 3.1 shows that the baseline model does reasonably well at reproducing the effect of a positive monetary shock. The response of the real output is positive and hump-shaped. Firm networking helps the model to generate a hump-shaped fall in unemployment, as well as a rise in vacancies. With firm networking, the real marginal cost becomes less sensitive to the monetary shock. From the New Keynesian Phillips Curve, a smaller increase in marginal cost gives a smaller response of inflation to the monetary shock.

Figure 3.2 plots the responses of selected variables to a positive neutral technology shock. The response of output is larger in the "Baseline" than in the "Standard" model. With firm networking, the neutral technology shocks affect the aggregate output via two channels. The first effect occurs directly via the production function. The second effect is indirect and passes through the intermediate input coming from other firms. As in Gali (1999), following a positive technology shock, a firm requires less labor input to produce the output, hence total hours decline on the short-run (not reported). Since the adjustment in total hours occurs both at the intensive and the extensive margins, hours per employee react more with roundabout production because production is larger. Hence firms post fewer vacancies and unemployment is larger.

Figure 3.3 displays the impulse responses to the investment shock. Following a positive investment shock, output, investment, hours, vacancies and employment rise. The most important result is the response of consumption. In the "Standard" model, consumption decreases on impact and increases only after a few periods. In the "Baseline" model, consumption rises immediately following the positive investment shock. With firm networking, the model does a good job in capturing the contemporaneous correlation between consumption and investment growth. [7] The positive investment shock has two effects on consumption : a positive income effect and a negative substitution effect. In the standard model, the negative substitution effect is strong. As a result, consumption falls on impact in response to a positive investment shock. In the "Baseline" model, firm networking reduces the negative substitution effect on consumption and generates a stronger positive income effect. As a consequence, consumption increases on impact in response to the investment shock. [8]

3.6 Conclusion

A New Keynesian model with unemployment search frictions is used to study the effect of firm networking in the transmission of shocks in aggregate fluc-

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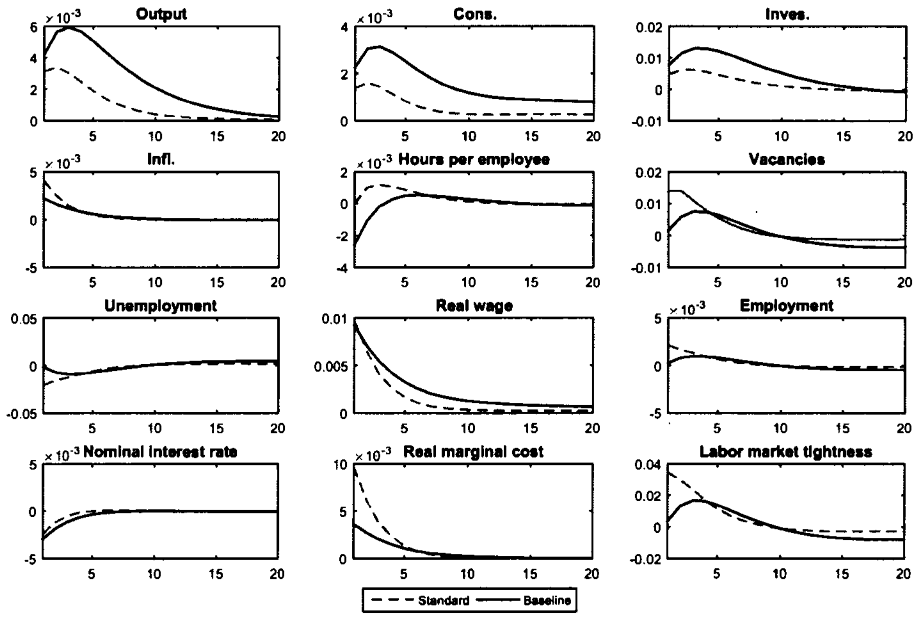
7. When the investment shock is more persistent, $\rho_i = 0.8$, it generates a more pronounced decline in consumption on impact with the standard model, while this response is still positive in the baseline model. A higher autoregressive parameter of the investment shock induces a higher and a more persistent response of the investment. Firms that are allowed to reoptimize their prices, anticipate it and will reset a higher price. This induces a stronger and a more persistent response of inflation. The response of consumption is then lower with $\rho_i = 0.8$ than with $\rho_i = 0.7$.

