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RÉSUMÉ

Cette thèse est composée de trois chapitres mettant en évidence certains mécanismes qui contribuent à améliorer l'utilité des modèles néokeynésiens pour l'analyse de politiques économiques et pour l'évaluation des coûts de l'inflation.

Le premier chapitre montre qu'un modèle néokeynésien avec des rigidités de prix à la Calvo n'est pas nécessairement en contradiction avec des évidences d'une faible corrélation entre la hausse de l'inflation et la dispersion des prix et ce, même pour des niveaux d'inflation proches de ceux des années 1970 et du début des années 1980. Par conséquent, comme le suggère Nakamura et al. (2017), il est peu probable que la dispersion des prix soit un facteur déterminant des coûts de l'inflation. Nous identifions ensuite les salaires rigides et les changements technologiques provenant du progrès technique neutre et des technologies spécifiques à l'investissement comme des facteurs qui altèrent le rôle allocatif des salaires en présence d'une inflation tendancielle positive. L'interaction entre ces facteurs génère une dispersion inefficace des salaires qui alimente à son tour les coûts de l'inflation. Nous montrons que ces coûts sont plus élevés quand la technologie suit une tendance stochastique plutôt qu'une tendance déterministe. Nous constatons également que les coûts de l'inflation sont très sensibles aux variations de l'élasticité de substitution entre les expertises de travail pour une variation modérée de l'inflation.

Le deuxième chapitre conteste l'idée selon laquelle les modèles néokeynésiens avec des salaires et des prix purement prospectifs ne peuvent pas expliquer la dynamique inertielle de l'inflation et de la production en réponse à une variation

de la demande globale (Chari, Kehoe et Mc Grattan, 2000). On remet également en question l'idée selon laquelle les modèles néokeynésiens doivent s'appuyer sur une marge ajoutée au coût marginal contracyclique comme canal de transmission clé pour les chocs de demande, ce qui ne semble pas cohérent avec certaines évidences (Galí, Gertler et Lopez-Salido, 2007, Nekarda et Ramey, 2013). Nous montrons qu'un modèle DSGE de taille moyenne exempt de clauses d'indexation des prix et des salaires, mais dans lequel les firmes produisent en réseau et financent l'achat de tous leurs intrants en empruntant d'un intermédiaire financier permet d'expliquer correctement la dynamique de l'inflation et l'output en réponse à un choc de demande ainsi que les évidences concernant la cyclicité de la marge ajoutée au coût marginal.

Dans le troisième chapitre nous utilisons les techniques bayésiennes pour estimer l'importance de la production en réseau et des fonds de roulement dans un modèle DSGE et en explorer les implications pour le cycle économique. Nos résultats confirment l'évidence d'une structure de production en réseau. Ils suggèrent également que les entreprises utilisent le fonds de roulement pour financer une fraction substantielle de leurs dépenses pour les intrants intermédiaires, les services du capital et le travail. Ces résultats restent consistants à l'ajout de chocs anticipés dans le modèle. Notre modèle avec réseaux de production et fonds de roulement s'ajuste également mieux aux données lorsque comparés à un modèle standard. Nous constatons aussi que la présence de ces deux ingrédients modifie de manière significative les sentiers de réponse des variables clés suivant les chocs à l'efficience marginale de l'investissement, à la productivité totale des facteurs, à la marge ajoutée au coût marginal et à la politique monétaire. Malgré l'utilisation des préférences standards, notre modèle de référence n'est pas sujet au problème de comouvement en raison de la réponse positive de la consommation suivant un choc à l'efficience marginale de l'investissement.

Mots - clés : Dispersion salariale ; inflation tendancielle ; coûts de l'inflation ; changement technologique ; modèle néokeynesien ; réseaux de firmes ; fonds de roulement ; dynamique de l'inflation ; multiplicateur de contrat pour l'output ; marge ajoutée au coût margina cycliquel ; probème de comouvement ; estimation bayésienne ;extended working capital ; chocs d'investissement ; comouvement du cycle réel ; source du cycle réel.

ABSTRACT

This thesis consists of three chapters that identify new channels that improve the usefulness of New Keynesian models for policy analysis and for the evaluation of inflation costs.

The first chapter shows that the Calvo price-setting model is not necessarily inconsistent with the evidence of a loose relationship between trend inflation and price dispersion. This can be true even for a level of inflation like that experienced during the 1970s and early 1980s. Therefore, as suggested by Nakamura et al. (2017), price dispersion is unlikely to be a key factor driving inflation costs. Then, we identify sticky wages and technical change stemming from neutral and investment-specific technological progress as factors distorting the allocative role of the wage system under positive trend inflation. The interaction between these factors generates inefficient wage dispersion, which in turn fuels inflation costs. We show that inflation costs conditioned on stochastic means are significantly larger with stochastic trends in both technologies than with deterministic trends. We also find that with high inflation, the costs of inflation are very sensitive to modest variations in the elasticity of substitution among differentiated labour skills. While estimating inflation costs is tainted with uncertainty, we believe that it is too early to announce the dismissal of the New Keynesian model as a useful vehicle to assess the costs of inflation.

The second chapter challenges the view that New Keynesian models with purely forward-looking wage and price setting cannot explain inertial inflation and output dynamics in response to a change in aggregate demand (Chari, Kehoe and

Mc Grattan, 2000; Mankiw and Reis, 2002). We also call into question a well-received idea that New Keynesian models must rely on a countercyclical markup of price over marginal cost as a key transmission channel for demand shocks, something that does not seem consistent with the evidence (Galí, Gertler and Lopez-Salido, 2007; Nekarda and Ramey, 2013). We show that a medium-scale DSGE model abstracting from *ad hoc* backward-looking wage and price setting mechanisms, but emphasizing firms networking and an extended working capital channel allowing firms to finance the costs of intermediate inputs, labor, and capital services can successfully address some of these apparent failures of purely forward-looking New Keynesian models.

The third chapter explores the business cycle implications of production networking and working capital in an estimated New Keynesian model. Using Bayesian methods, we estimate a medium-scale DSGE model that features production networks and an extended working capital channel. We offer evidence which strongly supports a network view of the production process. It also suggests that firms use working capital to finance a substantial fraction of their outlays for intermediate inputs, capital services and labor. These findings hold whether news shocks are included or not. Relative to a standard model which abstracts from these refinements, a comparison of the marginal likelihood statistics computed by modified harmonic mean estimation speaks clearly to the relative advantage and fit of our benchmark model. Compared to the standard model, we find that production networks and working capital significantly alter the impulse responses of key variables to marginal efficiency of investment (MEI), TFP, wage markup and monetary policy shocks. Despite standard preferences, our benchmark model is not prone to the "comovement problem". Central to our findings is a positive response of consumption following a MEI shock.

Keywords: Wage dispersion; trend inflation; inflation costs; technical change; New Keynesian model; firms networking; working capital; inflation dynamics; contract multiplier for output; cyclical markups; comovement problem; bayesian estimation;extended working capital; investment shocks, business cycle comovement; source of business cycles.

INTRODUCTION

Depuis les années 70 , la macroéconomie s'est graduellement dotée d'outils lui permettant de traiter les problèmes rencontrés à partir d'un cadre conceptuel cohérent, construit autour du comportement optimal des agents économiques et de l'hypothèse d'anticipations rationnelles. Ce noyau conceptuel de base s'est enrichi par l'ajout de frictions réelles et nominales, donnant naissance aux modèles néokeynésiens. Cette classe de modèles a facilité l'analyse normative et a permis de mieux comprendre les fluctuations macroéconomiques à cause de leur capacité à répliquer les évidences empiriques liées aux caractéristiques et à la dynamique du cycle économique.

Toutefois, en dépit de leurs succès, certains chercheurs mettent en doute la capacité des modèles néokeynésiens à évaluer les coûts de l'inflation et à servir d'outils d'analyse de la politique économique. Par exemple, les évidences empiriques dans Nakamura et al. (2017), selon laquelle la dispersion des prix serait insensible à une hausse de l'inflation, suggèrent que ces modèles ne sont pas utiles à l'évaluation des coûts de l'inflation car ces coûts reposent sur une relation positive entre la hausse de l'inflation et la dispersion des prix. Les modèles néokeynésiens peinent également à répliquer le comportement de certaines variables macroéconomiques sans recourir à des ingrédients ad hoc ou à des chocs structurels douteux. Ces anomalies ont porté Chari, Kehoe et Mc Grattan (2009) à affirmer que ces modèles ne sont pas utiles à l'analyse de politiques économiques.

Cette thèse est composée de trois chapitres qui identifient un ensemble de mécanismes clés permettant d'améliorer la performance des modèles néokeynésiens.

Le premier chapitre fait la preuve qu'un modèle néokeynésien classique avec des rigidités de prix à la Calvo (1983) n'est pas nécessairement inconsistant avec des évidences d'une faible corrélation entre la hausse de l'inflation et la dispersion des prix et ce, même pour des niveaux d'inflation proches de ceux des années 70 et 80. On montre ensuite que l'interaction entre les changements techniques et les salaires rigides constitue un canal alternatif à travers lequel ces modèles génèrent les coûts de l'inflation. On trouve que l'inflation peut générer des coûts élevés dépendamment du degré de substitution entre les expertises de travail. L'importance des coûts de l'inflation constitue un signal invitant les autorités monétaires à la prudence face aux propositions qui recommandent de hausser la cible d'inflation afin d'augmenter la marge de manœuvre des banques centrales en présence d'une récession.

Le deuxième chapitre 2 de la thèse développe un modèle dans lequel les firmes sont interconnectées et effectuent des emprunts pour financer leurs intrants. On montre que ce modèle, débarrassé de chocs structurels douteux et d'ingrédients ad hoc comme les clauses d'indexation, parvient à répliquer les évidences empiriques portant sur la dynamique de l'output et de l'inflation. Les réseaux de firmes et la structure de financement des intrants sont déterminants pour obtenir ces résultats.

Le chapitre 3 pousse plus loin l'analyse de notre modèle enrichi en demandant aux données, via une estimation Bayésienne du modèle, de nous fournir une évaluation de leur importance dans l'économie. Notre estimation confirme que les réseaux de firmes, via une part des inputs intermédiaires dans la production de 0.56, possède une importance significative dans l'économie. On a aussi confirmé que les firmes utilisent des emprunts auprès des institutions financières pour financer autour de 50% du coût de leurs intrants, dont le capital, le travail et les inputs intermédiaires.

Une autre anomalie que l'on retrouve dans ce type de modèle est leur incapacité à générer une corrélation positive entre la consommation et l'investissement. La raison est que la consommation répond négativement à l'impact suivant un choc d'investissement. Le modèle estimé produit une réponse non négative de la consommation suivant un choc d'investissement et une corrélation positive entre la consommation et l'investissement qui est plus proche des données que celle délivrée par les modèles qui ne possèdent pas nos ingrédients.

CHAPITRE I

LONG-RUN INFLATION AND THE DISTORTING EFFECTS OF STICKY WAGES AND TECHNICAL CHANGE

Abstract

We first establish that a Calvo price-setting model is not necessarily inconsistent with a weak relationship between trend inflation and price dispersion. This is true for a level of inflation like the one experienced during part of the 1970s and early 1980s. Then, we identify sticky wages and technical change stemming from neutral and investment-specific technological progress as factors disrupting the allocative role of the relative wage system under positive trend inflation. The interaction between these factors generates inefficient wage dispersion, which in turn fuels inflation costs. We show that the mean inflation costs are larger with trends in both technologies being stochastic as opposed to deterministic. But with high inflation, inflation costs are found to be very sensitive to relatively small variations in the elasticity of substitution among differentiated labour skills. We conclude from our findings that it is too early to announce the death of the NK model as a useful vehicle to assess the costs of inflation.

JEL classification : E31, E32.

Keywords : wage dispersion ; trend Inflation ; inflation costs ; technical change.

1.1 Introduction

Standard New Keynesian (NK) models identify sticky prices and inefficient price dispersion as key elements fueling inflation costs. However, Nakamura et al. (2017) cast doubts about the relevance of price dispersion as a mechanism driving inflation costs since they find no evidence of a relationship between higher trend inflation and increased price dispersion when using disaggregated price data covering part of the 1970s and early 1980s. Given this, our paper raises the following questions. Does the sticky-price NK model always imply a strong relationship between high inflation and inefficient price dispersion ? What are other channels than sticky prices and price dispersion that may fuel inflation costs ? Are these channels plausible upon varying inflation from a moderate to a high level ?

Our paper makes three main contributions to the literature on trend inflation. [1] First, using a plausibly calibrated sticky-price model, we show that high inflation does not necessarily lead to inefficient price dispersion. Second, we identify inefficient wage dispersion as an alternative to price dispersion as a potential factor fueling inflation costs. With positive trend inflation, we show that the interaction between sticky wages and technical change can significantly disrupt the allocative role of the wage system, hence leading to much higher welfare costs and output losses than with sticky prices only. This interaction is particularly disruptive with stochastic trends in neutral and investment-specific technologies. Third, we show that for a high level of inflation like that experienced in the 1970s and early 1980s, inefficient wage dispersion becomes highly sensitive to relatively modest variations in the elasticity of substitution among differentiated labour skills. For an inflation trend of 7%, which corresponds to the annualized average rate of inflation for the period 1972Q1-1983Q4, the welfare costs of inflation lie in the

1. See Ascari and Sbordone (2014) for a survey of this literature.

range between 5 and 18% for an elasticity of substitution among types of skills between 4 and 6.

We use a medium-scale NK model which emphasizes monopolistically competitive markets for intermediate goods and labour, technical change, trend inflation, real frictions and nominal wage and price rigidities. [2] We provide a quantitative assessment of inflation costs conditioned on non-stochastic steady states and stochastic means. Following Greenwood, Hercowitz, and Krusell (1997) and Fisher (2006), we assume that technical change stems from trend growth in neutral and investment-specific technological progress. Trends are either deterministic or stochastic. We consider stochastic trends because permanent technology shocks are often viewed as a natural way of modeling purely technological disturbances (Galí, 1999 ; Francis and Ramey, 2005 ; Basu, Fernald, and Kimball, 2006 ; Fisher, 2006).

We are not the first to account for neutral and investment-specific technical progress in a NK model. Justiniano, Primiceri, and Tambalotti (2011) incorporate incorporate non-stationary growth rates of neutral and investment-specific technologies in a medium-scale NK framework. But at the same time they assume that nominal wages and prices are indexed to past and steady-state inflation making trend growth and trend inflation irrelevant for equilibrium dynamics to a first-order approximation.

But the use of indexation has been criticized both on theoretical and empirical grounds (Woodford, 2007 ; Cogley and Sbordone, 2008 ; Chari, Kehoe, and McGrattan, 2009 ; Christiano, Eichenbaum, and Trabandt, 2016). Theoretically, it

2. The model closest to ours is one by Ascari, Phaneuf, and Sims (2016). A main difference however is our treatment of trend growth and the fact that our focus in this paper is quite different.

lacks microeconomic underpinnings. Empirically, it implies when used in a Calvo model that *all* nominal wages and prices change every 3 months, an implication which is counterfactual based on simple observation and microeconomic evidence on the frequency of wage and price adjustments (e.g. see Bils and Klenow, 2004; Nakamura and Steinsson, 2008; Eichenbaum, Jaimovich, and Rebelo, 2011; Barattieri, Basu, and Gottschalk, 2014). Moreover, if nominal wages and prices are effectively indexed in reality, it is hardly at a quarterly pace, in particular wage indexation which typically takes place about once a year. For these reasons, we abstract from indexation.

Our framework is somewhat similar to the model in Ascari, Phaneuf and Sims (2016) (hereafter, APS). But there are some important differences between the two models. First, their model incorporates a roundabout production structure and working capital while ours abstracts from these features. The reason for this is that APS focus on the welfare costs of moderate trend inflation ranging from 0 to 4%, whereas we look at the welfare costs and output losses of an inflation trend reaching 7% and 12%. Despite such high levels of inflation, we are able to obtain a unique rational expectations equilibrium and thus to obtain cost estimates. With roundabout production and working capital, the model fails to achieve determinacy at high levels of inflation. Second, we consider both stochastic and deterministic trends in neutral and investment-specific technologies, whereas APS assume deterministic trends only. While this distinction does not matter for the estimation of welfare costs and output losses conditioned on non-stochastic steady states, it does make a difference when it comes to inflation costs conditioned on stochastic means.

A first substantive finding is that we find that the "standard" NK Calvo model with sticky prices and flexible nominal wages is not necessarily at odd with the lack of relationship between high inflation and inefficient price dispersion.

Nakamura et al. (2017) argue that the sticky-price Calvo model predicts that inflation costs "are very large even for moderate levels of inflation". By contrast, we show that these costs can be fairly small even for a level of 7%, which is the annualized average rate of inflation observed from 1972Q1 to 1983Q4.

However, two conditions must be met to obtain this result. Firstly, the degree of price stickiness must be relatively low. To make our case, we set the average waiting time between price adjustments at 6.7 months based on Coibion and Gorodnichenko (2011) and Coibion, Gorodnichenko, and Wieland (2012), a value that we keep throughout our analysis.[3] Secondly, the elasticity of substitution among differentiated goods must be fairly low. In our baseline calibration, this elasticity is set at 4 following Nakamura et al. (2017), who motivate their choice on values of the elasticity of demand for individual products found in the industrial organization and international trade literatures (Berry, Levinsohn, and Pakes, 1995 ; Nevo, 2001 ; Broda and Weinstein, 2006). When both conditions are satisfied, we show that the welfare cost and output loss resulting from a 7% inflation trend are roughly 0.2%. Concomitantly, price dispersion is nearly unresponsive to trend inflation between 0 and 7%. For an inflation trend reaching 10%, the welfare costs and output losses are below 0.5%, meaning that price dispersion is also not very responsive to high inflation.

This leads to our second main contribution. We show that the interaction between sticky wages and technical change exacerbates inefficient wage dispersion in response to higher inflation. In turn, increased wage dispersion fuels inflation costs. Our baseline calibration sets the elasticity of substitution among types of skills at 4 to match the elasticity of substitution among types of goods. The Calvo

3. This corresponds to a Calvo probability of price non-reoptimization set at 0.55.

probability of wage non-reoptimization is set at 2/3.[4] The steady-state welfare cost and output loss of an inflation trend of 7% jump to 4.4% and 4%, respectively. Meanwhile, steady-state wage dispersion increases by 9.9% (relative to zero trend inflation). When conditioned on stochastic means, these figures are higher, and more so with stochastic trends.

What explains these findings? Consider first the "standard" medium-scale NK model of of Christiano, Eichenbaum, and Evans (2005). This model abstracts from technical change while assuming zero trend inflation.[5] In this model, the wage distribution is characterized by identical nominal wages in the steady state. Therefore, steady-state wage dispersion is zero. With positive trend inflation but no technical change, not all nominal wages are identical in the steady state, with newly-reset wages being high relative to old wages. Trend inflation then generates inefficient wage dispersion. With a convex disutility of labour, total labour disutility rises non-linearly with higher wage dispersion, making trend inflation costly. Adding technical change to sticky wages but assuming zero trend inflation will generate some wage dispersion relative to the no growth case. Adding positive trend inflation on top of sticky wages and technical change greatly amplifies these distortions, exacerbating wage dispersion and increasing the costs of inflation even more.[6]

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4. We set a higher value of the Calvo probability of non-reset wages (relative to non-reset prices) for two reasons. A first reason is that it is consistent with the estimates in Christiano, Eichenbaum, and Evans (2005). The second reason is that micro-level evidence on nominal wage (Barattieri, Basu, and Gottschalk, 2014) and price (Bils and Klenow, 2004) adjustments suggests that the average wating time interval is longer for wages than for prices.