8. Ascari, Sims and Phaneuf (2016) use the Hicksian decomposition proposed by King (1991) and develop an analysis about the problem of the contemporaneous correlation between consumption and investment growth.

tuations. The interaction between firm networking and the credible bargaining wage acts as an amplification source for real shocks because it introduces strategic complementarity between firms. This mechanism makes this class of models more consistent with observed business cycle fluctuations. Strategic complementarity reconciles inflation inertia with a cyclical marginal cost. Unemployment fluctuations are more consistent with data because future hours per workers are the driving force for job creation. The model successfully accounts for the positive response of consumption in response to an investment shock and for hump-shaped responses of unemployment and vacancies following a monetary shock.

One possible extension is to introduce financial intermediation. The object is to know whether financial intermediation is important for labor market dynamics when there is firm networking in the search and matching model.

Figure 3.1 Impulse responses to a monetary shock



This figure plots the response of output, consumption, investment, inflation, hours per employee, vacancies, unemployment, real wage, employment, interest rate, real marginal cost and labor market tightness to monetary shock. The solid line is for the version of the model with firm networking "Baseline". The "Standard" dashed line is for the model without firm networking. All curves are based on the model with credible alternating offer bargaining.

Table 3.1 Parameter values for baseline model

Parameter	value	Description
β	0.99	Discount factor
h_c	0.7	Parameter for internal habit formation
η	1	Frisch elasticity of labor supply
λ	0.1	Job separation rate
ϵ	0.5	Matching function elasticity
ξ	0.6	Firm's bargaining power
b	0.4	Unemployment benefits
χ	0.1	Vacancy posting cost
δ_p	0.66	Probability of price non-reoptimization
γ	6	Elasticity of substitution among goods in the retailer
ϱ	6	Elasticity of substitution among goods in the wholesaler
δ	0.025	Depreciation rate
α	0.33	Share parameter of capital services
s_1	3	Investment adjustment cost
γ_2	0.15	Coefficient in the utilization cost function
ζ	0.774	Efficiency parameter of the matching function
ϕ	0.61	Share of intermediate input
ρ_R	0.8	Degree of interest rate smoothing in the Taylor rule
ϕ_π	1.5	Taylor rule coefficient on inflation
ϕ_y	0.125	Taylor rule coefficient on output growth
ρ_a	0.95	Autocorrelation coefficient of the neutral technology shock
ρ_i	0.7	Autocorrelation coefficient of the investment shock
σ_r	0.0037	Standard deviation of the monetary shock
σ_i	0.0437	Standard deviation of the investment shock
σ_a	0.0050	Standard deviation of the neutral technology shock

Table 3.2 Steady state

Variable	Definition	Value
h_s	Hours per worker	0.33
π	Steady-state inflation	1
u_s	Unemployment rate	0.11
n_s	Employment	0.89
Z_s	Capital utilization	1
$d_s=\frac{\chi v_s}{y_s U_c(c_s)}$	The ratio of vacancy posting utility cost to GDP	0.01
z	The employer's cost of delay	0.066
q_s	The probability of a firm finding a worker	0.7

Table 3.3 The size of shocks- Split (1)

Shocks	Standard	Baseline
σ_a	0.0116	0.0050
σ_i	0.0500	0.0437
σ_r	0.0052	0.0037

Note : This table shows the standard deviations of three shocks used in the model with firm networking (the baseline model) and in the model without firm networking (the standard model). In both models, wages are determined by "CAOB". These standard deviations are chosen to match the observed volatility of output growth in the data. $\sigma_a, \sigma_i, \sigma_r$ denote the standard deviations for the neutral technology, the investment and the monetary shocks, respectively. For Split (1), the investment shock accounts for 50 percent of the variance of the output growth, while the contribution of the neutral technology shock and the monetary shock are 35 and 15 percent, respectively.

Table 3.4 Moments in the baseline and the standard models- Split (1)

	Standard deviation			Std. relative to output growth			Correlation with output growth		
Var.	Data	Standard	Baseline	Data	Standard	Baseline	Data	Standard	Baseline
y	0.0122	0.0122	0.0122	-	-	-	-	-	-
c	0.0074	0.0049	0.0058	0.6065	0.4076	0.4788	0.6486	0.5272	0.6855
i	0.0463	0.0399	0.0383	3.7950	3.2765	3.1425	0.7979	0.9338	0.9419
π	0.0060	0.0085	0.0046	0.4918	0.7024	0.3773	-0.1963	0.1973	0.1376
u	0.0651	0.0845	0.0625	5.3360	6.9262	5.1227	-0.6831	-0.7204	-0.2586
v	0.0645	0.0632	0.0497	5.2868	5.1863	4.0761	0.7031	0.7584	0.2644
θ	0.1225	0.1474	0.1121	10.040	12.0845	9.1942	0.7335	0.7384	0.2613
n	0.0059	0.0088	0.0067	0.4836	0.7221	0.5517	0.6762	0.7204	0.2586

Note : This table shows moments (in first differences) generated from the model with firm networking (the baseline model) and the model without firm networking (the standard model). In both models, wages are determined by "CAOB". Moments in the data correspond to quarterly series computed on the 1951Q1-2008Q2 sample.

Table 3.5 The size of shocks in models- Split (2) and (3)

	Split (2)		Split (3)	
Shocks	Standard	Baseline	Standard	Baseline
σ_a	0.0098	0.0042	0.0170	0.0073
σ_i	0.0547	0.0479	0	0
σ_r	0.0052	0.0037	0.0067	0.0047

Note : This table shows the standard deviations of three shocks used in the model with firm networking (the baseline model) and the model without firm networking (the standard model). In both models, wages are determined by "CAOB". The shock standard deviations are chosen to match the observed volatility of output growth in the data. $\sigma_a, \sigma_i, \sigma_r$ denote standard deviations for the neutral technology, the investment and the monetary shocks respectively. For Split (2), the variance of the output growth is accounted by 60 percent of the investment shock, 25 percent of the neutral technology shock, and 15 percent of the monetary shock. For split (3), the investment shock accounts for 0 percent of the variance of the output growth, while the contribution of the neutral technology shock and the monetary shock are 75 and 25 percent, respectively.

Table 3.6 Moments in the baseline and the standard models- Split (2) and (3)

Split (2)

	Standard deviation			Std. relative to output growth			correlation with output growth		
Var.	Data	Standard	Baseline	Data	Standard	Baseline	Data	Standard	Baseline
y	0.0122	0.0122	0.0122	-	-	-	-	-	-
c	0.0074	0.0044	0.0051	0.6065	0.3664	0.4247	0.6486	0.4033	0.6134
i	0.0463	0.0422	0.0405	3.7950	3.4646	3.3253	0.7979	0.9409	0.9505
π	0.0060	0.0084	0.0044	0.4918	0.6925	0.3606	-0.1963	0.2848	0.2482
u	0.0651	0.0894	0.0595	5.3360	7.3360	4.8783	-0.6831	-0.7587	-0.3854
v	0.0645	0.0669	0.0474	5.2868	5.4909	3.8906	0.7031	0.7997	0.3962
θ	0.1225	0.1561	0.1069	10.040	12.7972	8.7644	0.7335	0.7781	0.3904
n	0.0059	0.0093	0.0064	0.4836	0.7648	0.5254	0.6762	0.7587	0.3854

Split (3)