5. Their model includes backward-looking indexation while ours does not.

6. See Amano et al. (2009) for a similar reasoning in a simpler NK model with sticky wages and TFP growth.

Our third contribution is more like a caveat about the use of NK models as a useful device to assess inflation costs. We provide evidence of a relatively high sensitivity of inflation costs to modest variations in the elasticity of substitution among labour skills. An early study assuming monopolistically competitive labor markets is Huang and Liu (2002), who consider a range for this elasticity between 2 and 6 based on the microstudies of Griffin (1992, 1996). We conduct numerical experiments assuming that this elasticity ranges from 4 to 6. We find that the welfare costs of going from an inflation trend of 0% to 4% conditioned on means and stochastic trends is 1.8%, 3.1% and 5.6% with an elasticity of substitution of 4, 5 and 6, respectively. For an inflation trend going from 0% to 7%, these figures are 5%, 9% and 18%, respectively. Welfare costs of this magnitude may raise a certain amount of skepticism. Unfortunately, there is little evidence at hand that would help pinning down this elasticity with more precision.

The rest of the paper is organized as follows. Section 2 describes our DSGE model. Section 3 discusses calibration issues. Section 4 examines the relationship between higher inflation and increased price dispersion with sticky prices and flexible nominal wages. Section 5 documents how inflation costs are affected by the interaction between trend inflation, sticky wages and technical change. Section 6 assesses the plausibility of these channels. Section 7 contains concluding remarks.

1.2 A Medium-Scale NK Model With Technical Change and Positive Trend Inflation

This section outlines our model, which shares similarities with the NK models of of Erceg, Henderson, and Levin (2000), Huang, Liu, and Phaneuf (2004), Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). It includes imperfect competition in the markets for intermediate goods and labour, consumer habit formation, variable capacity utilization, investment adjustment costs and nominal wage and price rigidities in the form of Calvo contracts (Calvo, 1983). We extend this class of models to allow for technical change and non-zero trend inflation.

The economy is populated by five types of agents : employment agencies, households, final good producers, intermediate goods producers and a monetary authority. Competitive employment agencies transform differentiated skills into an aggregate labour input. Households derive utility from consumption and leisure, and supply differentiated skills. The final good producer operates in a perfectly competitive market, transforming differentiated intermediate goods into gross output. Intermediate goods producers produce differentiated goods using capital services and labour. A monetary authority sets monetary policy based on a Taylor-type of rule (Taylor, 1993).

1.2.1 Employment Agencies

Each period, perfectly competitive employment agencies aggregate differentiated labour services, $L_{it}, i \in [0, 1]$, into a homogenous labour input, L_t :

$$L_t = \left(\int_0^1 L_{it}^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}, \tag{1.1}$$

where $\sigma > 1$ is the elasticity of substitution among differentiated labour services. Profit maximization by perfectly competitive employment agences implies the following labour demand schedule :

$$L_{it} = \left(\frac{W_{it}}{W_t} \right)^{-\sigma} L_t, \tag{1.2}$$

where W_{it} is the nominal wage paid to labour of type i and W_t is the aggregate nominal wage index :

$$W_t^{1-\sigma} = \int_0^1 W_{it}^{1-\sigma} di. \tag{1.3}$$

1.2.2 Households and Wage Setting

There is a continuum of households, indexed by $i \in [0,1]$, specialized in supplying differentiated labour, L_{it}. Preferences are expressed with respect to consumption and labour. Because of staggered wage setting, households will have different incomes, consumption and savings. Following Erceg, Henderson, and Levin (2000), we assume state contingent securities providing insurance against idiosyncratic wage risk, so that consumption and investment are the same across households.

A typical household hence maximizes the expected value of his lifetime utility :

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\ln \left(C_t - hC_{t-1} \right) - \eta \frac{{L_{it}}^{1+\chi}}{1+\chi} \right), \tag{1.4}$$

where β is the discount factor, h is a parameter governing internal habit formation, η is a parameter governing the disutility of working, and χ is the inverse Frisch elasticity of labour supply.

Households own physical capital. In each period, they choose consumption C_t, labour L_{it}, investment I_t, savings in the form of nominal bonds B_t, and physical capital K_t. They also choose the capital utilization rate, u_t. Capital services $u_t K_t$, and labour are rented to firms at the rental rate R_t^k and the nominal wage W_{it}, respectively.

The household budget constraint is :

$$P_t \left(C_t + I_t + \frac{a(u_t) K_t}{V_t^I} \right) + \frac{B_{t+1}}{R_t} \leq W_{it} L_{it} + R_t^k u_t K_t + B_t + \Pi_t + T_t, \tag{1.5}$$

where P_t is the price of goods, Π_t represents dividends distributed to households, and T_t is a lump-sum transfer from the government to households. $a(u_t)$ is the cost of capital utilization expressed in terms of consumption goods and satisfying $a(1) = 0$, $a'(1) = 0$, $a''(1) > 0$. The cost of capital utilization is determined by :

$$a(u_t) = \gamma_1 (u_t - 1) + \frac{\gamma_2}{2} (u_t - 1)^2, \tag{1.6}$$

where γ_1 and $\gamma_2 \geq 0$ are two parameters. Following Christiano, Eichenbaum, and Evans (2005), we impose that utilization is one in the steady state ($u = 1$).

The law of motion for physical capital is :

$$K_{t+1} = V_t^I \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) I_t + (1-\delta)K_t, \tag{1.7}$$

where V_t^I is an investment-specific technological (hereafter IST) progress. Following Greenwood, Hercowitz, and Krusell (1997, 2000), the IST progress affects the rate of transformation between current consumption and future productive capital. Initially, we assume that the IST progress is non-stationary and that its growth rate, $v_t^I \equiv \triangle \ln V_t^I$, follows a random walk process with drift :

$$v_t^I = g_I + \varepsilon_t^I, \tag{1.8}$$

where g_I is the steady-state growth rate of IST progress, and ε_t^I an i.i.d. $N(0, \sigma_I^2)$ investment shock.

$S(\cdot)$ is a convex investment adjustment cost function satisfying $S = S' = 0$ and $S'' > 0$ in the steady state. The specific functional form of the investment adjustment cost is :

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - \mu_I\right)^2, \tag{1.9}$$

where κ is an adjustment cost parameter and μ_I is the long run growth of investment.

The first-order conditions for non-labour choices are :

$$r_t^k = \frac{1}{V_t^I}\left(\gamma_1 + \gamma_2(u_t - 1)\right), \tag{1.10}$$

$$\lambda_t^r = \mu_t V_t^I \left(1 - \frac{k}{2}\left(\frac{I_t}{I_{t-1}} - \mu_I\right)^2 - \kappa\left(\frac{I_t}{I_{t-1}} - \mu_I\right)\frac{I_t}{I_{t-1}}\right) + \beta E_t \mu_{t+1} V_{t+1}^I \kappa \left(\frac{I_{t+1}}{I_t} - \mu_I\right)\left(\frac{I_{t+1}}{I_t}\right)^2, \tag{1.11}$$

$$\mu_t = \beta E_t \lambda_{t+1}^r \left(r_{t+1}^k u_{t+1} - \frac{1}{V_{t+1}^I}\left(\gamma_1(u_{t+1} - 1) + \frac{\gamma_2}{2}(u_{t+1} - 1)^2\right)\right) + \beta(1-\delta) E_t \mu_{t+1}, \tag{1.12}$$

$$\lambda_t^r = \beta E_t R_t \pi_{t+1}^{-1} \lambda_{t+1}^r. \tag{1.13}$$

Nominal wages are set in a staggered fashion. Each period households face a probability ξ_w of not being able to reset their nominal wages. Households given the opportunity to reset their wages will choose the same nominal wage rate W_{it}^* maximizing the present discounted sum of expected utility (1.4) subject to the labour demand schedule (1.2). The optimal wage decision rule derived from the first-order conditions of the household's problem is :

$$\left(w_{it}^*\right)^{1+\sigma\chi} = \mu_w E_t \frac{\sum_{s=0}^{\infty} \left(\beta \xi_w\right)^s \eta \pi_{t+1,t+s}^{\sigma(1+\chi)} w_{t+s}^{\sigma(1+\chi)} L_{t+s}^{1+\chi}}{\sum_{s=0}^{\infty} \left(\beta \xi_w\right)^s \pi_{t+1,t+s}^{\sigma-1} w_{t+s}^{\sigma} \lambda_{t+s}^r L_{t+s}}, \tag{1.14}$$

where w_{it}^* is the optimal reset wage, and μ_w is the steady-state wage markup. Given our assumption about preferences and wage setting, all updating households have the same optimal reset wage denoted (in real terms) by $w_t^* = w_{it}^*$.

1.2.3 Final Good Producer

A perfectly competitive firm produces a final output, Y_t, using a continuum of differentiated goods, Y_{jt}, $j \in [0, 1]$. Final output is given by :

$$Y_t = \left(\int_{jt}^{1} Y_{jt}^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}, \tag{1.15}$$

where $\theta > 1$ is the elasticity of substitution among differentiated goods. Profit maximization and the zero-profit condition imply the following demand function for intermediate good j :

$$Y_{jt} = \left(\frac{P_{jt}}{P_t} \right)^{-\theta} Y_t, \tag{1.16}$$

where P_{jt} is price of good j and P_t the aggregate price index which is given by :

$$P_t^{1-\theta} = \int_0^1 P_{jt}^{1-\theta} dj. \tag{1.17}$$

1.2.4 Intermediate Goods Producers

An intermediate good producer j uses the following production function to produce output Y_{jt} :

$$Y_{jt} = \max\left\{ A_t \widehat{K}_{jt}^{\alpha} L_{jt}^{1-\alpha} - \Upsilon_t F, 0 \right\}, \tag{1.18}$$

where $\widehat{K}_{jt}$ and L_{jt} are the amount of capital services and labour, respectively, used in the production of good j. The parameter α is the share of capital services in total income. A_t is the stochastic level of neutral technology whose growth rate, $z_t \equiv \Delta \ln A_t$, follows a random walk with drift :

$$z_t = g_z + \varepsilon_{z,t}. \tag{1.19}$$

g_z is the steady-state growth rate of neutral productivity, and $\varepsilon_{z,t}$ an i.i.d. $N\left(0,\sigma_z^2\right)$ TFP shock. F is a fixed cost ensuring zero profits in the steady state and the existence of a balanced growth path. Υ_t represents a stochastic growth factor stemming from neutral and investment-specific technologies :

$$\Upsilon_t = (A_t)^{\frac{1}{1-\alpha}} \left(V_t^I\right)^{\frac{\alpha}{1-\alpha}}. \tag{1.20}$$

Intermediate goods producers are price takers in the market for inputs. They choose inputs so as to minimize total cost, subject to the constraint of producing enough to meet demand. The cost minimization problem of a typical intermediate good firm j is :

$\min_{\widehat{K}_t, L_t} R_t^k \widehat{K}_{jt} + W_t L_{jt}$,subject to :

$$A_t \widehat{K}_{jt}^{\alpha} L_{jt}^{1-\alpha} - \Upsilon_t F \geq \left(\frac{P_{jt}}{P_t}\right)^{-\theta} Y_t. \tag{1.21}$$

Since capital is perfectly mobile across firms, capital services and labour will be hired in the same ratios by all firms. Under these conditions, all intermediate goods firms will have the same real marginal cost :

$$mc_t = \overline{\alpha} A_t^{(\alpha-1)} \left(r_t^k\right)^{\alpha} (w_t)^{(1-\alpha)}, \tag{1.22}$$

where $\overline{\alpha} \equiv \alpha^{-\alpha}(1-\alpha)^{\alpha-1}$, r_t^k is the real rental rate on capital services, and w_t is the real wage.

Solving the firm's cost minimization problem also yields the following conditional demand functions for the two inputs :

$$K_{jt} = \alpha mc_t \left(Y_{jt} + \Upsilon_t F\right), \tag{1.23}$$

$$L_{jt} = (1-\alpha) mc_t \left(Y_{jt} + \Upsilon_t F\right). \tag{1.24}$$

Each period intermediate good producers face a probability ξ_p of not being able to reset their prices. Firms that are able to reset choose the same price P_{jt}^*

maximizing the present discounted value of future profits, subject to (1.16) and cost minimization :

$$\max_{P_{jt}} \quad E_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \frac{\lambda_{t+s}}{\lambda_t} \left[P_{jt} Y_{j,t+s} - MC_{j,t+s}) \right], \tag{1.25}$$

where λ_t is the marginal utility of nominal income, ξ_p^s is the probability that a price chosen in period t is still effective in period $t+s$ and $MC_{j,t}$ is nominal marginal cost. Profit maximization yields the following optimal price :

$$p_{jt}^* = \mu_p \frac{E_t \sum_{s=0}^{\infty} (\xi_p \beta)^s \lambda_{t+s}^r mc_{jt+s} \pi_{t+1,t+s}^{\theta} Y_{t+s}}{E_t \sum_{s=0}^{\infty} (\xi_p \beta)^s \lambda_{t+s}^r \pi_{t+1,t+s}^{\theta-1} Y_{t+s}}, \tag{1.26}$$

with $p_{jt}^* \equiv \frac{P_{jt}^*}{P_t}$ denoting the optimal price, μ_p is the steady-state price markup, λ_t^r is the marginal utility of an additional unit of real income received by the household and $\pi_{t+1,t+s}$ is cumulative inflation between t and $t+s-1$. Since all updating firms have the same markup and the same marginal cost, they will fix the same optimal price $p_t^* = p_{jt}^*$.

1.2.5 Monetary Policy Rule

The monetary authority conducts monetary policy based on the following Taylor rule :

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y_{t-1}} g_Y^{-1}\right)^{\alpha_{\Delta y}} \right]^{1-\rho_R} \varepsilon_t^r. \tag{1.27}$$

This rule says that the nominal interest rate adjusts in response to deviations of inflation from an exogenously fixed steady-state target, $\left(\frac{\pi_t}{\pi}\right)$, and to deviations of output growth $\left(\frac{Y_t}{Y_{t-1}}\right)$ from steady state, g_Y. The parameter ρ_R governs interest-rate smoothing, α_π and α_y are control parameters, and ε_t^r is an i.i.d. $N(0, \sigma_r^2)$ monetary policy shock.

This specification is different from the textbook Taylor rule (Galí, 2003), , wherein the monetary authority adjusts the nominal interest rate in response to deviations of inflation from target and to the output gap, defined as the current level of output less the level of output at flexible nominal wages and prices. It also differs from the Taylor rule used by Smets and Wouters (2007), who assume a response of nominal interest rates to inflation, the output gap and the output growth gap. So, the main difference is that we omit the output gap.

We are not the first to adopt this stand. Erceg and Levin (2003) also use an interest rate reaction function involving the output growth rate rather than the level of the output gap because the former specification is more consistent with an empirical analysis of interest rate determination. Furthermore, Coibion and Gorodnichenko (2011) show that in an economy where trend inflation is positive, adopting a Taylor rule with a reaction to the growth rate of output will more likely ensure determinacy than one including the output gap.

1.2.6 Equilibrium and Aggregation

Given the monetary policy, an equilibrium for our model consists in allocations and prices such that households and firms take their own nominal wages and prices as given, *i*) each household maximizes utility subject to its budget constraint ; *ii*) each firm solves its cost minimization problem ; and *iii*) the markets for goods, labour, capital services and bonds clear.

Market-clearing in the markets for capital services and labour, (1.23) and (1.24), yields the following aggregate factor demands :

$$\widehat{K}_t = \alpha \frac{mc_t}{r_t^k} \left(v_t^p Y_t + \Upsilon_t F \right), \tag{1.28}$$

$$L_t = (1-\alpha) \frac{mc_t}{w_t} \left(v_t^p Y_t + \Upsilon_t F \right), \tag{1.29}$$

where

$$\upsilon_t^p = (1 - \xi_p) p_t^{*-\theta} + \xi_p \pi_t^\theta \upsilon_{t-1}^p. \tag{1.30}$$

υ_t^p is price dispersion.

Aggregate inflation and the aggregate real wage are given by :

$$1 = \xi_p \pi_t^{\theta-1} + (1 - \xi_p) \left(p_t^*\right)^{1-\theta}, \tag{1.31}$$

$$w_t^{1-\sigma} = \xi_w \left(w_{t-1} \pi_t\right)^{1-\sigma} + (1 - \xi_w) \left(w_t^*\right)^{1-\sigma}. \tag{1.32}$$

Integrating over all households' budget constraints yields the aggregate resource constraint of the economy :

$$Y_t = C_t + I_t + \frac{a(u_t) K_t}{V_t^I} \tag{1.33}$$

1.2.7 Stationarizing the Model

The baseline model is driven by two stochastic processes exhibiting a unit root, all variables except hours, real marginal cost, capital utilization, inflation and the interest rate, are growing over time. Most of them will grow at the common growth factor :

$$\Upsilon_t = (A_t)^{\frac{1}{1-\alpha}} \left(V_t^I\right)^{\frac{\alpha}{1-\alpha}}.$$

Ensuring stationarity of the model requires dividing these variables by Υ_t. The capital stock will grow faster due to growth in investment-specific productivity, $\widetilde{K}_t \equiv \frac{K_t}{\Upsilon_t V_t^I}$ being stationary. The stationary rental rate on capital will be $\widetilde{r}_t^k \equiv r_t^k V_t^I$, and the stationary marginal utility of income, $\widetilde{\lambda}_t^r \equiv \lambda_t^r \Upsilon_t$.

1.2.8 Deterministic Trends

In the paper we also report results with deterministic trends. In this case, both neutral productivity, A_t, and IST, V_t^I, follow a process with a trending and stationary component :

$$A_t = A_t^{\tau} \widetilde{A}_t, \tag{1.34}$$

$$V_t^I = V_t^{I,\tau} \widetilde{V}_t^I. \tag{1.35}$$

The trend components are :

$$A_t^{\tau} = g_A A_{t-1}^{\tau}, \tag{1.36}$$

$$V_t^{I,\tau} = g_I V_{t-1}^{I,\tau}, \tag{1.37}$$

where g_A and g_I represent the average growth rate of neutral productivity and relative price of investment.

The stationary components follow an AR(1) process in the log, with the non-stochastic mean level normalized to unity :

$$\ln(\widetilde{A}_t) = \rho_A \ln(\widetilde{A}_{t-1}) + \varepsilon_{A,t}, \quad 0 \leq \rho_A < 1, \tag{1.38}$$

$$\ln(\widetilde{V}_t^I\ ) = \rho_I \ln(\widetilde{V}_{t-1}^I\ ) + \varepsilon_t^I, \quad 0 \leq \rho_I < 1. \tag{1.39}$$

The innovations $\varepsilon_{A,t}$ and $\varepsilon_{I,t}$ are drawn from a mean zero normal distribution with known standard deviation equal to σ_z and σ_I.

The common growth factor in the deterministic case is :

$$\Upsilon_t = (A_t^{\tau})^{\frac{1}{1-\alpha}} \left(V_t^{I,\tau}\right)^{\frac{\alpha}{1-\alpha}} \tag{1.40}$$

1.2.9 Aggregate Welfare, Wage Dispersion and Welfare Costs

We are interested in the welfare costs and output losses of positive trend inflation relative to zero trend inflation. Measuring output loss is straightforward. The welfare costs are computed from a consumption-equivalent welfare loss metric that measures how much consumption households have to give up in an initial state to enjoy the same level of utility as in a final state. Aggregate welfare is defined by the following value function :

$$V_t = \int_0^1 V_{it} di, \tag{1.41}$$

where $V_t(i)$ is from (1.4). Integrating across households, and making use of labour demand (1.2), aggregate welfare V_t can be expressed as :

$$V_t = \ln(C_t - bC_{t-1}) - \eta v_t^w \frac{L_t^{1+\chi}}{1+\chi} + \beta E_t V_t, \tag{1.42}$$

where v_t^w is wage dispersion given by :

$$v_t^w = (1-\xi_w)\left(\frac{w_t}{w_t^*}\right)^{\sigma(1+\chi)} + \xi_w \left(\frac{w_t}{w_{t-1}}\pi_t\right)^{\sigma(1+\chi)} v_{t-1}^w. \tag{1.43}$$

Note that wage dispersion, which belongs to the aggregate welfare function V_t, is increasing in the parameters governing the elasticity of substitution among differentiated labour skills σ and the inverse Frisch labour supply elasticity χ. A higher value of these parameters will therefore increase wage dispersion, generating higher inflation costs for a given level of trend inflation. As we later show, our evidence suggests that wage dispersion is significantly more costly than price dispersion.