	Standard deviation			Std. relative to output growth			correlation with output growth		
Var.	Data	Standard	Baseline	Data	Standard	Baseline	Data	Standard	Baseline
y	0.0122	0.0122	0.0122	-	-	-	-	-	-
c	0.0074	0.0067	0.0081	0.6065	0.5566	0.6716	0.6486	0.9646	0.9682
i	0.0463	0.0249	0.0243	3.7950	2.0463	1.9966	0.7979	0.9769	0.9823
π	0.0060	0.0107	0.0058	0.4918	0.8794	0.4817	-0.1963	-0.0107	-0.1337
u	0.0651	0.0564	0.0713	5.3360	4.6248	5.8497	-0.6831	-0.5580	0.1985
v	0.0645	0.0422	0.0564	5.2868	3.4629	4.6234	0.7031	0.5756	-0.2151
θ	0.1225	0.0984	0.1276	10.040	8.0689	10.4679	0.7335	0.5668	-0.2060
n	0.0059	0.0058	0.0076	0.4836	0.4821	0.6301	0.6762	0.5580	-0.1985

Note : This table shows moments (in first difference) generated from the model with firm networking (the baseline model) and the model without firm networking (the standard model). In both models, wages are determined by "CAOB". Moments in the data correspond to quarterly series computed on the 1951Q1-2008Q2 sample. For Split (2), the variance of the output growth is accounted by 60 percent of the investment shock, 25 percent of the neutral technology shock, and 15 percent of the monetary shock. For split (3), the investment shock accounts for 0 percent of the variance of the output growth, while the contribution of the neutral technology shock and the monetary shock are 75 and 25 percent, respectively.

Table 3.7 The size of shocks with CAOB/Nash wages- Split (1)

	CAOB wage		Nash wage	
Shocks	Standard	Baseline	No FN, Nash	FN, Nash
σ_a	0.0116	0.0050	0.0127	0.0050
σ_i	0.0500	0.0437	0.0536	0.0437
σ_r	0.0052	0.0037	0.0055	0.0037

Note : This table shows the standard deviation of three shocks generated from different models. Wages are determined in two ways. "CAOB wage" denotes the model with credible alternating offer bargaining, and "Nash wage" denotes the model with the standard Nash wage bargaining à la Diamond-Mortensen-Pissarides. The column labeled "Standard" corresponds to the standard model in which there is no firm networking and CAOB wages. The column labeled "Baseline" corresponds to the model with firm networking and CAOB wages. The column labeled "No FN, Nash" shows statistics for the model without firm networking and with Nash wage bargaining. The column labeled "FN, Nash" shows statistics for the model with both firm networking and Nash wage bargaining. For Split (1), the investment shock accounts for 50 percent of the variance of the output growth, while the contribution of the neutral technology shock and the monetary shock are 35 and 15 percent, respectively.

Table 3.8 Moments in models with CAOB/Nash wages- Split (1)

CAOB wage

	Standard Deviation			Std. relative to output growth		
Var.	Data	Standard	Baseline	Data	Standard	Baseline
y	0.0122	0.0122	0.0122	-	-	-
c	0.0074	0.0049	0.0058	0.6065	0.4076	0.4788
i	0.0463	0.0399	0.0383	3.7950	3.2765	3.1425
π	0.0060	0.0085	0.0046	0.4918	0.7024	0.3773
u	0.0651	0.0845	0.0625	5.3360	6.9262	5.1227
v	0.0645	0.0632	0.0497	5.2868	5.1863	4.0761
θ	0.1225	0.1474	0.1121	10.040	12.0845	9.1942
n	0.0059	0.0088	0.0067	0.4836	0.7221	0.5517

Nash wage

	Standard Deviation			Std. relative to output growth		
Var.	Data	No FN, Nash	FN, Nash	Data	No FN, Nash	FN, Nash
y	0.0122	0.0122	0.0122	-	-	-
c	0.0074	0.0052	0.0059	0.6065	0.4270	0.4852
i	0.0463	0.0424	0.0378	3.7950	3.4819	3.1032
π	0.0060	0.0090	0.0047	0.4918	0.7450	0.3860
u	0.0651	0.0178	0.0134	5.3360	1.4744	1.1051
v	0.0645	0.0672	0.0450	5.2868	5.5154	3.6919
θ	0.1225	0.0812	0.0560	10.040	6.6612	4.5915
n	0.0059	0.0055	0.0036	0.4836	1.4098	1.2622