After detrending the value function, we obtain :

$$V_t = \widetilde{V}_t^c + V_t^n + \Psi_t, \tag{1.44}$$

$$\widetilde{V}_t^c = \ln\left(\widetilde{C}_t - bg_{\Upsilon,t}^{-1}\widetilde{C}_{t-1}\right) + \beta E_t \widetilde{V}_{t+1}^c, \tag{1.45}$$

$$V_t^n = -\eta \frac{L_t^{1+\chi}}{1+\chi} v_t^w + \beta E_t V_{t+1}^n. \tag{1.46}$$

A ~ over a variable denotes it has been detrended to make it stationary. The term Ψ_t emerges when stationarizing the aggregate welfare and is given by :

$$\Psi_t = \frac{\beta}{1-\beta} \ln g_{\Upsilon,t+1} + \beta \Psi_{t+1}. \tag{1.47}$$

The consumption-equivalent welfare metric, λ, is :

$$\lambda = 1 - \exp\left[(1-\beta)(E(V_f) - E(V_i))\right], \tag{1.48}$$

where V_i is welfare in an initial state and V_f is welfare in a final state. We provide consumption-equivalent welfare losses computed from non-stochastic steady-state values of V_f and V_i, and from stochastic means.

1.3 Model Calibration

1.3.1 Non-Shock Parameters

The values assigned to the parameters of the model are summarized in Table 1.1. We set the discount factor $\beta = 0.99$, implying an annual real rate of interest of 4 percent in the steady state. The parameter h determining consumer habit formation is set to 0.8, in line with other estimates reported in the literature. The weight on the disutility of labour is $\eta = 6$, implying that steady-state labour hours is 1/3. The inverse Frisch labour supply elasticity χ is 1. The capital depreciation rate is set to $\delta = 0.025$, for an annual rate of capital depreciation of 10 percent. The value of the share of capital services α is 1/3. The investment adjustment cost parameter κ is 3, consistent with estimates in Christiano, Eichenbaum, and Evans (2005), Justiniano, Primiceri, and Tambalotti (2011) and and Phaneuf and Victor (2017). We set $\gamma_1 = 1$, so that steady-state utilization is 1, and $\gamma_2 = 0.05$ following Justiniano, Primiceri, and Tambalotti (2011).

The elasticities of substitution among differentiated goods θ and differentiated labour skills σ are both set equal to 4. The value $\theta = 4$ is the same as in Nakamura et al. (2017), who base their choice on estimates of the elasticity of demand for individual products in the industrial organization and international trade literatures (Berry, Levinsohn, and Pakes, 1995 ; Nevo, 2001 ; Broda and Weinstein, 2006). The value $\sigma = 4$ is taken from Huang and Liu (2002) who consider a range for this parameter from 2 to 6 based on the microstudies by Griffn (1992, 1996). We also assess the sensitivity of our results to higher values of σ, that is to $\sigma = 5, 6$.

To fix ξ_p, the probability that a firm will not reset its price, we follow Coibion and Gorodnichenko (2011) and Coibion, Gorodnichenko, and Wieland (2012). That is, ξ_p is set to 0.55, which amounts to firms resetting prices every 6.7 months on average. This is about midway between the micro estimates of Bils and Klenow (2004), who find that firms change prices every four to five months, and those of Nakamura and Steinsson (2008), who find that firms change prices every nine to 11 months. Moreover, using a sample of data from 1960Q1 to 2003Q4, Cogley and Sbordone (2008) report an estimate of ξ_p of 0.58 and no backward-looking indexation based on a sticky-price model with time-varying trend inflation. The degree of nominal wage stickiness ξ_w is set to 2/3, which amounts to households resetting nominal wages once every 9 months on average. This is consistent with evidence reported in Christiano, Eichenbaum, and Evans (2005), but is somewhat conservative in light of the micro estimates in Barattieri, Basu, and Gottschalk (2014).

The parameters of the Taylor rule are chosen as follows : the interest rate smoothing parameter is set to 0.8, the parameter governing the response of interest rates to the deviations of inflation from target (or trend inflation) is 1.5, and that of the deviations of output growth from steady state is 0.2. These are relatively standard values in the literature.

1.3.2 Trend Growth, Trend Inflation and Shock Parameters

The values assigned to trend growth, trend inflation and the shock parameters are summarized in Table 1.2. Detailed information about how the dataset was assembled can be found in the appendix. The trend growth rate investment-specific technology, g_I, equals the negative of the average growth rate of the relative price of investment goods to the price of consumption goods. It is is obtained by mapping the model to the data. Investment is the sum of expenditures on new durables and private fixed investment, while consumption represents the sum of consumer expenditures on nondurables and services. These series are borrowed from the BEA for the period 1960Q1-2007Q3.

The average growth rate of the relative price of investment goods for our sample is -0.00472, which implies $g_I = 1.00472$. Aggregate output (or real GDP) is the sum of non-durable consumption, services consumption, expenditure on durables, and fixed investment. Real per capita GDP is computed by subtracting from the log-level the log civilian non-institutionalized population. The average growth rate of the resulting output per capita series for our sample period is 0.005712, implying $g_Y = 1.005712$ or 2.28% a year. The standard deviation of output growth over the same period is 0.0078. Given that the growth rate of IST is $g_I = 1.00472$, we pick g_A to generate the appropriate average growth rate of output. This implies $g_A = 1.0022$ or a measured TFP growing at about 1% per year.

The corresponding price deflator is the ratio between the nominal and real GDP series. The average growth rate of the price index for our sample period is 0.0088, implying an average rate of inflation (or trend inflation) $\pi^* = 1.0088$ or an average annual rate of inflation of 3.52%. When considering the years of high inflation 1972Q1-1983Q4, π^* is 1.0175, meaning that the average annual rate of inflation for these years was 7%.

Random shocks matter for the estimation of inflation costs conditioned on stochastic means. In the model presented in Section 2, business-cycle fluctuations are driven by two non-stationary technology shocks and a stationary monetary policy shock whose standard deviations are σ_z, σ_I, and σ_r, respectively.

To determine the numerical values of σ_z, σ_I, and σ_r, we ask that the volatility of output growth in the model matches its counterpart in the data, and this for a level of trend inflation of 3.52%. In our simulations, we assign to each type of shock a target percentage of contribution to the unconditional variance decomposition of output growth. Our baseline calibration assigns 50% of this unconditional variance to the investment shock, 35% to the TFP shock, and 15% to the monetary policy shock. This percentage split is broadly consistent with that found in estimated medium-scale NK models (Justiniano, Primiceri, and Tambalotti, 2010, 2011 ; Khan and Tsoukalas, 2011, 2012 ; Phaneuf and Victor, 2017). Applying this procedure to the model with stochastic trends results into the following sizes of shocks : $\sigma_I = 0.0182$, $\sigma_z = 0.0062$, and $\sigma_r = 0.0025$. With deterministic trends, we choose a conventional value for the autoregressive parameter of the stationary neutral technology shock of $\rho_A = 0.95$. Following Justiniano, Primiceri, and Tambalotti (2010), we set the value of the AR(1) coeffcient of the IST shock to $\rho_I = 0.72$. the sizes of shocks are $\sigma_I = 0.0147$, $\sigma_z = 0.0064$, and $\sigma_r = 0.0028$.

1.4 Trend Inflation and Price Dispersion

Nakamura et al. (2017) argue that the standard NK model with nominal price rigidity predicts high inflation costs, and this even for moderate levels of trend inflation. To make their point, they proceed in two steps. In a first step, they identify price dispersion as the main factor fueling inflation costs in fairly standard NK models with either menu cost or Calvo price setters. In a second step, they use disaggregated price data covering the late 1970s and part of the 1980s to show that high trend inflation does not lead to inefficient price dispersion.

The illustrative models used by Nakamura et al. abstract from capital accummulation and other real frictions like consumer habit formation. The production technology is such that a firm's own output depends on hours and idiosyncratic firm productivity that follows an AR(1) process. They do not take economic growth into account. The monetary authority is assumed to have control over nominal output. Specifically, nominal output follows a random walk with drift. In the menu cost model, the level of the menu cost and the standard deviation of the idiosyncratic shock are calibrated to match the monthly median frequency of price change and the median absolute size of price changes in their dataset. In the Calvo model, they set the frequency of price change equal to the median frequency of price change in their dataset and the standard deviation of the idiosyncratic shocks to the same value as in the menu cost model. In both models, the first-order autoregressive parameter of the process for idiosyncratic productivity is 0.7. With this calibration, they show that the welfare cost of moving from 0% to 12% inflation is roughly 10%.

Here, we offer evidence shedding light on the link between price dispersion and inflation in our model. We use for this purpose a version of the Calvo model presented in Section 2 where we assume sticky prices and flexible nominal wages. We identify some conditions under which high inflation does not necessarily lead to inefficient price dispersion.

Following Christiano (2015), we take the period 1972Q1-1983Q4 as one of high inflation in the United States. We have seen in Section 3, the annualized average rate of inflation experienced over that period was 7%. We calculate the welfare costs and output losses of an inflation trend moving from 0% to 10% conditioned on steady states and means in three different models : *i)* a sticky-price model with no trend growth (SP, no G), *ii)* a sticky-price model with deterministic trends (SP, DT) and *iii)* a sticky-price model with stochastic trends (SP, ST). The results are presented in Table 1.3. Also reported are the percentage increases in price dispersion accompanying the estimates of inflation costs.

What immediately strikes the eye is that the welfare costs and output losses of a 7% inflation trend are fairly small in all sticky-price models, that is 0.2% or less. Therefore, seen through the lens of sticky-price models, a period of high inflation like the 1970s and the early 1980s was not too costly. Concomitantly to these findings, we find that the increase in price dispersion is also fairly small. Note that even a 10% inflation trend is not too costly, for there we find that the welfare costs and output losses are 0.46% at most, far from the figures reported by Nakamura et al. (2017).[7]

Now, we want to give some idea why Nakamura et al. (2017) report an estimate of the welfare cost of 12% inflation which is around 10%. For this, we simulate a model version closer to their Calvo model that has no capital (and hence no investment adjustment costs and no capital utilization), no consumer habit and no economic growth. Furthermore, the utility function (1.4) is replaced by $\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t [\log C_t - L_{it}]$,and the budget constraint (1.5) by $\mathrm{P}_t C_t + \frac{B_{t+1}}{R_t} \leq W_t L_t + B_t + \Pi_t + T_t$.Furthermore, the production function is given by $\mathrm{Y}_{jt} = A_t L_{jt}$.

We keep the Taylor rule stated before. In their calibration, they set the frequency of price change in the Calvo model so that it equals the median frequency of price change in their dataset. Unfortunately, no information is available about the implication of this for the value of ξ_p, the probability of non-reset prices. Therefore, we proceed as follows. Assuming $\theta = 4$ as Nakamura et al. do, we compute the steady-state consumer-equivalent welfare loss corresponding to different values of ξ_p and different levels of inflation. We do this using the model described above. The results are presented in Table 1.4.

One can see that the welfare cost of moving from 0% to 12% inflation reaches 10% when $\xi_p = 0.82$, or prices change every 16.7 months on average. Note that in this case, the increase in steady-state price dispersion is large at 11.3%. The connection between trend inflation and inefficient price dispersion is thus very strong. In comparison, with $\xi_p = 0.55$, the welfare cost of a 12% inflation trend is much smaller at 0.55%.

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7. Note however that we are assuming homogeneous capital so that a firm's real marginal cost does not depend on its own level of output. Would capital be firm-specific instead, the model would support lower levels of trend inflation while achieving determinacy (see Bakhshi et al. (2007)).

We conclude from the results in this section that the Calvo model with sticky prices only does not automatically imply a strong connection between higher trend inflation and increased price dispersion. But then, as pointed out by Nakamura et al. (2017), there is a need to find alternatives to sticky prices and price dispersion as factors that can possibly explain inflation costs.

1.5 Inefficient Wage Dispersion, Technical Change and Costly Inflation

This section identifies some alternatives to sticky prices and price dispersion as possible sources of inflation costs in a NK setting. We provide some evidence stressing the role of sticky wages and technical change in generating inefficient wage dispersion in response to higher trend inflation. In turn, increased wage dispersion leads to higher inflation costs. Next, we provide some intuitions as to why the interaction between sticky wages and technical change generates significant inflation costs compared to sticky prices.

1.5.1 Inflation Costs

We report estimates of inflation costs from three different models : *i*) sticky wages and sticky prices without trend growth (SPSW, no G), *ii*) sticky wages and sticky prices with deterministic trends (SPSW, DT) and *iii*) sticky wages and sticky prices with stochastic trends (SPSW, ST). Based on these three models, we generate the welfare costs and output losses of trend inflation conditioned on steady states and means.

We perform numerical experiments assuming the following percentage range for trend inflation : 0-2%, 0-4%, 2-4% and 0-7%. We do this for the following reasons. Assessing inflation costs in the 0-2% and 2-4% trend inflation range allows us to show that increasing trend inflation by 2% will be more costly starting from a 2% trend than from 0%. This will give us some idea of how costly it would be for the Fed to increase its inflation target, and by the same token trend inflation, from 2% to 4% as some observers have recently proposed. Looking at the 0-7% range allows us to gauge how wage dispersion is affected by higher inflation in the spirit of the test proposed by Nakamura et al. (2017).

Panel A of Table 1.5 presents the welfare costs and the ouput losses conditioned on non-stochastic steady states and stochastic means. Panel B shows how wage dispersion is affected by different levels of trend inflation in the three models. A first observation is that the welfare costs and output losses of trend inflation are significantly higher with sticky wages and sticky prices than with sticky prices only. Just adding sticky wages to sticky prices in a model without technical change results into steady-state welfare costs and output losses of a 7% inflation trend that are more than 10 times larger than with sticky prices alone.

The difference is even bigger when technical change and sticky wages are both added to sticky prices. Then, we find that the inflation costs are magnified nearly 25 times for an inflation trend of 7%. In particular, with stochastic trends the mean welfare cost of a 7% inflation trend is nearly 5%, and the output loss about 4.3%. Recall that these figures are both 0.19% with sticky prices and stochastic trends. As Panel B of the table indicates, mean wage dispersion then increases by 11%. In the meantime, price dispersion is almost unresponsive to trend inflation.

Note also that it would be costly to increase trend inflation from 2% to 4%. Conditioned on means and stochastic trends, the welfare cost of an increase in trend inflation from 2% to 4% is 1.17% and the output loss is 1.04%. These are significant increases accompanying the moderate rise in long-run inflation. Note also that it is significantly more costly to raise trend inflation by 2% starting from a level of 2% than from 0%. In fact, the inflation costs of a rise from 0% to 2% trend inflation are roughly half of what they are from 2% to 4% trend inflation.

What these findings tell us? Seen through the lens of our medium-scale NK model with technical change, the inflation costs resulting from sticky prices, technical change and price dispersion are just a side-show compared to those implied by sticky wages, technical change and wage dispersion.

1.5.2 Why Is Wage Dispersion So Costly?

Why does the interaction between sticky wages and technical change generate significant inflation costs? [8] In a medium-scale NK model with zero trend inflation but without economic growth, like the model of Christiano, Eichenbaum, and Evans (2005), all wages are identical in the steady state. This is not the case with positive trend inflation as Figure 1.1 shows. Here, the distribution of nominal wages is described by a positively sloped non-linear curve. Recently reset nominal wages are high relative to older non-reset wages.

Figure 1.2 conveys information about the steady-state total disutility of working of "high" vs "low" wage labour under positive trend inflation. "High" wage labour refers to households that recently had the opportunity to reset their nominal wages under positive trend inflation. "Low" wage labour refers to households who were unable to reset their wages. This figure shows that under positive trend inflation, there will be less of high wage labour and more of low wage labour hired in the steady state.

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8. We are thankful to Johannes Wieland for suggesting insights for this discussion.

Figure 1.3 shows how the expected total disutility of working is affected by wage dispersion. This figure shows that the expected total disutility of labour is higher with wage dispersion (i.e. with positive trend inflation) than without wage dispersion (i.e. with zero trend inflation). In turn, non-zero wage dispersion makes inflation costly. Note that with convex disutility of labour, the welfare costs of inflation will increase non-linearly as trend inflation gets higher. By making types of skills more substitutable, a higher σ will also increase wage dispersion and thus inflation costs. By contrast, a more elastic labour supply will generate smaller wage dispersion, and hence smaller inflation costs.

Figure 1.4 illustrates the case where technical change is added to sticky wages and positive trend inflation. This figure shows that technical change further amplifies monopolistic distortions in the form of increased steady-state wage dispersion relative to the no growth case. In a growing economy, the "high" wages of households who are able to reset their wages are even higher in the steady state relative to the "low" wages of households who are unable to reset their wages. As a result, wage dispersion is higher with technical change.

1.5.3 Deterministic vs Stochastic Trends

Table 1.5 reports the mean welfare costs and output losses generated by positive trend inflation. Inflation costs are higher conditioned on stochastic trends than on deterministic trends. Figures 1.5 to 1.7 convey information about the impulse responses of relative reset prices, reset wages, price dispersion and wage dispersion to a negative shock to the nominal interest rate (Figure 1.5), a positive shock to neutral technology (Figure 1.6) and a positive investment shock (Figure 1.7) under deterministic and stochastic trends, and this for an inflation trend of 0% and 7%. These responses succinctly summarize the effects of shocks on monopolistic distortions for these alternative scenarios.

A first observation is that whether trends are deterministic or stochastic, price dispersion does not respond very much to shocks in the presence of positive trend inflation. This implies that mean inflation costs will not be too affected by increased price dispersion. By contrast, the wage dispersion responses are positive and relatively strong with an inflation trend of 7% when trends are stochastic. Wage dispersion reacts particularly strongly to TFP and investment shocks with stochastic trends, explaining why mean inflation costs are systematically higher than steady-state costs.

Looking at the response of reset wage helps understand why wage dispersion reacts so strongly to both types of technology shocks under stochastic trends. There we see that positive TFP and investment shocks are followed by a surge in reset wage. Trend inflation makes price- and wage-setting relatively more forward-looking, for the reason that with positive trend inflation the cost of being stuck with a price or wage chosen today far into the future is higher. Therefore, price- and wage-setters respond relatively more to TFP and investment shocks with higher levels of trend inflation, as evidenced by the responses of the relative reset price and reset wage for updating firms and households in the graphs. Of course, reset wage responds much more than relative reset price to both technology shocks, being the key factor fueling welfare costs and output losses conditioned on stochastic means.

1.6 Inflation Costs and Differentiated Labour Skills

So far, we have assessed the costs of inflation under the assumption that the elasticities of substitution among differentiated goods and labour skills are both equal to 4. In this section, we show that these estimates are quite sensitive to small variations in the value of σ (the elasticity of substitution among differentiated labour skills) in some acceptable range. We do this since we do not have at our disposal direct evidence that would help to pin this elasticity with greater precision. Huang and Liu (2002) propose a range for σ between 2 and 6 based on the microstudies of Griffin (1992, 1996). We consider $\sigma = 4{,}5, 6$.

For the sake of brevity, we reassess the welfare costs and output losses of trend inflation using the NK model with sticky wages, sticky prices and stochastic trends. Panels A, B and C of Table 1.6 summarize the welfare costs and output losses conditioned on non-stochastic steady states and stochastic means for $\sigma = 4, 5, 6$.

The welfare costs of a 7% inflation trend conditioned on steady states are 4.4%, 7.8% and 13% for $\sigma = 4, 5, 6$. The corresponding output losses are 4%, 7.1% and 12%. The welfare costs conditioned on means are 4.8%, 9% and 17.5%, and the mean output losses are 4.3%, 8% and 15.1%. What is striking about these figures is how sensitive the estimates of the welfare costs and output losses are to modest variations in σ. Note also the large increases in wage dispersion that drive these costs. For a trend inflation of 7%, the steady-state wage dispersion increases by 9.9%, 18.4% and 33.7% for $\sigma = 4, 5$ and 6. Mean wage dispersion increases by 11%, 21% and 45%. Recall that meanwhile price dispersion is almost insensitive to higher trend inflation.

How costly would be a moderate increase in trend inflation from 2% to 4%? The steady-state welfare costs of going from 2% to 4% trend inflation are 1.1%, 1.8% and 3% for $\sigma = 4, 5, 6$. The same costs conditioned on means are 1.2%, 2.1% and 3.8%. The corresponding steady-state output losses are 1%, 1.7% and 2.6% and the mean output losses, 1%, 1.8% and 3.3%.

1.6.1 Concluding Remarks

Are New Keynesian models useful to assess the costs of inflation ? Given the evidence presented in our paper, we think we cannot offer a decisive answer to this question and that it is too early to announce the death of New Keynesian models as useful vehicles to assess the costs of inflation.

We have shown that high inflation does not necessarily imply highly inefficient price dispersion. But then an alternative to the standard mechanism had to be found. We have identified inefficient wage dispersion as an alternative channel by which trend inflation can generate substantial inflation costs. Taking into account the interaction between sticky wages and technical change significantly disrupts the allocative role of the wage system when inflation is high.

That said, we have also found that inflation costs are quite sensitive to modest variations in the elasticity of substitution among differentiated labour skills. As a consequence, there is a certain amount of uncertainty about the estimates of inflation costs in NK models. We believe that more research needs to be done to identify other channels that can explain inflation costs and assess their empirical plausibility.

Table 1.1 Calibrated Parameters

Parameter	Value	Description
β	0.99	Discount factor
b	0.8	Internal habit formation
η	6	Labor disutility
χ	1	Frisch elasticity
κ	3	Investment adjustment cost
δ	0.025	Depreciation rate
γ_1	$u = 1$	Utilization adjustment cost linear term
γ_2	0.05	Utilization adjustment cost squared term
ξ_p	0.55	Calvo price
ξ_w	0.66	Calvo wage
θ	4	Elasticity of substitution : goods
σ	4	Elasticity of substitution : labor
α	1/3	Capital share
ρ_i	0.8	Taylor rule smoothing
α_π	1.5	Taylor rule inflation
α_y	0.2	Taylor rule output growth

Note : This table shows the calibrated parameters used in our quantitative analysis. A description of each parameter is provided in the right column. The parameter on the linear term in the utilization adjustment cost function, γ_1, is chosen to be consistent with a steady state normalization of utilization to 1. Given other parameters this implies a value $\gamma_1 = 0.0457$. The fixed cost of production, F, is chosen so that profits equal zero in steady state. Given other parameters, this implies a value of $F = 0.1973$.

Table 1.2 Steady-State Trend Growth and Shock Parameters

	g_A	g_I	σ_r	σ_I	σ_z
Baseline	1.0022	1.0047	0.0025	0.0182	0.0062
Deterministic	1.0022	1.0047	0.0028	0.0147	0.0064

Note : This table reports the baseline values of the parameters of the stochastic processes used in our quantitative simulations. The trend growth rate of the investment shock process is chosen to match the average growth rate of the relative price of investment goods in the data. The trend growth of the neutral productivity process is chosen to match the average growth rate of output observed in the sample conditional on the growth rate of the IST process. The shock standard deviations are chosen to match the observed volatility of output growth in the data, with the investment shock accounting for 50% of the variance of output growth, the neutral shock 35%, and the monetary shock 15%.

Table 1.3 Welfare Costs and Price Dispersion in Sticky-Price Models.

Panel A : Inflation costs

Models			0-2	0-4	0-7	0-10
SP, no G	Welfare	SS	0.00	0.04	0.18	0.44
		Means	0.00	0.05	0.20	0.46
	Output Loss	SS	0.00	0.04	0.18	0.44
		Means	0.00	0.04	0.20	0.46
SP, DT	Welfare	SS	0.00	0.04	0.18	0.44
		Means	0.00	0.04	0.19	0.45
	Output Loss	SS	0.00	0.04	0.18	0.44
		Means	0.00	0.04	0.19	0.45
SP, ST	Welfare	SS	0.00	0.04	0.18	0.44
		Means	0.00	0.04	0.19	0.45
	Output Loss	SS	0.00	0.04	0.18	0.44
		Means	0.00	0.04	0.19	0.45

Panel B : Price dispersion

Models		0	2	4	7	10
SP, no G	SS	1.0000	1.0001	1.0006	1.0018	1.0038
	Means	1.0004	1.0006	1.0010	1.0022	1.0043
SP, DT	SS	1.0000	1.0001	1.0006	1.0018	1.0038
	Means	1.0003	1.0005	1.0009	1.0022	1.0042
SP, ST	SS	1.0000	1.0001	1.0006	1.0018	1.0038
	Means	1.0003	1.0005	1.0009	1.0022	1.0041

Note : This table shows the welfare costs, output losses and price dispersion of trend inflation going from (i) 0% to 2% (ii) 0% to 4% (iii) 0% to 7% (iv) 0% to 10%, conditioned on steady states (SS) and means in sticky-price models : (i) without economic growth (SP, no G), (ii) with deterministic trends (SP, DT) and (iii) with stochastic trends (SP, ST).

Table 1.4 Welfare Costs and Price Dispersion in Nakamura et al. (2017)

		0-2	0-4	0-7	0-12
$\zeta_p = 0.55$	Welfare	0.01	0.05	0.18	0.55
	Price Dispersion	1.0001	1.0006	1.0018	1.0056
$\zeta_p = 0.66$	Welfare	0.03	0.12	0.39	1.29
	Price Dispersion	1.0003	0.0012	1.0040	1.0133
$\zeta_p = 0.75$	Welfare	0.06	0.26	0.91	3.27
	Price Dispersion	1.0006	1.0027	1.0094	1.0343
$\zeta_p = 0.82$	Welfare	0.14	0.63	2.34	10.00
	Price Dispersion	1.0015	1.0066	1.0246	1.1132

Note : This table shows the welfare costs and price dispersion in [?] for trend inflation going from (i) 0% to 2% (ii) 0% to 4% (iii) 0% to 7% (iv) 0% to 12%, conditioned on steady states (SS).

Table 1.5 Welfare Costs and Wage Dispersion with Sticky Prices and Sticky Wages.

Panel A : Inflation costs

Models			0-2	0-4	2-4	0-7
SPSW, no G	Welfare	SS	0.13	0.64	0.52	2.31
		Means	0.14	0.67	0.53	2.36
	Output Loss	SS	0.07	0.52	0.45	2.05
		Means	0.08	0.54	0.46	2.09
SPSW, DT	Welfare	SS	0.56	1.62	1.07	4.43
		Means	0.57	1.65	1.09	4.50
	Output Loss	SS	0.48	1.45	0.97	4.04
		Means	0.49	1.47	0.99	4.09
SPSW, ST	Welfare	SS	0.56	1.62	1.07	4.43
		Means	0.62	1.79	1.17	4.83
	Output Loss	SS	0.48	1.45	0.97	4.04
		Means	0.52	1.55	1.04	4.31

Panel B : Wage dispersion

Models		0	2	4	7
SPSW, no G	SS	1.0000	1.0031	1.0134	1.0467
	Means	1.0013	1.0045	1.0148	1.0484
SPSW, DT	SS	1.0041	1.0160	1.0383	1.0990
	Means	1.0054	1.0174	1.0398	1.1008
SPSW, ST	SS	1.0041	1.0160	1.0383	1.0990
	Means	1.0075	1.0203	1.0440	1.1086

Note : This table shows the welfare costs, output losses and wage dispersion of trend inflation going from (i) 0% to 2% (ii) 0% to 4% (iii) 2% to 4% (iv) 0% to 7%, conditioned on steady states (SS) and means in models with sticky prices and sticky wages : (i) without economic

Table 1.6 Sensitivity of Welfare Costs to Variations in σ

Panel A : $\sigma = 4$

Models			0-2	0-4	2-4	0-7
SPSW, ST	Welfare	SS	0.56	1.62	1.07	4.43
		Means	0.62	1.79	1.17	4.83
	Output Loss	SS	0.48	1.45	0.97	4.04
		Means	0.52	1.55	1.04	4.31
	Wage Dispersion	SS	1.0160	1.0383	1.0219	1.0990
		Means	1.0203	1.0440	1.0232	1.1086

Panel B : $\sigma = 5$

Models			0-2	0-4	2-4	0-7
SPSW, ST	Welfare	SS	0.91	2.71	1.81	7.76
		Means	1.08	3.15	2.09	9.00
	Output Loss	SS	0.80	2.44	1.65	7.10
		Means	0.91	2.73	1.84	7.96
	Wage Dispersion	SS	1.0257	1.0643	1.0376	1.1838
		Means	1.0336	1.0764	1.0414	1.2112

Panel C : $\sigma = 6$

Models			0-2	0-4	2-4	0-7
SPSW, ST	Welfare	SS	1.38	4.24	2.89	13.00
		Means	1.85	5.57	3.79	17.54
	Output Loss	SS	1.23	3.84	2.64	11.92
		Means	1.55	4.77	3.27	15.12
		SS	1.0387	1.1022	1.0611	1.3373

Figure 1.1 Steady-State Wage Distribution with Positive Trend Inflation

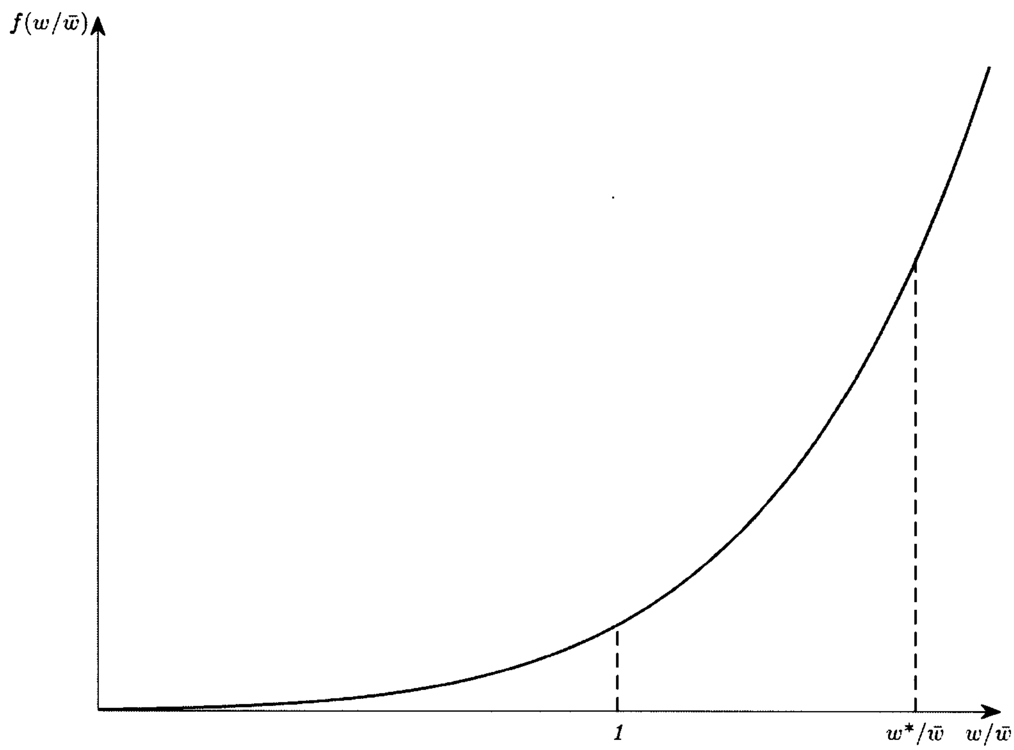
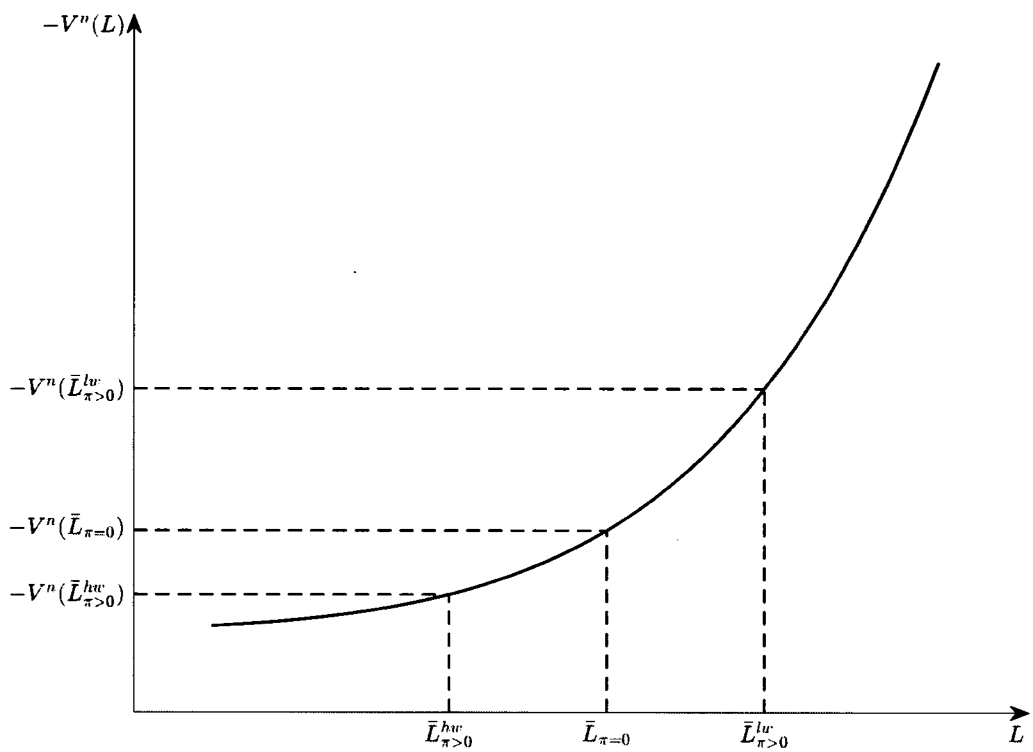
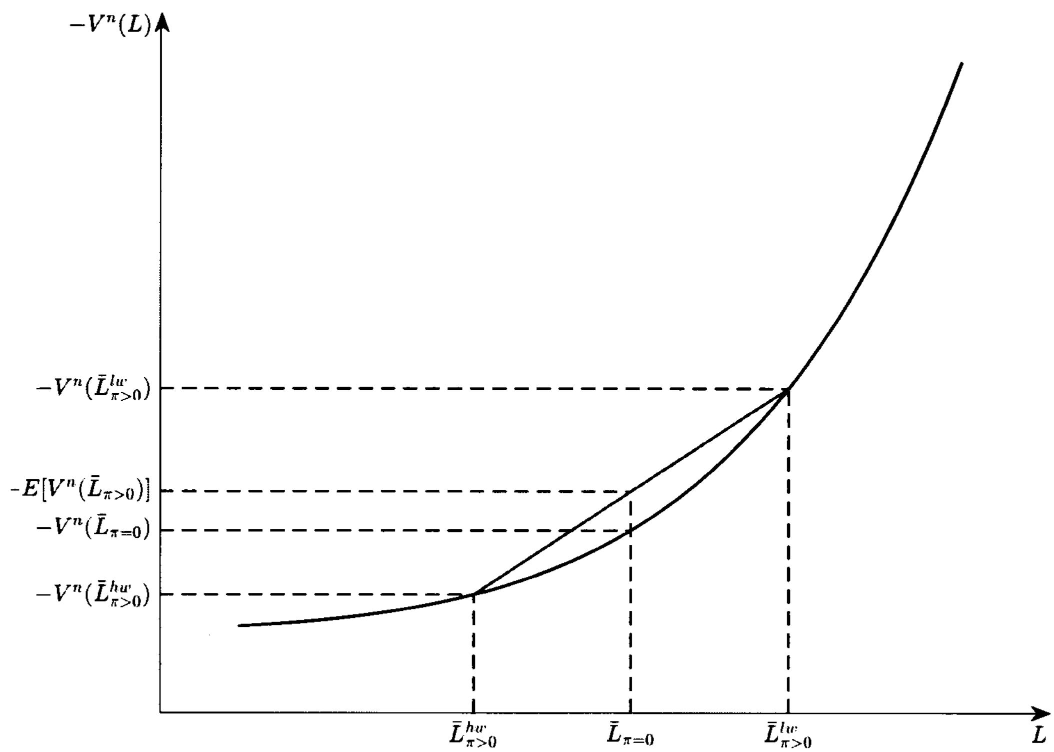


Figure 1.2 Disutility of Working Under Positive Trend Inflation



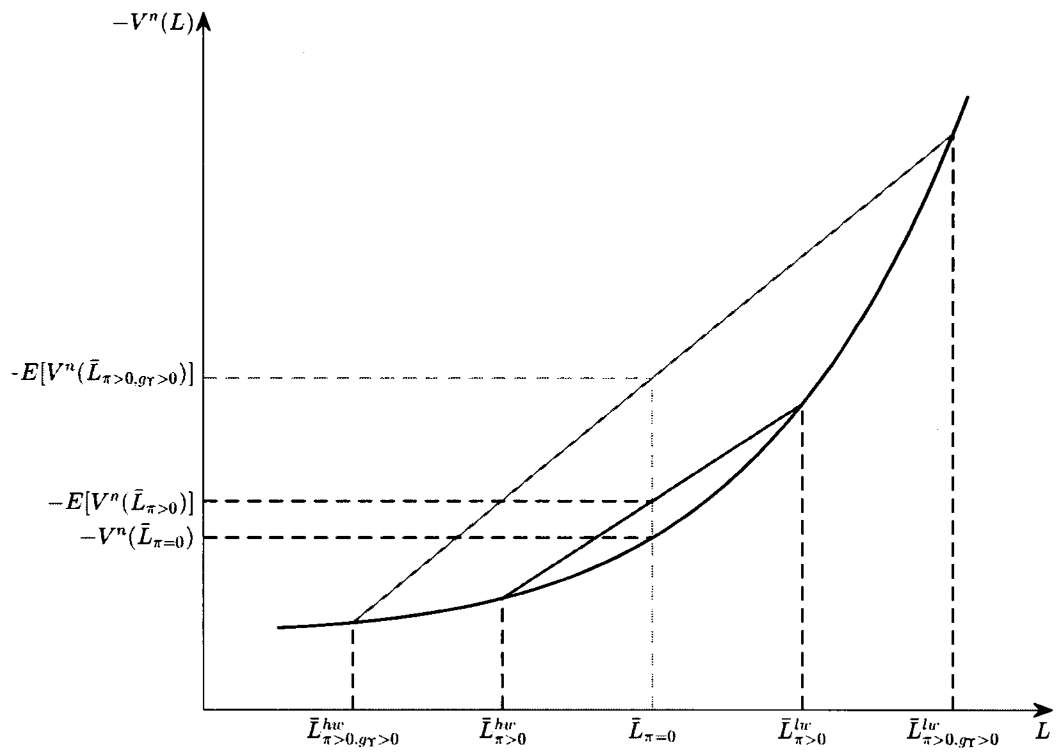
Note : This figure shows the steady-state total disutility of working of "high" (hw) vs "low" wage (lw) labour under positive trend inflation.