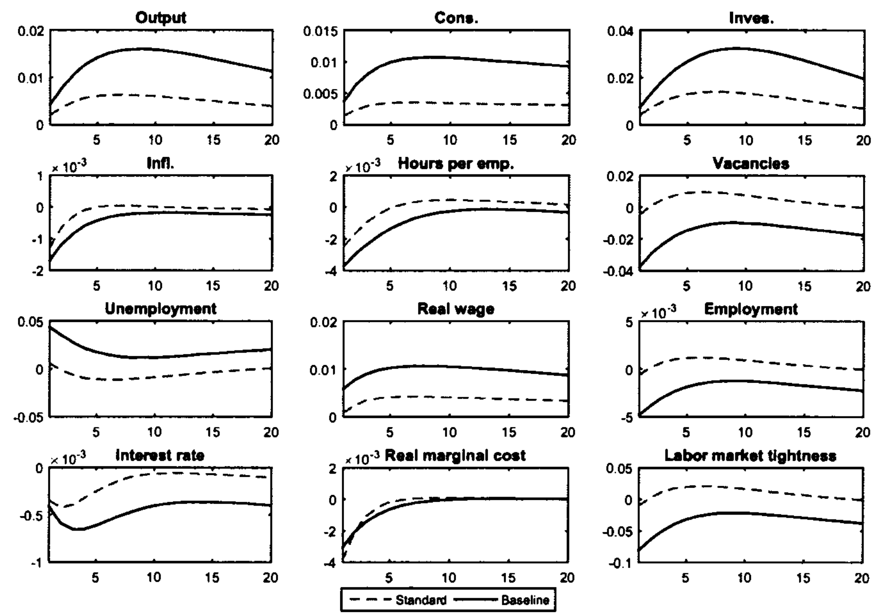
Note : This table compares selected moments in data to those simulated in different models. Statistics in the data correspond to quarterly series computed over the 1951Q1-2008Q2 sample. "CAOB wage" denotes the model with credible alternating offer bargaining and "Nash wage" denotes the model with the standard Nash wage bargaining à la Diamond-Mortensen-Pissarides. The column labeled "Standard" corresponds to the standard model in which there is no firm networking and with CAOB wages. The column labeled "Baseline" corresponds to the model with firm networking and CAOB wages. The column labeled "No FN, Nash" shows statistics for the model without firm networking and with Nash wage bargaining. The column labeled "FN, Nash" shows statistics for the model with both firm networking and Nash wage bargaining. For Split (1), the investment shock accounts for 50 percent of the variance of the output growth, while the contribution of the neutral technology shock and the monetary shock are 35 and 15 percent, respectively.

Table 3.9 Inflation autocorrelations with CAOB wage- split (1)

	1	2	3	4	5
Data	0.762	0.720	0.736	0.674	0.607
Standard	0.613	0.367	0.216	0.125	0.071
Baseline	0.773	0.602	0.475	0.381	0.312