Figure 1.3 Costly Wage Dispersion



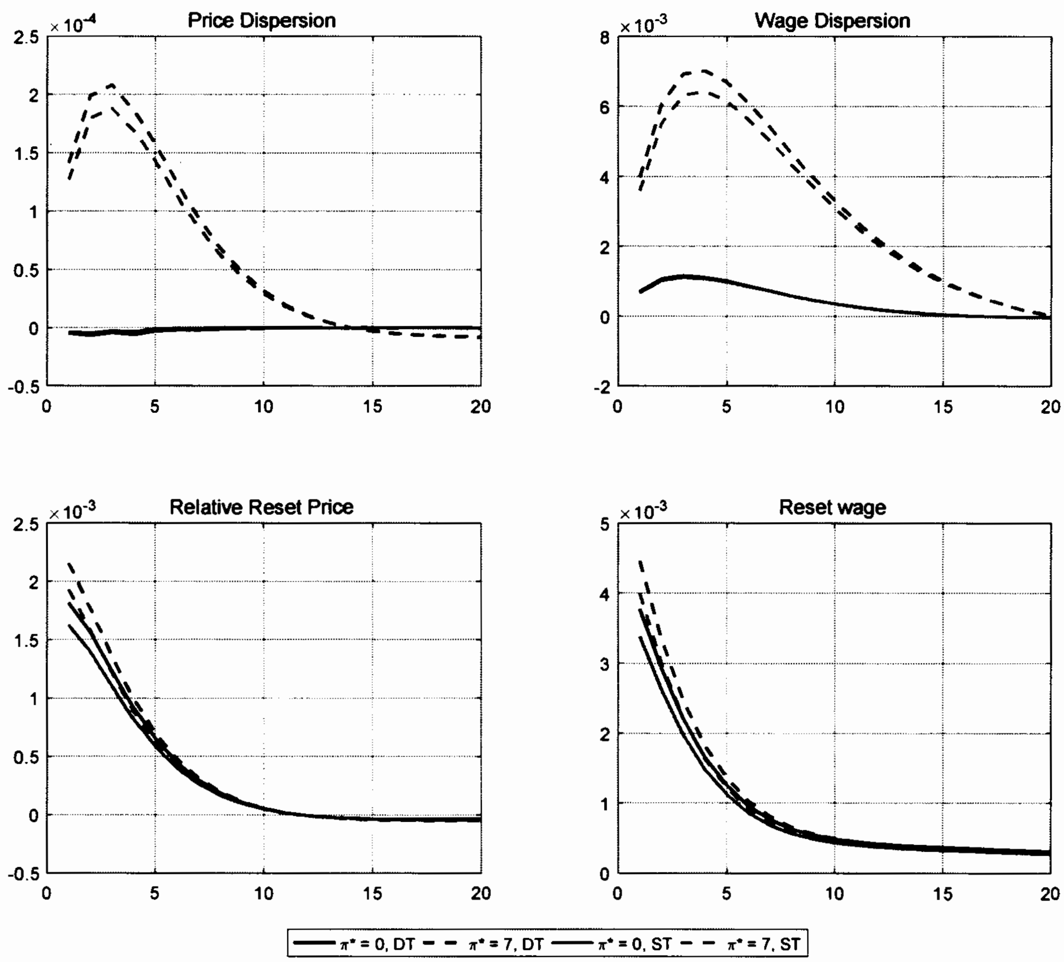
Note : This figure compares the steady-state total disutility of labour with and without wage dispersion.

Figure 1.4 Costly Wage Dispersion and Technical Change



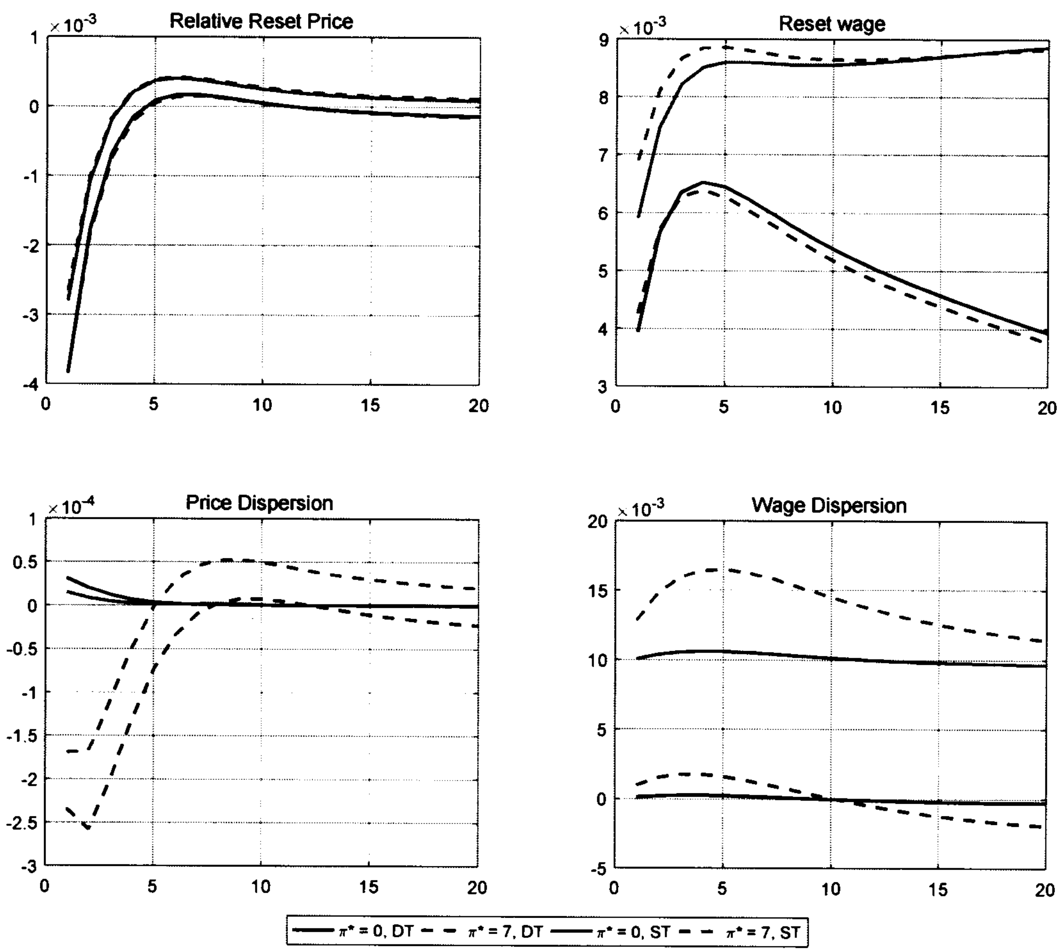
Note : This figure shows the impact of technical change on the steady-state total disutility of labour under positive trend inflation.

Figure 1.5 Responses to a monetary policy shock



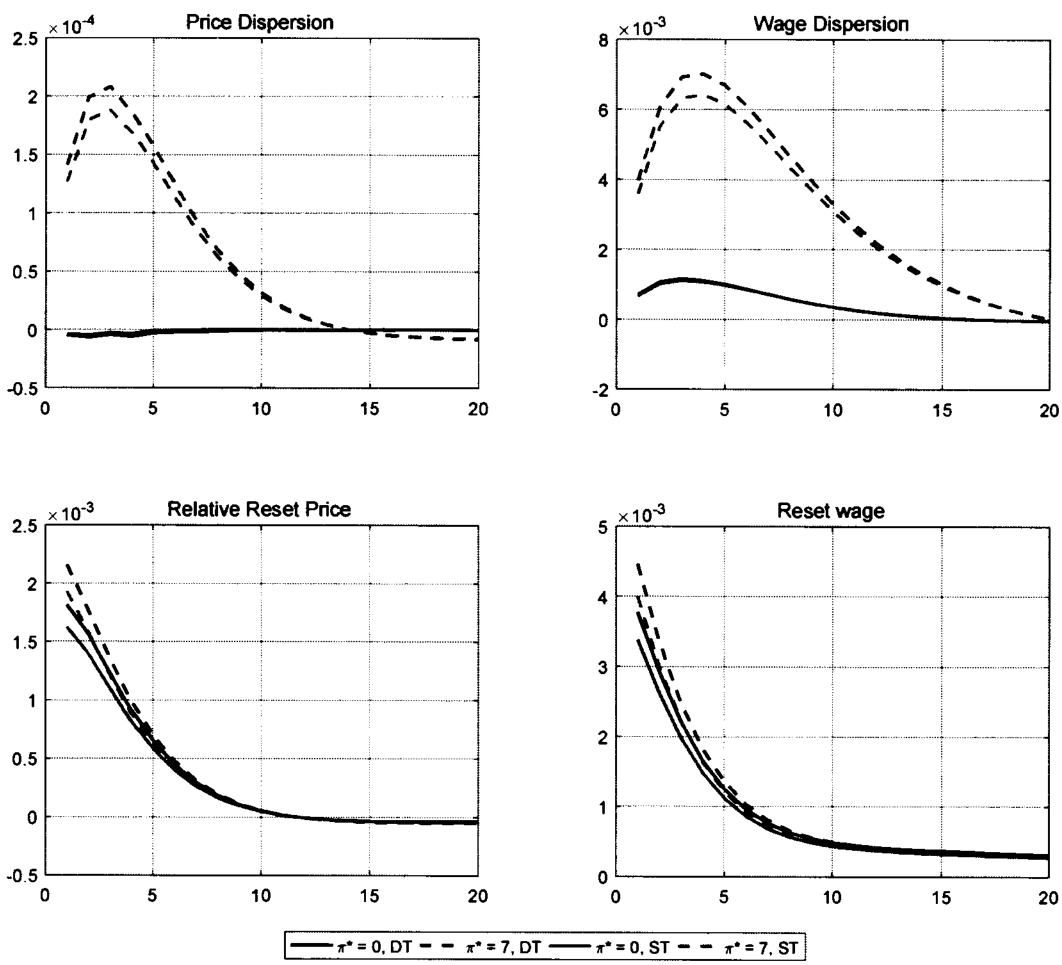
Note : DT : Deterministic Trend ; ST : Stochastic Trend ; π^* : Steady-State value of inflation.

Figure 1.6 Responses to a neutral technology shock



Note : DT : Deterministic Trend ; ST : Stochastic Trend ; π^* : Steady-State value of inflation.

Figure 1.7 Responses to an investment shock



Note : DT : Deterministic Trend ; ST : Stochastic Trend ; π^* : Steady-State value of inflation.

CHAPITRE II

A PURELY FORWARD-LOOKING WAGE AND PRICE SETTING FRAMEWORK USEFUL FOR BUSINESS CYCLE ANALYSIS

Abstract

We formulate a medium-scale DSGE model that emphasizes a strong interplay between a roundabout production structure and a working capital channel that requires firms to borrow funds to finance the costs of all their variable inputs and not just the wage bill. Despite an absence of backward-looking price and wage indexation our model generates a response of inflation which is mute on impact of a monetary policy shock, but highly persistent and very hump-shaped afterwards. It also yields a large contract multiplier for output, two times larger than the one implied by a model relying on indexation only. We also show that the response of the price markup can be positive on impact of an expansionary monetary policy shock, which differs from the standard countercyclical markup channel emphasized in conventional New Keynesian models.

JEL classification : E31, E32.

Keywords : New Keynesian Model; Firms Networking; Working Capital; Inflation Dynamics; Contract Multiplier for Output; Cyclical Markups; Comovement Problem.

2.1 Introduction

Chari, Kehoe, and McGrattan (2009) (hereafter CKM) question the usefulness of medium-scale New Keynesian models (e.g. see Christiano, Eichenbaum, and Evans, 2005 ; Smets and Wouters, 2007) on the grounds that to achieve empirical plausibility this class of models must rely on shocks which are "dubiously structural" and not invariant to a wide range of policy interventions, as well as on ad hoc wage and price setting mechanisms such as the quarterly indexation of nominal wages and prices to the previous period rate of inflation that are inconsistent with microeconomic evidence. Our paper proposes a framework which is both immune to these criticisms and useful for business cycle analysis.

While sharing similarities with the model of Christiano, Eichenbaum, and Evans (2005) (here after, CEE), our framework differs along the following five dimensions. First, it abstracts from the indexation of nominal wages and prices to the previous quarter's rate of inflation (CEE, 2005). The use of indexation has been criticized by a number of researchers. Woodford (2007) argues that "the model's implication that prices should continuously adjust to changes in prices elsewhere in the economy flies in the face of the survey evidence." Cogley and Sbordone (2008) mention that backward wage and price setting mechanisms "lack a convincing microeconomic foundation".

Second, our model features production networking, or the use by firms of intermediate goods in an input-output production structure, a feature of U.S. production which is well documented empirically with a typical firm selling 50 percent or more of its output to other firms (Basu, 1995 ; Huang, Liu, and Phaneuf, 2004 ; Phaneuf and Victor, 2017).[1] Firms networking is known to introduce strategic

1. Christiano (2015) introduces the term "firms networking" to designate a type of model with a roundabout production structure.

complementarities and thereby makes marginal cost less sensitive to input factor prices. As such, it flattens the slope of the New Keynesian Phillips Curve (NKPC).

Third, firms borrow working capital to finance their outlays for intermediate inputs, capital services and labor. In Christiano and Eichenbaum (1992), CEE (1997, 2005), Ravenna and Walsh (2006) and Tillmann (2008), working capital serves only to finance wage payments before the proceeds of sale are received. There are a few exceptions to models where working capital finances only the wage bill. Assuming that working capital is used to purchase commodities and finance wage payments, Chowdhury, Hoffmann, and Schabert (2006) provide VAR evidence for the G7 countries supporting their specification. In Christiano, Trabandt, and Walentin (2011), working capital is used to finance payments to labor and materials input, with the intent of showing that intermediate inputs and working capital can possibly lead to indeterminacy even if the central bank complies with the Taylor principle. Phaneuf and Victor (2017) report evidence obtained through Bayesian methods of an extended working capital channel wherein firms finance a substantial fraction of payments to intermediate inputs, capital services and labor.

In our model, working capital can be used in an extended form to finance the cost of all inputs, a case to which we refer as "extended borrowing." It can also be used in a limited form, a case we call "limited borrowing", to finance only subsets of these three inputs. As we later show, varying the extent to which working capital finances inputs has rich consequences for the short-run dynamics of inflation and output, as well as for the cyclical behavior of the price markup conditioned on a monetary policy shock.

Fourth, our baseline model embeds real per capita output growth stemming from trend growth in neutral and investment-specific technology. Accounting for economic growth is an important element that helps explaining some key business cycle comovements in the data.

Fifth, aggregate fluctuations are driven by three arguably structural shocks : total factor productivity (TFP), marginal efficiency of investment (MEI) and monetary policy. In the estimated medium-scale DSGE models of Justiniano and Primiceri (2008), Justiniano, Primiceri, and Tambalotti (2010, 2011), Khan and Tsoukalas (2012), and Phaneuf and Victor (2017), these shocks explain a large fraction of the variance of output growth, investment growth and hours.

We use our model with purely forward-looking wage and price setting to address four main questions. A first question is : can it generate a highly persistent and hump-shaped response of inflation to a monetary policy shock without assuming backward-looking elements in wage and price setting ? The second question is : does it deliver "large" contract multipliers for output in the terminology of Chari, Kehoe, and McGrattan (2000) ? A third question is : can it predict a procyclical price markup conditional on a monetary policy shock as the evidence in Nekarda and Ramey (2013) seems to suggest, and yet implies that the price markup is unconditionally countercylical (Bils, Klenow, and Malin, 2016) ? Finally, the fourth question is : can it generate moments which are broadly consistent with the data ? We provide affirmative answers to the four questions.

The paper is divided in two main parts. As in CKM (2000), Mankiw and Reis (2002) and CEE(2005), the first part focuses on the transmission of monetary policy shocks. We use our baseline model to answer the first two questions about the inflation response, the contract multiplier for output and part of the third question about the response of the price markup conditional on a monetary policy shock. The second answers part of the third question about the unconditional cyclicality of the price markup, and the fourth question about our model's ability to match key moments in the data.

Our main findings can be summarized as follows. While abstracting from the indexation of nominal wages and prices to past inflation, our baseline model predicts a response of inflation which is mute on impact of a monetary policy shock and very persistent and hump-shaped afterwards. [2] Absent firms networking, working capital and indexation, the response of inflation is largest on impact of a monetary policy shock and only weakly persistent afterwards, and this although the model includes sticky wages and sticky prices and several real frictions. Without firms networking and working capital, full indexation to past inflation can by itself generate a response of inflation which is persistent and hump-shaped, lending credence to criticisms that New Keynesian models need to rely on questionable backward wage and price setting assumptions to generate plausible inflation and output dynamics.

The key ingredient accounting for our findings despite purely forward-

2. Christiano, Trabandt, and Walentin (2010) are able to generate a persistent and hump-shaped response of inflation to a monetary policy shock in a model similar to ours without assuming backward indexation of prices. Their model also generates a non-inertial response of inflation to a productivity shock. Their model features a large degree of wage rigidity (Calvo parameter of 0.75), but more importantly, full indexation of wages to lagged inflation. Christiano, Eichenbaum, and Trabandt (2015a) and Christiano, Eichenbaum, and Trabandt (2015b) dispense with wage rigidity altogether, combining Calvo price stickiness into a search and matching model of the labor market. The model features no backward indexation of prices to lagged inflation. While their models do generate an inertial response of inflation to a monetary policy shock relative to the inflation response to a productivity shock, and also permit the study of the behavior of key labor market variables (like the unemployment rate), they nevertheless fall short of generating a hump-shaped inflation response to a policy shock. In particular, inflation responds positively on impact to an expansionary monetary policy shock and its peak response is soon thereafter in most specifications of the model in these papers.

looking wage and price setting is the interaction between production networking and working capital. Firms networking induces strategic complementarity into price setting, and is thus isomorphic to prices being stickier. This makes inflation less sensitive to changes in real marginal cost by a factor of proportionality reflecting the share of intermediate inputs in production. The inflation response to a policy shock is then smaller and more persistent. Working capital in its extended form contributes to make the response of inflation very hump-shaped. Because of working capital, the nominal interest rate has a direct effect on marginal cost. This limits the initial increase in marginal cost associated with an expansionary policy shock. If firms borrow working capital to finance the costs of all of their inputs, the impact of the nominal interest on real marginal cost is the strongest. If borrowing is limited, the impact of the nominal interest rate is naturally smaller, but is stronger if working capital serves to finance the purchase intermediate inputs rather than wage payments. Via the Phillips Curve, a smaller increase in marginal cost keeps inflation from initially rising by as much. Since the cut in interest rates is only temporary, as the interest rate begins to rise after impact due to the expansionary effects of the policy shock, marginal cost also begins to rise, which puts upward pressure on inflation and results in hump-shaped inflation dynamics.

Our baseline model is also able to address the "persistence problem" emphasized by CKM (2000). Output responds significantly to a monetary policy shock, in a hump-shaped and inertial fashion. We find that the half-life of output conditional on a monetary shock is fourteen quarters, or three and a half years. This is substantially larger than the output half-life in a model without extended borrowing and firms networking, and perhaps more importantly, is also higher than the half-life in a version of the model that includes backward indexation. Our model delivers these results of a persistent and hump-shaped response of inflation, and a large contract multiplier for output for empirically plausible average waiting times between wage and price adjustments.

Some other substantive findings pertain to the cyclical behavior of markups. In the literature, the evidence about the cyclical behavior of the price markup does not speak with of one voice. Galí, Gertler, and López-Salido (2007) report evidence of a price markup which is either weakly countercyclical or weakly procyclical depending on alternative methods and measures. The evidence in Nekarda and Ramey (2013) points to a mildly procyclical price markup. Still, Bils, Klenow, and Malin (2016) argue that the price markup is countercyclical. So, whether the price markup is countercyclical or procyclical depends very much on the specific theory and methodology used by the authors. Evidence concerning the conditional cyclicality of the price markup is also mixed, Galí, Gertler, and López-Salido (2007) reporting that the price markup falls following a negative shock to the nominal interest rate and Nekarda and Ramey (2013) offering evidence of a rise in the price markup. We are agnostic about the specific evidence to explain, and propose instead a framework which is sufficiently rich to allow identification of conditions under which the price markup either rises or falls following a monetary policy shock, and whether it is unconditionally procyclical or countercyclical in alternative specifications of the New Keynesian model.

A procyclical price markup conditioned on a negative shock to the nominal interest rate would run counter to the conventional wisdom from textbook New Keynesian models that a countercyclical markup is the key transmission mechanism of aggregate demand shocks (e.g.Woodford, 2003, 2011). In the basic New Keynesian model, prices are sticky and wages are perfectly flexible, so marginal cost responds more to an expansionary policy shock than the aggregate price index. As a result, the price markup is strongly countercyclical at the onset of a monetary policy shock. Assuming the coexistence of price and wage rigidity in the absence of firms networking and working capital will not generate a procyclical price markup conditioned on a monetary policy shock, regardless of whether or not backward indexation is included in our model. In fact, without firms networking and working capital, we find that the correlation between the price markup and output driven by the monetary policy shock is always close to -1.0.

By contrast, our baseline model which includes working capital extending to all production factors predicts a mildly procyclical price markup conditioning on a monetary policy shock. However, in our baseline model the price markup is unconditionally countercyclical whether measured in first-differences or HP-filtered log-levels. Meanwhile, both the wage markup and the labor wedge are countercyclical conditional on the policy shock and unconditionally. But unlike the price markup, the cyclical behavior of the wage markup and labor wedge conditioned on a monetary policy shock is not too affected by the presence of firms networking and working capital.

A final set of findings pertains to our model's ability to match key moments in the data. First, it generates unconditional volatility statistics of key variables which are plausible vis-à-vis the data. Perhaps more importantly, it does not suffer from the so-called "comovement problem" (Khan and Tsoukalas, 2011 ; Furlanetto and Seneca, 2014). Anomalous comovements between consumption, investment and hours often arise in general equilibrium models with standard (i.e. time-separable) preferences if the leading source of business cycle fluctuations is other than a TFP shock, for example a MEI shock (Barro and King, 1984). In the medium-scale models of Justiniano, Primiceri, and Tambalotti (2010, 2011), the unconditional correlation between consumption growth and investment growth is negative while it is mildly positive in the data (0.43).

Our model implies that the unconditional correlation between consumption growth and investment growth is 0.3 if working capital fully finances the cost of production factors and 0.42 if it finances just half of this cost. The unconditional correlation between consumption growth and the level of hours (hours being stationary in our model) is 0.04 if working capital fully finances payments to factors and 0.03 if it finances half of these payments, the correlation observed in the data being 0.07.

These results mainly reflect the fact that a positive MEI shock in our model is followed by a positive response of consumption. Ascari, Phaneuf, and Sims (2016) provide an explanation as to why a positive MEI shock is either followed by a short-run decrease or short-run increase in consumption. In a model without firms networking, a Hicksian decomposition (e.g. King, 1991) reveals that the negative substitution effect on consumption induced by the positive MEI shock outweighs the positive income effect which is very weak, so that on balance consumption falls in the wake of a MEI shock. The interaction between firms networking and economic growth strengthens the positive income effect on consumption of a MEI shock, which can then overturn the negative substitution effect, so that on impact consumption rises.[3] Their model however abstracts from working capital. Our findings show that this original intuition carries over to our model which includes working capital.

A final substantive result is that, consistent with evidence from the data, our model predicts that the unconditional correlation between inflation and the interest rate is significantly positive, that between inflation and consumption growth is mildly negative, and the correlations between the interest rate and either output growth, consumption growth or investment growth are weakly negative.

The remainder of the paper is organized as follows. Section 2 presents our

3. Their model abstracts from working capital.

model with economic growth, firms networking and working capital. Section 3 discusses issues related to calibration. Section 4 studies the transmission of monetary policy shocks in our framework. Section 5 looks at unconditional business cycle moments implied by our model and those in the data. Section 6 contains concluding remarks.

2.2 A Medium-Scale DSGE Model with Firms Networking and Extended Borrowing

We propose a medium-scale DSGE model in the spirit of CEE (2005). It includes nominal rigidities in the form of Calvo wage and price contracts, habit formation in consumption, investment adjustment costs, variable capital utilization, and a Taylor rule. We augment the model to include firms networking and an extended working capital or cost channel. The subsections below lay out the decision problems of the relevant model actors. The full set of conditions characterizing the equilibrium are shown in the Appendix.

2.2.1 Good and Labor Composites

There is a continuum of firms, indexed by $j \in (0,1)$, producing differentiated goods with the use of a composite labor input. The composite labor input is aggregated from differentiated labor skills supplied by a continuum of households, indexed by $h \in (0,1)$. Differentiated goods are bundled into a gross output good, X_t. Some of this gross output good can be used as a factor of production by firms. Net output is then measured as gross output less intermediate inputs. Households can either consume or invest the final net output good. The composite gross output and labor input are :

$$X_t = \left(\int_0^1 X_t(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}, \tag{2.1}$$

$$L_t = \left(\int_0^1 L_t(h)^{\frac{\sigma-1}{\sigma}} dh \right)^{\frac{\sigma}{\sigma-1}}. \tag{2.2}$$

The parameters $\theta > 1$ and $\sigma > 1$ denote the elasticities of substitution between goods and labor, respectively. The demand schedules for goods of type j and labor of type i respectively are :

$$X_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\theta} X_t \quad \forall j, \tag{2.3}$$

$$L_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\sigma} L_t \quad \forall h. \tag{2.4}$$

The aggregate price and wage indexes are :

$$P_t^{1-\theta} = \int_0^1 P_t(j)^{1-\theta} dj, \tag{2.5}$$

$$W_t^{1-\sigma} = \int_0^1 W_t(h)^{1-\sigma} dh. \tag{2.6}$$

2.2.2 Households

There is a continuum of households, indexed by $h \in (0, 1)$, who are monopoly suppliers of labor. They face a downward-sloping demand curve for their particular type of labor given in (2.4). Following Calvo (1983), each period, there is a fixed probability, $(1 - \xi_w)$, that households can adjust their nominal wage, with $0 \leq \xi_w < 1$. Non-updated wages may be indexed to lagged inflation via the parameter $\zeta_w \in [0, 1]$. As in Erceg, Henderson, and Levin (2000), we assume that utility is separable in consumption and labor. State-contingent securities insure households against idiosyncratic wage risk arising from staggered wage setting. With this setup, households are identical along all dimensions other than labor supply and nominal wages. We therefore suppress dependence on h except for choice variables related to the labor market.

The problem of a particular household is to optimize the present discounted value of flow utility subject to a flow budget constraint, (2.8), a law of motion for physical capital, (3.18), the demand curve for labor, (2.10), and a constraint describing the Calvo wage setting process, (2.11) :

$$\max_{C_t, L_t(i), K_{t+1}, B_{t+1}, I_t, Z_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t \left(\ln\left(C_t - bC_{t-1}\right) - \eta \frac{L_t(i)^{1+\chi}}{1+\chi} \right), \tag{2.7}$$

subject to the following budget constraint,

$$P_t \left(C_t + I_t + \frac{a(Z_t)K_t}{\varepsilon_t^{I,\tau}} \right) + \frac{B_{t+1}}{1+i_t} \leq W_t(i)L_t(i) + R_t^k Z_t K_t + \Pi_t + B_t + T_t, \tag{2.8}$$

and the physical capital accumulation process,

$$K_{t+1} = \varepsilon_t^{I,\tau} \vartheta_t \left(1 - S\left(\frac{I_t}{I_{t-1}} \right) \right) I_t + (1-\delta)K_t. \tag{2.9}$$

Here, P_t is the nominal price of goods, C_t is consumption, I_t is investment measured in units of consumption, K_t is the physical capital stock, and Z_t is the level of capital utilization. $W_t(i)$ is the nominal wage paid to labor of type i, and R_t^k is the common rental price on capital services (the product of utilization and physical capital). Π_t and T_t are, respectively, distributed dividends from firms and lump sum taxes from the government, both of which households take as given. B_t is a stock of nominal bonds that the household enters the period with. $a(Z_t)$ is a resource cost of utilization, satisfying $a(1) = 0$, $a'(1) = 0$, and $a''(1) > 0$. This resource cost is measured in units of physical capital. $S\left(\frac{I_t}{I_{t-1}}\right)$ is an investment adjustment cost, satisfying $S\left(g_I\right) = 0$, $S'\left(g_I\right) = 0$, and $S''\left(g_I\right) > 0$, where $g_I \geq 1$ is the steady state (gross) growth rate of investment. i_t is the nominal interest rate. $0 < \beta < 1$ is a discount factor, $0 < \delta < 1$ is a depreciation rate, and $0 \leq b < 1$ is a parameter for internal habit formation. χ is the inverse Frisch labor supply elasticity and η is a scaling parameter on the disutility from labor.

$\varepsilon_t^{I,\tau}$, which enters the capital accumulation equation by multiplying investment and the budget constraint in terms of the resource cost of capital utilization, measures the level of IST. It follows a deterministic trend with no stochastic component. The deterministic trend matches the observed downward trend in the relative price of investment goods in the data. The exogenous variable ϑ_t, which enters the capital accumulation equation in the same way as the IST term, is a stochastic MEI shock. Justiniano, Primiceri, and Tambalotti (2011) draw the distinction between these two types of investment shocks, showing that IST shocks map one-to-one into the relative price of investment goods, while MEI shocks do not impact the relative price of investment.[4] They find that MEI shocks are critical for business cycles, while stochastic shocks to IST have no effect on output at business cycle frequencies. These findings justify our choice of having the MEI component stochastic while the IST term only affects trend growth.

The demand curve for labor and the constraint describing Calvo wage setting respectively are :

$$L_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\sigma} L_t, \tag{2.10}$$

$$W_t(h) = \begin{cases} W_t^*(h) & w/\ prob\ \ 1-\xi_w \\ (1+\pi_{t-1})^{\zeta_w} W_{t-1}(h) & otherwise \end{cases}. \tag{2.11}$$

It is straightforward to show that all households given the opportunity to change their wage will adjust to a common reset wage, W_t^*.

2.2.3 Firms

The production function for a typical producer j is :

$$X_t(j) = \max\left\{A_t\Gamma_t(j)^{\phi}\left(\widehat{K}_t(j)^{\alpha}L_t(j)^{1-\alpha}\right)^{1-\phi} - \Upsilon_t F, 0\right\}, \tag{2.12}$$

---

4. In the model, the relative price of investment goods is easily seen to be $\frac{1}{\varepsilon_t^{I,\tau}}$. The division by $\varepsilon_t^{I,\tau}$ in the resource cost of utilization is therefore necessary so that capital is priced in terms of consumption goods.

where A_t is neutral productivity, F is a fixed cost, and production is required to be non-negative. Υ_t is a growth factor. Given Υ_t, F is chosen to keep profits zero along a balanced growth path, so the entry and exit of firms can be ignored. $\Gamma_t(j)$ is the amount of intermediate input, and $\phi \in (0,1)$ is the intermediate input share. Intermediate inputs come from aggregate gross output, X_t. $\widehat{K}_t(j)$ is capital services, while $L_t(j)$ is labor input. This production function differs from the standard in the New Keynesian DSGE literature in its addition of intermediate goods, $\Gamma_t(j)$.

A firm gets to choose its price, $P_t(j)$, as well as quantities of the intermediate input, capital services, and labor input. It is subject to Calvo pricing, where each period there is a $(1-\xi_p)$ probability that a firm can re-optimize its price, with $0 \leq \xi_p < 1$. Non-updated prices may be indexed to lagged inflation at $\zeta_p \in [0,1]$. In other words, a firm's price satisfies :

$$P_t(j) = \begin{cases} P_t^*(j) & w/\ prob\ \ 1-\xi_p \\ (1+\pi_{t-1})^{\zeta_p} P_{t-1}(j) & otherwise \end{cases} . \tag{2.13}$$

An updating firm will choose its price to maximize the present discounted value of flow profit, where discounting is by the stochastic discount factor of households as well as the probability that a price chosen today will still be in effect in the future. It is straightforward to show that all firms given the ability to change their price will adjust to a common reset price, P_t^*.

Regardless of whether a firm can re-optimize its price, it will always choose inputs so as to minimize cost, subject to the constraint of meeting demand at its price. A key assumption is that firms must finance some or all of their variable inputs through intra-period loans from a financial intermediary. The financial intermediary returns the interest earned on these loans to the household lump sum. The cost-minimization problem of a typical firm is :

$$\min_{\Gamma_t,\widehat{K}_t,L_t} \quad (1-\psi_\Gamma+\psi_\Gamma(1+i_t))P_t\Gamma_t+(1-\psi_K+\psi_K(1+i_t))R_t^k\widehat{K}_t+(1-\psi_L+\psi_L(1+i_t))W_tL_t \tag{2.14}$$

s.t.

$$A_t\Gamma_t^\phi\left(\widehat{K}_t^\alpha L_t^{1-\alpha}\right)^{1-\phi}-\Upsilon_tF\geq\left(\frac{P_t(j)}{P_t}\right)^{-\theta}X_t. \tag{2.15}$$

Here ψ_l, $l=\Gamma,K,L$, is the fraction of payments to a factor that must be financed at the gross nominal interest rate, $1+i_t$. With $\psi_l=0$ for all l, firms do not have to borrow to pay any of their factors. The use of working capital may be limited. When used to finance only wage payments as in CEE (1997; 2005) and Ravenna and Walsh (2006), we set $\psi_\Gamma=\psi_K=0$ and $\psi_L=1$, a case to which we refer as LBW. When used to finance only the purchase of intermediate goods, a case we refer to as LBI, we set $\psi_L=\psi_K=0$ and $\psi_\Gamma=1$. Assuming $\psi_l=1$ for all l means that all factor payments are financed through working capital, so that the factor prices relevant for firms are the product of the gross nominal interest rate and the factor price. We refer to this case as extended borrowing (EB). To economize on notation, we define $\Psi_{l,t}=(1-\psi_l+\psi_l(1+i_t))$ for $l=\Gamma,K,L$.

Applying some algebraic manipulations to the first order conditions for the cost-minimization problem yields an expression for real marginal cost, v_t, which is common across all firms :

$$v_t=\overline{\phi}\Psi_{\Gamma,t}^\phi\left(\Psi_{K,t}r_t^k\right)^{\alpha(1-\phi)}\left(\Psi_{L,t}w_t\right)^{(1-\alpha)(1-\phi)}, \tag{2.16}$$

with $\overline{\phi}\equiv\frac{1}{\phi}\left(\frac{\phi}{1-\phi}\right)^{1-\phi}\left(\frac{1}{\alpha}\right)^{1-\phi}\left(\frac{\alpha}{1-\alpha}\right)^{(1-\alpha)(1-\phi)}$. The variables r_t^k and w_t are the real rental rate on capital services and the real wage for labor, respectively. This general expression encompasses several special cases. In a model where both firms networking ($\phi = 0$) and financial intermediation ($\Psi_{l,t} = 1$ for all l) are excluded, the expression for real marginal cost reduces to :

$$v_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^{\alpha} (r_t^k)^{\alpha}(w_t)^{1-\alpha}. \tag{2.17}$$

For the case of firms networking and limited borrowing, with working capital covering only wage payments (LBW), real marginal cost is :

$$v_t = (1+i_t)^{(1-\alpha)(1-\phi)} \overline{\phi} \left(r_t^k\right)^{\alpha(1-\phi)} w_t^{(1-\alpha)(1-\phi)}. \tag{2.18}$$

The real marginal cost expression in Christiano, Eichenbaum, and Evans (2005) is obtained by setting $\phi = 0$ in (2.17). With firms networking and limited borrowing with working capital financing only intermediate goods (LBI), real marginal cost is :

$$v_t = (1+i_t)^{\phi} \overline{\phi} \left(r_t^k\right)^{\alpha(1-\phi)} w_t^{(1-\alpha)(1-\phi)}. \tag{2.19}$$

Combining firms networking and extended borrowing (EB) gives the expression :

$$v_t = (1+i_t) \overline{\phi} \left(r_t^k\right)^{\alpha(1-\phi)} w_t^{(1-\alpha)(1-\phi)}. \tag{2.20}$$

According to these expressions, once our model accounts for borrowing, either in a limited or extended form, the nominal interest rate directly impacts real marginal cost. More importantly, the impact of the nominal interest on marginal cost increases with the extent of required borrowing. With working capital financing only the wage bill, the impact of the nominal interest on the real marginal cost is determined by the exponent $(1-\alpha)(1-\phi)$. With working capital financing only the purchase of intermediate goods, the impact of the nominal rate is determined by ϕ which is larger than $(1-\alpha)(1-\phi)$. Finally, with extended working capital, $(1+i_t)$ has an exponent of one, which is greater than in the last two cases under limited borrowing.

2.2.4 Monetary Policy

Monetary policy follows a Taylor rule :

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i} \left[\left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y_{t-1}} g_Y^{-1}\right)^{\alpha_y}\right]^{1-\rho_i} \varepsilon_t^r. \tag{2.21}$$

The nominal interest rate responds to deviations of inflation from an exogenous steady-state target, π, and to deviations of output growth from its trend level, g_Y. ε_t^r is an exogenous shock to the policy rule. The parameter ρ_i governs the smoothing-effect on nominal interest rates while α_π and α_y are control parameters. We restrict attention to parameter configurations resulting in a determinate rational expectations equilibrium.

2.2.5 Aggregation

Given properties of Calvo (1983) price and wage setting, aggregate inflation and the real wage evolve according to :

$$1 = \xi_p \pi_t^{\theta-1} \pi_{t-1}^{\zeta_p(1-\theta)} + (1-\xi_p)\left(p_t^*\right)^{1-\theta} \tag{2.22}$$

$$w_t^{1-\sigma} = \xi_w \left(\frac{w_{t-1}\pi_{t-1}^{\zeta_w}}{\pi_t}\right)^{1-\sigma} + (1-\xi_w)\left(w_t^*\right)^{1-\sigma} \tag{2.23}$$

The notation here is that $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is aggregate gross inflation, $p_t^* \equiv \frac{P_t^*}{P_t}$ is the relative reset price, $w_t \equiv \frac{W_t}{P_t}$ is the real wage, and $w_t^* \equiv \frac{W_t^*}{P_t}$ is the real reset wage. Market-clearing for capital services, labor, and intermediate inputs requires that $\int_0^1 \widehat{K}_t(j)dj = \widehat{K}_t$, $\int_0^1 L_t(j)dj = L_t$, and $\int_0^1 \Gamma_t(j)dj = \Gamma_t$. This means that aggregate gross output can be written :

$$s_t X_t = \Gamma_t^\phi \left(\widehat{K}_t^\alpha L_t^{1-\alpha}\right)^{1-\phi} - F \tag{2.24}$$

where s_t is a price dispersion variable that can be written recursively :

$$s_t = (1-\xi_p) p_t^{*-\theta} + \xi_p \pi_{t-1}^{-\zeta_p\theta} \pi_t^\theta s_{t-1} \tag{2.25}$$

Using the market-clearing conditions, the aggregate factor demands can be written :

$$\Gamma_t = \phi v_t \Psi_\Gamma^{-1} (X_t + F) \tag{2.26}$$

$$\widehat{K}_t = \alpha(1-\phi)\frac{v_t}{\Psi_K r_t^k}(X_t + F) \tag{2.27}$$

$$L_t = (1-\alpha)(1-\phi)\frac{v_t}{\Psi_L w_t}(X_t + F) \tag{2.28}$$

Aggregate net output, Y_t, is gross output minus intermediate input :

$$Y_t = X_t - \Gamma_t \tag{2.29}$$

Integrating over household budget constraints yields the aggregate resource constraint :

$$Y_t = C_t + I_t + a(Z_t)K_t \tag{2.30}$$

2.2.6 Shock Processes

Neutral productivity obeys a process with both a trending and stationary component. A_t^τ is the deterministic trend component, where g_A is the gross growth rate :

$$A_t = A_t^\tau \widetilde{A}_t, \tag{2.31}$$

$$A_t^\tau = g_A A_{t-1}^\tau. \tag{2.32}$$

The initial level in period 0 is normalized to 1 : $A_0^\tau = 1$. The stationary component of neutral productivity follows an AR(1) process in the log, with the non-stochastic mean level normalized to unity, and innovation, u_t^A, drawn from a mean zero normal distribution with known standard deviation equal to s_A :

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(s_A u_t^A\right), \quad 0 \le \rho_A < 1, \tag{2.33}$$

The IST term obeys the following deterministic trend, where g_{ε^I} is the gross growth rate and the initial level in period 0 is normalized to unity :

$$\varepsilon_t^{I,\tau} = g_{\varepsilon^I} \varepsilon_{t-1}^{I,\tau} \tag{2.34}$$

The MEI shock follows a stationary AR(1) process, with innovation drawn from a mean zero normal distribution with standard deviation s_I :

$$\vartheta_t = (\vartheta_{t-1})^{\rho_I} \exp(s_I u_t^I), \quad 0 \leq \rho_I < 1 \tag{2.35}$$

The only remaining shock in the model is the monetary policy shock, ε_t^r. We assume that is drawn from a mean zero normal distribution with known standard deviation s_r.