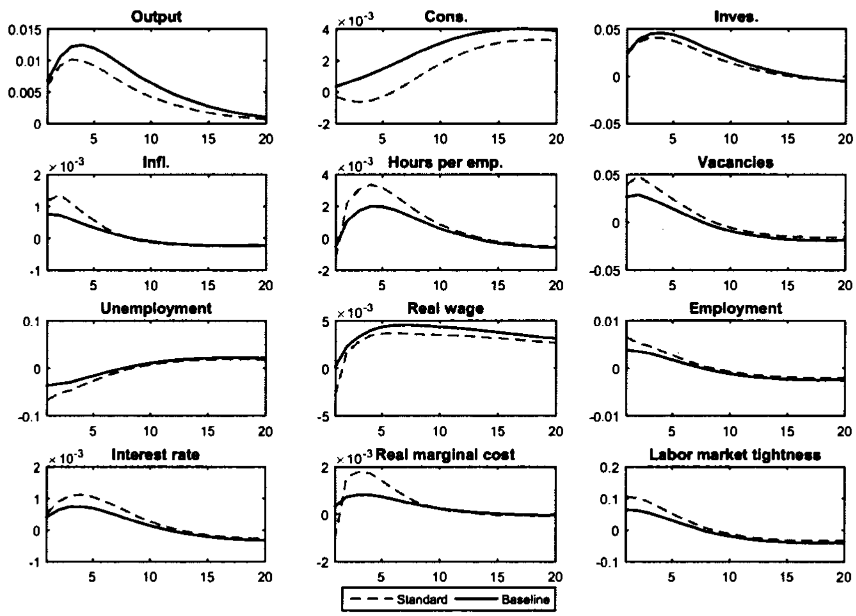
Note : This table shows statistics for autocorrelations of inflation at different lags for different versions of the model. The row labeled "Data" reproduces the autocorrelations observed in the U.S. data from 1951Q1 to 2008Q2. The row labeled "Standard" shows autocorrelations of inflation in the model without firm networking. The row labeled "Baseline" uses the baseline model with firm networking. In all cases, wages are determined by "CAOB". For Split (1), the investment shock accounts for 50 percent of the variance of the output growth, while the contribution of the neutral technology shock and the monetary shock are 35 and 15 percent, respectively.

Figure 3.2 Impulse responses to a neutral technology shock



Note : This figure plots the response of variables to a neutral technology shock. The solid line is for the version of the model with firm networking “Baseline”. The “Standard” dashed line is for the model without firm networking. All curves are based on the model with credible alternating offer bargaining.

Figure 3.3 Impulse responses to an investment shock



Note : This figure plots the response of variables to an investment shock. The solid line is for the version of the model with firm networking "Baseline". The "Standard" dashed line is for the model without firm networking. All curves are based on the model with credible alternating offer bargaining.

APPENDIX A

INVESTMENT SHOCKS, PRODUCTION NETWORKING AND UNEMPLOYMENT

A.1 All equilibrium equations

$$\lambda_t^{AR} = \frac{1}{c_t - h_c c_{t-1}} - E_t \frac{\beta h_c}{c_{t+1} - h_c c_t}, \tag{A.1}$$

$$r_t^k = \gamma_1 + \gamma_2 (Z_t - 1), \tag{A.2}$$

$$\lambda_t^{AR} = E_t \beta \lambda_{t+1}^{AR} (1 + R_t) \frac{1}{\pi_{t+1}}, \tag{A.3}$$

$$\begin{aligned} \lambda_t^{AR} &= \lambda_t^B \varepsilon_t^I \left[1 - \frac{s_1}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - s_1 \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \\ & E_t \beta \lambda_{t+1}^B \varepsilon_{t+1}^I s_1 \left(\frac{I_t}{I_{t-1}} - 1 \right) (\frac{I_t}{I_{t-1}})^2, \end{aligned} \tag{A.4}$$

$$\lambda_t^B = \beta E_t \lambda_{t+1}^{AR}\left[r_{t+1}^k Z_{t+1} - \gamma_1(Z_t - 1) - \frac{\gamma_2}{2}(Z_t - 1)^2\right] + \beta E_t \lambda_{t+1}^B (1-\delta), \quad \text{(A.5)}$$

$$r_t^k = \alpha(1-\phi) mc_t A_t \left(\frac{\Gamma_t}{K_t}\right)^{\phi}\left(\frac{K_t}{n_t h_t}\right)^{(1-\alpha)(\phi-1)}, \quad \text{(A.6)}$$

$$w(h_t) = (1-\xi)[mc_t mpl_t h_t + \frac{z}{U_c(c_{t-1}, c_t)}] + \xi[\frac{b}{U_c(c_{t-1}, c_t)} + \frac{\frac{h_{it}^{1+\eta}}{1+\eta}}{U_c(c_{t-1}, c_t)}], \quad \text{(A.7)}$$