2.2.7 Functional Forms

We assume that the resource cost of utilization and the investment adjustment cost function have the following functional forms :

$$a(Z_t) = \gamma_1(Z_t - 1) + \frac{\gamma_2}{2}(Z_t - 1)^2, \tag{2.36}$$

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - g_I\right)^2, \tag{2.37}$$

where $\gamma_2 > 0$ is a free parameter ; as $\gamma_2 \to \infty$ utilization becomes fixed at unity. γ_1 must be restricted so that the optimality conditions are consistent with the normalization of steady state utilization of 1. $\kappa \geq 0$ is a free parameter. The functional form for the investment adjustment cost is standard in the literature (e.g. Christiano, Eichenbaum, and Evans, 2005).

2.2.8 Growth

Most variables inherit trend growth from the deterministic trends in neutral and investment-specific productivity. Let this trend factor be Υ_t. Output, consumption, investment, intermediate inputs, and the real wage all grow at the rate of this trend factor on a balanced growth path : $g_Y = g_I = g_\Gamma = g_w = g_\Upsilon = \frac{\Upsilon_t}{\Upsilon_{t-1}}$. The capital stock grows faster due to growth in investment-specific productivity, with $\widetilde{K}_t \equiv \frac{K_t}{\Upsilon_t \varepsilon_t^{I,\tau}}$ being stationary. Given our specification of preferences, labor hours are stationary. The full set of equilibrium conditions re-written in stationary terms can be found in the Appendix.

One can show that the trend factor that induces stationarity among transformed variables is :

$$\Upsilon_t = (A_t^\tau)^{\frac{1}{(1-\phi)(1-\alpha)}} \left(\varepsilon_t^{I,\tau}\right)^{\frac{\alpha}{1-\alpha}}. \tag{2.38}$$

This reverts to the conventional trend growth factor in a model with growth in neutral and investment-specific productivity when $\phi = 0$. Under this restriction, intermediates are irrelevant for production, and the model reduces to the standard New Keynesian model. Interestingly, from (2.38), it is evident that a higher value of ϕ amplifies the effects of trend growth in neutral productivity on output and its components. For a given level of trend growth in neutral productivity, the economy grows faster the larger is the share of intermediates in production.

2.3 Calibration

2.3.1 Non-Shock Parameters

The calibration used for non-shock parameters is summarized in Table 2.1. Some parameter values, like β, b, η, χ, δ and α are standard in the literature.

Others require some explanations.

The parameter governing the size of investment adjustment costs κ is 3, corresponding to the estimate in Phaneuf and Victor (2017). This is somewhat higher than the estimate in CEE (2005) (2.48), but somewhat lower than that in JPT (2011) (3.142). The parameter on the squared term in the utilization adjustment cost is set to $\gamma_2 = 0.05$. This is broadly consistent with the evidence in Basu and Kimball (1997) and Dotsey and King (2006), and is middle range between Justiniano, Primiceri, and Tambalotti (2010, 2011) who estimate this parameter to be about 0.15, and CEE (2005), who fix this parameter at 0.00035. [5] The parameter θ is the elasticity of substitution between differentiated goods and is set at 6. This implies a steady-state price markup of 20 percent, which is consistent with Rotemberg and Woodford (1997). The parameter σ is the elasticity between differentiated labor skills and is also set at 6 (e.g. Huang and Liu, 2002; Griffin, 1992).

The Calvo probabilities for wage and price non-reoptimization both take a value of 0.66. This implies an average waiting time between price changes of 9 months. Bils and Klenow (2004) emphasize the median of price changes as a measure of frequency of price adjustments. They report that the median duration of prices is 5.5 months after removing sales price changes. For a purely forward-looking Calvo model with no backward indexation, Cogley and Sbordone (2008) approximate the median waiting time of a price change by $-\ln(2)/\ln(\xi_p)$. Setting $\xi_p = 0.66$ therefore implies a median duration of prices of 5.1 months, which is broadly consistent with the evidence reported in Bils and Klenow (2004).

Our calibration of $\xi_w = 0.66$ implies that the average duration between wage

5. CEE set $\frac{\gamma_2}{\gamma_1} = 0.01$; given the parameterization of γ_1 to be consistent with steady state utilization of unity, this implies $\gamma_2 = 0.000457$.

adjustments is 9 months, which is somewhat higher than the macro estimate of 0.64 reported in CEE (2005), but somewhat lower than the estimate of 0.71 in Altig et al. (2011). In some sensitivity analysis, we also look at the impact of a higher average duration of wage contracts. For this, we consider the evidence in Barattieri, Basu, and Gottschalk (2014), who analyze micro-data for the U.S. economy. They find that the average quarterly probability of a wage change lies between 0.211 and 0.266, implying a value of ξ_w in the range of 0.75-0.80. Justiniano, Primiceri, and Tambalotti (2010, 2011) also report higher estimates of ξ_w in this range using a New Keynesian model with several shocks, but without firms networking or a working capital channel.

The parameter ϕ measures the share of payments to intermediate inputs in total production. In the literature, this parameter is found to be in the range of 0.5 to 0.8. Huang, Liu, and Phaneuf (2004) provide justifications for a value of ϕ of 0.7. Using the fact that the weighted average revenue share of intermediate inputs in the U.S. private sector was roughly 52 percent in 2002, and knowing that the cost share of intermediate inputs equals the revenue share times the markup, Nakamura and Steinsson (2010) set $\phi = 0.7$. However, their calibration of θ implies a steady state price markup of 1.33, while ours corresponds to a steady state price markup of 1.2, resulting in $\phi = 0.625$. Phaneuf and Victor (2017) estimate this parameter through Bayesian methods. They report a point estimate which is 0.56. We set $\phi = 0.6$ as our benchmark.

The parameters of the Taylor rule include the smoothing parameter set at 0.8, the coefficient on inflation at 1.5, and the coefficient on output growth at 0.2. We assume that there is zero trend inflation, $\pi = 0$. As a baseline, we also assume that there is no backward indexation of prices or wages to lagged inflation, i.e. $\zeta_p = \zeta_w = 0$.

2.3.2 Shock Parameters

The calibration used for shock parameters is summarized in Table 2.2. Mapping the model to the data, the trend growth rate of the IST term, g_{ε^I}, equals the negative of the growth rate of the relative price of investment goods. To measure this in the data, we define investment as expenditures on new durables plus private fixed investment, and consumption as consumer expenditures of nondurables and services. These series are from the BEA and cover the period 1960 :I-2007 :III, to leave out the financial crisis.[6] The relative price of investment is the ratio of the implied price index for investment goods to the price index for consumption goods. The average growth rate of the relative price from the period 1960 :I-2007 :III is -0.00472, so that $g_{\varepsilon^I} = 1.00472$. Real per capita GDP is computed by subtracting the log civilian non-institutionalized population from the log-level of real GDP. The average growth rate of the resulting output per capita series over the period is 0.005712, so that $g_Y = 1.005712$ or 2.28 percent a year. Given the calibrated growth of IST, we then use (2.38) to set $g_A^{1-\phi}$ to generate the appropriate average growth rate of output. This implies $g_A^{1-\phi} = 1.0022$ or a measured growth rate of TFP of about 1 percent per year.[7] The price deflator is the ratio between the nominal and the real GDP series.

Regarding the calibration of the shocks, we set the autoregressive parameter of the neutral productivity shock at 0.95. Based on the estimate in Justiniano,

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6. A detailed explanation of how these data are constructed can be found in Ascari, Phaneuf, and Sims (2015).

7. Note that this is a lower average growth rate of TFP than would obtain under traditional growth accounting exercises. This is due to the fact that our model includes FN, which would mean that a traditional growth accounting exercise ought to overstate the growth rate of true TFP.

Primiceri, and Tambalotti (2011), we set the baseline value of the autoregressive parameter of the MEI process at 0.8. To determine the numerical values for s_I, s_A, and s_r, we adopt the following procedure. We ask that our baseline model (or any particular model for this matter) matches the actual volatility of output growth (0.0078) for the period 1960 :Q1-2007 :Q3. For this, we assign to each shock a target percentage contribution to the unconditional variance decomposition of output growth. Our baseline calibration assigns 50 percent of the unconditional variance decomposition of output growth to the MEI shock, 35 percent to the TFP shock, and 15 percent to the monetary policy shock based on the following reasons. Justiniano, Primiceri, and Tambalotti (2011) estimate a medium-scale New Keynesian model that abstracts from roundabout production and working capital with 8 different types of shocks. They find that the MEI shock accounts for nearly 60 percent of output fluctuations, while the TFP shock contributes to about 25 percent. Several other studies also find that investment shocks explain a larger fraction of output fluctuations than TFP shocks (Fisher, 2006; Justiniano and Primiceri, 2008; Justiniano, Primiceri, and Tambalotti, 2010; Altig et al., 2011). Estimating a medium-scale DSGE model with roundabout production, Phaneuf and Victor (2017) report that the MEI shock explains about 50 percent of the forecast error variance of output growth.[8] Because we have chosen to dispense

8. One exception, however, is Smets and Wouters (2007), who report that investment shocks account for less than 25 percent of the forecast error variance of GDP at any horizon. Justiniano, Primiceri, and Tambalotti (2010) explore the reasons for these differences, showing that the smaller contribution of investment shocks in Smets and Wouters (2007) results from their definition of consumption and investment which includes durable expenditures in consumption while excluding the change in inventories from investment, although not from output. With the more standard definition of consumption and investment found in the business-cycle literature (e.g., Cooley and Prescott, 1995; Christiano, Eichenbaum, and Evans, 2005; Del Negro et al., 2007), they find that investment shocks explain more than 50 percent of business-cycle fluctuations.

with "dubiously" structural shocks, we adopt the split of shocks : 50 percent to the MEI shock, 35 percent to the TFP shock and 15 percent to the monetary policy shock. Applying this procedure, we obtain $s_I = 0.0266$, $s_A = 0.0027$, and $s_r = 0.0018$.

2.4 Transmission of Monetary Policy Shocks

This section studies the transmission of monetary policy shocks in our baseline model and some alternative models. Woodford (2009) argues that this is a particularly useful way of discriminating among alternative models and not a claim that such disturbances are a primary source of aggregate variability. We take our baseline model to be the specification in which there is firms networking (FN) and extended borrowing (EB), and where all factors of production are financed by working capital. We focus on impulse responses and second moments conditional to a monetary policy shock, and assess the roles that different model features play in generating the results. Subsection 2.4.1 focuses on the dynamic responses of output and inflation to a monetary policy shock. Subsection 2.4.2 focuses on the cyclical behavior of the price and wage markups and of the labor wedge conditional on monetary policy shocks.

2.4.1 Inflation and Output Dynamics

Figure 2.1 plots the model impulse responses of output and inflation to a one standard deviation expansionary monetary policy shock (i.e. a negative shock to the Taylor rule). The solid lines show the responses in our baseline model. For point of comparison, we also present impulse responses under three alternative specifications. The first two gauge the relative contribution of EB and FN in generating our main findings. The dotted lines show responses in which there is no extended borrowing (nor limited borrowing, so that none of the factors of production must be financed through working capital, i.e. $\psi_\Gamma = \psi_K = \psi_L = 0$). The dashed lines show the responses in which there is no firms networking (i.e $\phi = 0$). The third specification is one where there is no extended borrowing and no firms networking, but in which prices and wages are fully indexed to lagged inflation (i.e. $\zeta_p = \zeta_w = 1$) ; the responses are represented by dashed lines with "+" markers.

In our baseline model output rises by about 0.24 percent on impact of the monetary policy shock. This jump is roughly half the magnitude of the peak output response, which is 0.45 percent and occurs about four quarters subsequent to the shock. The response of output is highly persistent, being positive more than five years after the shock ; it also displays a pronounced hump-shaped pattern. The response of inflation is mute on impact of the shock, and reaches a peak after about four quarters. Like the output response, the inflation impulse response to the policy shock is very persistent.

When there is no working capital at all (dotted lines), the impulse response of inflation is largest on impact, and exhibits no hump-shape. Thus, working capital is needed to generate a hump-shaped inflation response. The response of output is also somewhat smaller compared to our baseline model. If instead there is no firms networking but all factors are financed via working capital (dashed lines), the response of inflation is positive on impact and hump-shaped, the peak response occuring roughly three quarters subsequent to the shock. The short-run response of inflation exceeds that in the baseline model and is also less persistent. The absence of firms networking implies that the slope of the New Keynesian Phillips Curve is steeper relative to our baseline model, making inflation more responsive to the monetary policy shock and lowering inflation persistence. As a result, the response of output is also significantly smaller and less persistent than in the baseline model.

The dashed lines with "+" markers take the "standard" New Keynesian model without EB and FN and modify it so that both prices and wages are fully indexed to one period lagged inflation (i.e. $\zeta_p = \zeta_w = 1$). Indexation has been advanced in the literature as a way to generate more inertia in the response of inflation to a policy shock (CEE, 2005). This specification does result in a hump-shaped response of inflation. But with indexation, the inflation response also reverts to zero from its peak more quickly than in the baseline model which does not feature any indexation. The counterpart of backward indexation however is to make the output response to a policy shock significantly smaller and less persistent, a feature of the standard medium-scale New Keynesian model that has been overlooked so far in the literature.

The reasons why a model with backward indexation can produce a hump-shaped response of inflation to a monetary policy shock are well understood in the literature (e.g. see Christiano, Eichenbaum, and Evans, 2005; Walsh, 2005). But how does our model without wage and price indexation succeed in generating hump-shaped inflation dynamics? The two key model ingredients giving rise to this pattern are firms networking and a working capital channel. These two channels can be seen in equation (2.20), which is the expression for real marginal cost in our model. Because working capital results in the nominal interest rate having a direct effect on marginal cost, it works to limit the increase in marginal cost associated with an expansionary policy shock. Via the traditional Phillips Curve, a smaller increase (or a decrease) in marginal cost keeps inflation from initially rising by as much. Because the cut in interest rates is only temporary, as the interest rate starts to rise after impact, marginal cost begins to rise, which puts upward pressure on inflation and can result in hump-shaped inflation dynamics. Firms networking works through a similar channel. Positive values of ϕ limit the sensitivity of marginal cost to fluctuations in factor prices, and therefore allow output to expand by more without marginal cost (and hence inflation) rising by much.

What happens if working capital serves to finance the costs of fewer inputs than in our baseline model ? Figure 2.2 compares the responses of output, inflation, and real marginal cost and its components when working capital finances the costs of all inputs (solid lines), the cost of intermediate inputs only (dotted lines), and the cost of labor only (dashed lines). The three models include firms networking. The greater the extent of working capital is, the lower the response of inflation on impact of a monetary policy shock and the more persistent the response is. Correspondingly, the response of output is stronger and more persistent with more inputs financed via working capital. With working capital financing more inputs, the response of real marginal cost becomes more negative despite the fact that the responses of the real wage and the real rental rate become larger due to a larger expansion in output.

So the question is : what factor drives the greater decline in the real marginal cost accompanying the model with EB relative to the models with LBI and LBW ? The answer to this question is easily understood by comparing the alternative expressions for real marginal in equations (2.20), (2.19) and (2.18). In the baseline model, the nominal interest rate has a proportional impact on real marginal cost. In the model where only the purchase of intermediate goods is financed through working capital, equation (2.19) shows that the effect of the nominal rate on real marginal cost is determined by the exponent $\phi = 0.6$, which is lower than in the model with EB. When working capital is used to finance the wage bill only, equation (2.18) shows that the nominal rate affects the real marginal cost to an extent governed by the exponent $(1-\alpha)(1-\phi) = 0.266$, which is 2.26 times smaller than in the model with LBI and 3.76 times smaller than in the model with EB.

Table 2.3 presents some statistics summarizing the dynamics of inflation and output conditioned on monetary policy shocks. It shows autocorrelation coefficients for inflation at different lag lengths. In the baseline model, the first order autocorrelation of inflation is 0.946. Inflation is highly persistent, with an autocorrelation coefficient at a one year lag of more than 0.5. The autocorrelation coefficients of inflation are higher (by 0.1 or more) at all lags in the base model relative to the version of the model with no working capital and no firms networking. The model without working capital and firms networking, but augmented with full backward indexation, produces a first order autocorrelation of inflation of 0.947, which is essentially the same as in the benchmark model, but the autocorrelations at lags of 2-5 quarters are higher in the baseline model than in the backward indexation model, especially at higher lags.

To measure the strength of internal propagation in models with nominal contracts, CKM (2000) focus on the half-life of output, representing the number of quarters it takes for the response of output to equal one-half its impact response (rounded to the nearest integer). They provide evidence of a relatively small contract multiplier for output in a variety of DSGE models with intertemporal links.

In our baseline model, the half-life of output is 14 quarters, or three and a half years. Although price and wage setting is purely forward-looking, our model is obviously not prone to CKM' criticism that models with nominal rigidities cannot generate a large contract multiplier for output. In the model with no working capital and no firms networking, the half-life of output is still substantial but half of a year shorter than in the baseline model at 12 quarters. Perhaps surprisingly, the half-life of output is significantly lower in the model with full backward indexation of prices and wages, with a half-life of only 7 quarters, half of what this multiplier is in our baseline model.

2.4.2 Markups and the Labor Wedge

The basic transmission mechanism by which positive demand shocks raise output in the textbook New Keynesian model is via a countercyclical price markup over marginal cost (e.g.Woodford, 2003, 2011). But the evidence in the literature about the cyclicality of the price markup conditioned on demand shocks is mixed. Galí, Gertler, and López-Salido (2007) provide evidence of a rise in the price markup following a contractionary monetary policy shock, while Nekarda and Ramey (2013) offer evidence of a fall in that markup.