$$K_{t+1}^p = \varepsilon_t^I(1 - \frac{s_1}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2) I_t + (1-\delta) K_t^p, \quad \text{(A.8)}$$

$$u_t = 1 - n_t, \quad \text{(A.9)}$$

$$\theta_t = \frac{v_t}{u_t}, \quad \text{(A.10)}$$

$$y_t = c_t + I_t + \left[\gamma_1(Z_t - 1) + \frac{\gamma_2}{2}(Z_t - 1)^2\right] K_t^p + \frac{\chi}{U_c(c_t, c_{t+1})} v_t, \quad \text{(A.11)}$$

$$K_t = Z_t K_t^p, \quad \text{(A.12)}$$

$$\frac{\chi}{q(\theta_t)} = \beta\xi E_t \frac{\eta}{1+\eta} h_{t+1}^{\eta+1} - \beta(1-\xi)z - \beta b\xi + \beta E_t(1-\lambda)\frac{\chi}{q(\theta_{t+1})}, \tag{A.13}$$

$$mpl_t = (1-\alpha)(1-\phi)A_t \left(\frac{\Gamma_t}{K_t}\right)^{\phi} \left(\frac{K_t}{n_t h_t}\right)^{\phi(1-\alpha)+\alpha}, \tag{A.14}$$

$$n_{t+1} = (1-\lambda)n_t + p(\theta_t)(1-n_t), \tag{A.15}$$

$$M(u_t, v_t) = \zeta v_t^{\epsilon} u_t^{1-\epsilon}, \tag{A.16}$$

$$p(\theta_t) = \frac{M(u_t, v_t)}{u_t}, \tag{A.17}$$

$$q(\theta_t) = \frac{M(u_t, v_t)}{v_t}, \tag{A.18}$$

$$s_t = (1-\delta_p)p_t^{*(-\gamma)} + \delta_p \pi_t^{\gamma} s_{t-1}, \tag{A.19}$$

$$s_t X_t = A_t \Gamma_t^{\phi} \left(K_t^{\alpha} \left[n_t h_t\right]^{1-\alpha}\right)^{1-\phi} - F, \tag{A.20}$$

$$1 = \delta_p \pi_t^{(\gamma-1)} + (1-\delta_p) p_t^{*(1-\gamma)}, \tag{A.21}$$

$$p_t^* = \frac{\gamma}{\gamma-1}(\frac{\varrho}{\varrho-1})\frac{x_t^1}{x_t^2}, \tag{A.22}$$

$$x_t^1 = \lambda_t^{AR} mc_t X_t + \delta_p \beta \pi_{t+1}^{\gamma} x_{t+1}^1, \tag{A.23}$$

$$x_t^2 = \lambda_t^{AR} X_t + \delta_p \beta \pi_{t+1}^{\gamma-1} x_{t+1}^2, \tag{A.24}$$

$$mc_t = \frac{h_t^{\eta}}{mpl_t U_c(c_{t-1}, c_t)}, \tag{A.25}$$

$$A_t = (A_{t-1})^{\rho_a} \exp(\mu_a), \tag{A.26}$$

$$\varepsilon_t^I = (\varepsilon_{t-1}^I)^{\rho_i} \exp(\mu_i), \tag{A.27}$$

$$\frac{(1+R_t)}{(1+R)} = [(\frac{\pi_t}{\pi})^{\phi_\pi}(\frac{y_t}{y_{t-1}})^{\phi_y}]^{1-\rho_R}[\frac{(1+R_{t-1})}{(1+R)}]^{\rho_R}\varepsilon_t^R, \tag{A.28}$$

$$\varepsilon_t^r = (\varepsilon_{t-1}^r)^{\rho_r} \exp(\mu_r), \tag{A.29}$$

$$\phi mc_t A_t \left(\frac{\Gamma_t}{K_t}\right)^{(\phi-1)} \left(\frac{K_t}{n_t h_t}\right)^{(\alpha-1)(1-\phi)} = 1, \tag{A.30}$$

$$y_t = X_t - \Gamma_t. \tag{A.31}$$

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