The evidence about the unconditional cyclicality of the price markup is also mixed. Galí, Gertler, and López-Salido (2007) present evidence of a price markup which is either weakly countercyclical or weakly procyclical unconditionally depending on alternative model specifications and measures. Nekarda and Ramey (2013) challenge these findings based on some evidence that points to a price markup which is moderately procyclical unconditionally. Still, Bils, Klenow, and Malin (2016) report evidence of a countercyclical price markup. Therefore, whether the price markup is countercyclical or procyclical conditionally or unconditionally depends very much on the specific theory and methodology used by the authors. Meanwhile, the wage markup and the labor wedge are found to be countercyclical empirically.[9]

We do not take a firm stand on the issue of the observed cyclicality of the price markup, but analyze instead the implications of different model versions for

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9. The labor wedge is the sum of the two equilibrium markups, that of price over marginal cost and that of real wages over the marginal rate of substitution.

the conditional and unconditional cyclicality of markups and the labor wedge. The present subsection looks at the cyclicality of markups and the labor wedge conditioned on a monetary policy shock. The next section examines unconditional cyclical markups when other types of shocks are added to the models.

We find that the response of the price markup to an expansionary monetary policy is quite sensitive to assuming firms networking and working capital either in its extended form or its limited form covering intermediate inputs only. In fact, we find that the price markup switches from strongly countercyclical conditionally without firms networking and extended working capital to mildly procyclical with these features included in the model. When accounting for backward indexation without these features, we find that the conditional price markup is strongly countercyclical. In fact, without firms networking and working capital, the correlation between output and the price markup driven by a monetary policy shock is close to -1.0, with or without indexation.

Panel A of Figure 2.3 plots the impulse responses of the price markup, Panel B the response of the wage markup, and Panel C the response of the labor wedge to an expansionary monetary policy shock for different specifications of our model. The solid lines show the responses in our baseline model. The dotted lines are for the responses from the model that features firms networking and LBI. The dashed-line responses are from the model with firms networking and LBW. The dashed lines with dots are from the model without firms networking and working capital. Finally, the responses with the dashed lines marked with "+" are from the model that excludes both firms networking and financial intermediation but includes full indexation of nominal wages and prices to the previous quarter's rate of inflation.

The response of the price markup varies quite significantly among alternative model specifications. This is not the case for the wage markup or the labor wedge. One sees that in our baseline model the price markup initially rises and remains positive for about four quarters, after which time it goes slightly negative before returning to trend. Without firms networking and working capital, the response of the price markup is negative.

The dotted lines in Figure 2.3 show that insofar as working capital is used to finance intermediate goods, the response of the price markup will remain positive in the short run. From the dashed line price markup response, we see that things are different if working capital serves to finance the wage bill only, which is generally the case in existing DSGE models with financial intermediation. Then, the response of the price markup is weak and positive only for one period and turns negative after.

The dashed lines with dots shows the response of the price markup for a model where there is no firms networking, no working capital and no indexation. The response is negative for the twenty quarters after the monetary policy shock. The dashed line with "+" markers plots the impulse response of the price markup in a version of the model in which there is neither firms networking nor working capital, but in which prices and wages are fully indexed to lagged inflation. Though full indexation alone is capable of generating hump-shaped inflation dynamics (see Figure 2.1), it does little to change the dynamic response of the price markup when the model abstracts from firms networking and working capital. The response of the markup is negative for about five periods and then turns weakly positive, implying a markup which is strongly countercyclical conditionally.

Panel B of Figure 2.3 plots the impulse responses of the wage markup. One notes that the negative responses of the wage markup to an expansionary monetary policy shock are almost identical in models with firms networking and working capital, whether borrowing is extended or limited. The dashed line with "+" markers shows that in a model without firms networking and working capital but with indexation, the response of the wage markup is negative for about five periods and then turns slightly positive before returning to zero. Panel C of Figure 2.3 plots the impulse responses of the labor wedge. The negative responses of the labor wedge closely follow those of the wage markup.

Tables 2.5 to 2.7 present some statistics for the conditional cyclicality of the price markup, the wage markup, and the labor wedge with different model specifications. We measure the cyclicality of markups and the labor wedge by the conditional correlation with real GDP. For this, we use two different filtering devices – first differences and HP-filtered log-levels.

Regardless of filtering method, our baseline model generates a procyclical price markup conditional on a monetary policy shock. The correlation between the first log differences of the price markup and output is 0.38. This correlation is not far from the unconditional correlation estimated by Nekarda and Ramey (2013) of 0.495. When the series are HP-filtered, the correlation between the price markup and output is 0.16 in our baseline model. This is somewhat smaller than the correlation of 0.325 reported by Nekarda and Ramey (2013). We keep for the next section examination of the cyclicality of the price markup when other types of shocks are added to the baseline model.

Removing extended borrowing from the model results in a conditional correlation between output and the price markup which is close to -1.0, and this no matter what the filtering method is. With extended borrowing but without firms networking, the correlation is 0.16 with first differences, and -0.43 with HP-filtered log-levels. Therefore, combining firms networking and extended working capital is required for the model to produce a procyclical price markup conditional on a monetary policy shock.

The model with firms networking and working capital financing only intermediate goods delivers a correlation between the first log differences of the price markup and output of 0.24, which is lower than in our baseline model. With HP-filtered log-levels, the correlation is -0.25. The model in which working capital finances only the wage bill does not perform as well, producing a correlation between output and the price markup which is -0.15 with first log differences, and -0.73 with HP-filtered log-levels. Therefore, the greater the extent of working capital, the less countercyclical the price markup is conditionally. With full coverage of factor payments by working capital, the price markup turns procyclical conditionally.

Just as it is key to generating a hump-shaped response of inflation to a policy shock, the working capital channel is the key mechanism delivering a conditionally procyclical price markup. Our baseline model implying a conditional procyclical price markup assumes that all factors must be fully financed via working capital, i.e. $\psi_\Gamma = \psi_{\dot{K}} = \psi_L = 1$. One might wonder whether intermediate values of these parameters would also generate a procyclical markup. In Figure 2.4 we plot the cyclicality of the price markup (with the two different filtering methods) for values of ψ between 0 and 1, where we assume that $\psi_l = \psi$ for all three factors. When there is no working capital channel at all ($\psi = 0$), the correlation of the markup with output is close to -1 regardless of filter. When focusing on the correlation in first differences, our model generates a positive correlation between the markup and output conditional on a policy shock for values of $\psi \geq 0.35$. For HP filtered data, ψ must be bigger than about 0.92 to generate a procyclical markup. In other words, while a working capital channel is required to generate a procyclical markup conditional on a policy shock, the entirety of factor payments do not have to be financed with working capital for this result to obtain.

While the cyclical behavior of the price markup conditioned on a monetary policy shock can vary quite significantly depending on model specifications, this is not the case of the cyclical behavior of the wage markup and labor wedge. We find that the correlations between the wage markup and output are always very negative, and this no matter what filtering method is used. We also find that the labor wedge is generally more countercyclical than the wage markup. These findings about the cyclicalities of the wage markup and the labor wedge are very consistent with the evidence in Galí, Gertler, and López-Salido (2007).[10]

2.5 Matching Business Cycle Moments

This section assesses the ability of our baseline model to match a number of key moments in the data using a parsimonious selection of shocks which hopefully escapes the criticism by CKM (2009). For this, we assume that business cycle fluctuations are driven by neutral technology and MEI shocks in addition to monetary policy shocks. Simulations are performed under the assumption that the size of shocks is the one for which our baseline model (or any other particular model) matches the volatility of output growth in the data (0.0078), with 50 percent of the variance of output growth assigned to the MEI shock, 35 percent to the neutral technology shock, and 15 percent to the monetary policy shock, and this for the reasons we ahve explained before. Values of shocks and non-shocks parameters used in the simulations are found in Table 2.1 and 2.2.

We begin by looking at volatility and comovement business cycle statistics. The sample period is 1960 :Q2-2007 :Q3. The volatility statistics involve the growth rates of output, consumption, investment and hours, as well as the volati-

10. They refer to the "gap" which is simply the negative of the sum of the logs of the price markup and the wage markup, thus the negative of our labor wedge.

lity of inflation and the nominal interest rate. While we report the volatility of the growth rate in hours, when it comes to correlations, we report comovements between the level of hours and the growth rates of output and consumption, because in our model hours worked are stationary in levels.

Table 2.4 compares volatility and comovement business cycle statistics from the data to the unconditional volatilities and correlations implied by the baseline model. Panel A in Table 2.4 displays volatility statistics with the first row reporting those in the data. Consumption growth is 40 percent less volatile than output growth. Investment growth is 2.6 times more volatile than output growth. First-differenced hours are about as volatile as output growth. Inflation is somewhat less volatile than output growth. The nominal interest is slightly more volatile than output growth. These relative volatilities are well known stylized facts in the business cycle literature. The baseline model matches the volatility of output growth in the data by construction. It generates plausible unconditional volatility statistics in spite of omitting several other types of shocks routinely embedded in medium-scale New Keynesian models.

Our baseline model does surprisingly well facing the so-called "comovement problem", which usually arises in models featuring standard (i.e. time-separable) preferences where an investment shock is the leading disturbance driving business cycle fluctuations (Fisher, 2006 ; Justiniano and Primiceri, 2008 ; Justiniano, Primiceri, and Tambalotti, 2010, 2011). In medium-scale New Keynesian models, the comovement problem consists in anomalous comovements involving consumption growth, investment growth and output growth. In the data, the correlation between consumption growth and investment growth is positive. Meanwhile, the correlation between consumption growth and output growth is positive and high. Typically, existing New Keynesian models with standard preferences such as those of Justiniano, Primiceri, and Tambalotti (2010, 2011) imply a negative unconditional correlation between consumption growth and investment growth, and a positive but low correlation between consumption growth and output growth. These anomalies are generally associated with a short-run decline in consumption that follows a positive MEI shock.

Barro and King (1984) have foreseen that non-TFP shocks, like investment shocks, would have difficulty generating plausible business cycle comovements of output, consumption, investment, and hours if they are the key source of business cycle fluctuations. For example, in the standard neoclassical framework, a positive shock to the marginal productivity of investment will increase the rate of return on capital, giving households the incentive to save (invest) more in the present and postpone consumption for the future. Consumption will then fall after the shock. In turn, lower consumption will increase the marginal utility of income, shifting labor supply to the right along a fixed labor demand schedule. Hours and output will rise, while the real wage and labor productivity will fall. As a result, the investment shock will generate an investment boom accompanied by a short-run fall in consumption. Insofar as the leading disturbance is an investment shock, the unconditional correlation between consumption and investment will be negative. The model will also imply anomalous comovements between consumption and hours.

Recent medium-scale New Keynesian models have been prone to this problem as well. A few solutions have been proposed in a New Keynesian context that involve the use of non-standard preferences. Khan and Tsoukalas (2011) address the comovement problem by combining into a medium-size DSGE model the non-standard form of preferences proposed by Jaimovich and Rebelo (2009) which cancels the wealth effect on labor supply with a cost of capital utilization specified in terms of increased capital depreciation. Furlanetto and Seneca (2014) combine sticky prices with preferences implying an Edgeworth complementarity between consumption and hours worked.

Panel B in Table 2.4 presents some interesting comovements, the first row reporting those in the data. Despite standard preferences, our baseline model implies an unconditional correlation between consumption growth and investment growth of 0.31, which is near the actual correlation in the data (0.436). The unconditional correlation between consumption growth and output growth implied by our model is 0.55 compared to 0.75 in the data. Meanwhile, the unconditional correlation between consumption growth and the level of hours found in the model is 0.035 compared to 0.075 in the data. Clearly, despite that the MEI shock is the leading source of business cycle fluctuations, our purely forward-looking wage and price setting model is not plagued by the comovement problem.

To understand the success of our model along this particular dimension, Figure 2.5 displays the response of consumption to a positive MEI shock in two models : *i*) our baseline model and *ii*) a model version without firms networking and growth. The reason for this is that Ascari, Phaneuf, and Sims (2016) have recently shown using the Hicksian decomposition proposed by King (1991) that with standard preferences, and in the absence of firms networking and growth, the positive income effect induced by a MEI shock is just not strong enough to overcome the negative substitution effect on consumption, so that on balance consumption will fall on impact of a positive MEI shock. However, their model abstracts from the interaction between firms networking and extended working capital which is so critical in our model to obtain rich inflation dynamics consisting, among others, in a highly persistent and hump-shaped response of inflation following a monetary policy shock. Figure 2.5 brings confirmation that this original insight still applies to our baseline model, for if we abstract from firms networking and growth, consumption falls during seven quarters following the MEI shock, while with these two features included, consumption is near zero on impact but then rises afterwards.

Returning to Panel B of Table 2.4, one sees that the baseline model does quite well matching the correlation between consumption growth and inflation. In the data, this correlation is -0.42 compared to the unconditional correlation of -0.34 in the model. The model closely matches the correlation between inflation and the interest rate (0.675 vs 0.61). Note also that the baseline model predicts negative and weak unconditional correlations between the interest rate and output growth, the interest rate and consumption growth, and the interest and investment growth, just as they are in the data. One drawback, however, is that the baseline model predicts that the unconditional correlation between inflation and output growth, and that between inflation and investment growth are both mildly positive, instead of mildly negative as they are in the data.

Another question we wish to address is that of the cyclicality of markups (wage and price) and the labor wedge in our three-shock baseline model. This can be seen in Tables 2.8 to 2.10 that report correlation between output on the one hand, and the price markup, the wage markup and the labor wedge on the other, either measured in first differences and HP-filtered log-levels in many different models. Despite the fact that our baseline model predicted a positive correlation between output and the price markup conditional on a monetary policy shock, it implies an unconditional countercyclical price markup when TFP, MEI and monetary policy shocks are included in the model. In fact, the price markup is countercyclical unconditionally in all model versions. Therefore, our unconditional evidence about the cyclical behavior of the price markup can hardly be reconciled with the positive (unconditional) correlation reported by Nekarda and Ramey (2013), but is more consistent with some of the evidence in Galí, Gertler, and López-Salido (2007) and Bils, Klenow, and Malin (2016). Meanwhile, the wage markup and the labor wedge are also found to be countercylical unconditionally in all models.

A final concern is the following. How would our main results be affected if firms were to use working capital to finance only a fraction of their outlays for intermediate inputs, labor and capital services instead of the totality of their factor payments? The reason for raising this question is that, using Bayesian methods, Phaneuf and Victor (2017) have estimated the extent of factor payments financed through working capital to be in the range between 43 and 50 percent depending on the production factor.

What we do next is to look at the implications of our framework when 50 percent instead of 100 percent of each factor payment is financed through working capital. Figure 2.6 shows that the response of inflation to a monetary policy shock still is highly persistent and hump-shaped and so is the response of output. A look at Table 2.11 suggests that, if anything, reducing the extent of factor payments financed through working capital to 50 percent does not have a significant impact on the ability of the model to match moments in the data. Finally, Tables 2.12 to 2.14 show that in this case, the price markup, the wage markup and the labor wedge all remain countercyclical unconditionally.

2.6 Conclusion

In this paper we have built a medium-scale DSGE model and studied its implications for the dynamics of inflation, output, and the price markup over marginal cost. In addition to many of the usual ingredients of these models, our model includes firms networking in the form of a roundabout production structure and assumes a working capital channel wherein firms borrow to finance the full cost of factor payments or only a fraction of this cost. The model delivers a response of inflation which is mute on impact of a monetary policy shock, but highly persistent and hump-shaped afterwards. It also generates a large contract multiplier for output in the form of a large and highly persistent response of output. It does so with a price markup that can be procyclical conditioned on a monetary policy shock, but countercyclical unconditionally.

The model successfully accounts for some key business cycle moments like the negative correlation between the nominal interest rate and the growth rates of output, consumption and investment. It also accounts for the negative comovement between inflation and consumption growth. Despite the fact that a MEI shock is the leading source of business cycle fluctuations, it correctly predicts a positive correlation between the growth rates of consumption, investment and output, and the level of hours, avoiding the so-called "comovement problem".

Many papers include backward-indexation or rule of thumb price setters into New Keynesian models to help account for the sluggish behavior of inflation. These features are theoretically unattractive and imply that prices and wages adjust every quarter, which is strongly at odds with available evidence. Our analysis suggests that these features are not necessary to understand the inertial behavior of inflation. Our model with purely forward-looking price and wage setting does at least well as a model with backward-indexation in accounting for inertial inflation dynamics, and does better producing a contract multiplier for output twice as large as that generated by indexation.

Table 2.1 Parameter Values.

Parameter	Value	Description
β	0.99	Discount factor
b	0.8	Internal habit formation
η	6	Labor disutility
χ	1	Frisch elasticity
κ	3	Investment adjustment cost
δ	0.025	Depreciation rate
γ_1	$Z^* = 1$	Utilization adjustment cost linear term
γ_2	0.05	Utilization adjustment cost squared term
ξ_p	0.66	Calvo price
ξ_w	0.66	Calvo wage
ζ_p	0	Price indexation
ζ_w	0	Wage indexation
θ	6	Elasticity of substitution : goods
σ	6	Elasticity of substitution : labor
ϕ	0.6	Intermediate share
α	1/3	Capital share
ψ_L	1	Fraction of labor financed
ψ_K	1	Fraction of capital financed
ψ_Γ	1	Fraction of intermediates financed
ρ_i	0.8	Taylor rule smoothing
α_π	1.5	Taylor rule inflation
α_y	0.2	Taylor rule output growth

Note : This table shows the values of the parameters used in quantitative analysis of the model. A description of each parameter is provided in the right column. The parameter on the linear term in the utilization adjustment cost function, γ_1, is chosen to be consistent with a steady state normalization of utilization to 1. Given other parameters this implies a value $\gamma_1 = 0.0457$. The fixed cost of production, F, is chosen so that profits equal zero in the non-stochastic steady state. Given other parameters, this implies a value of $F = 0.0183$.

Table 2.2 Shock Parameters.

g_A	g_{ε^I}	ρ_r	s_r	ρ_I	s_I	ρ_A	s_A
$1.0022^{1-\phi}$	1.0047	0	0.0018	0.8	0.0266	0.95	0.0027

Note : This table gives the baseline values of the parameters of the stochastic processes used in our quantitative simulations. The trend growth rate of the IST process is chosen to match the average growth rate of the relative price of investment goods in the data. The trend growth growth of the neutral productivity processes is chosen to match the average growth rate of output observed in the sample conditional on the growth rate of the IST process. Given the assumed values of autoregressive parameters governing the stochastic processes, the shock standard deviations are chosen to match the observed volatility of output growth in the data, with the MEI shock accounting for 50 percent of the variance of output growth, the neutral shock 35 percent, and the monetary shock 15 percent.

Table 2.3 Output and Inflation Dynamics.

		Inflation autocorrelation				
		Lag				
	Output half-life	1	2	3	4	5
Base model	14	0.9457	0.8269	0.6799	0.5287	0.3874
No EB, no FN	12	0.8220	0.6437	0.4839	0.3499	0.2426
No EB, no FN, full indexation	7	0.9473	0.8187	0.6476	0.4641	0.2914

Note : This table shows some statistics from different versions of the model. The column labeled "Output half-life" shows the half-life of output in response to a monetary policy shock, which we define as the number of quarters (rounded to the nearest integer) after which the impulse response of output is one-half its impact response. The remaining columns show autocorrelations of inflation at different lags. The row labeled "No EB, no FN" refers to a version of the model with no extended borrowing and no firms networking. The remaining row augments this case to consider full indexation of prices and wages to lagged inflation.

Table 2.4 Business Cycle Moments

Panel : A : Volatility

	$\sigma(\Delta C)$	$\sigma(\Delta I)$	$\sigma(\Delta L)$	$\sigma(\Delta P)$	$\sigma(r)$
Data	(0.0047)	(0.0202)	(0.0079)	(0.0065)	(0.0082)
Based Model	0.0033	0.0242	0.0077	0.0038	0.0047

Panel B : Correlation

	$\rho(\Delta Y, \Delta C)$	$\rho(\Delta Y, \Delta I)$	$\rho(\Delta Y, L)$	$\rho(\Delta Y, r)$
Data	(0.7542)	(0.9192)	(0.1105)	(-0.2456)
Base Model	0.5539	0.9514	0.0599	-0.1095
	$\rho(\Delta Y, \Delta P)$	$\rho(\Delta C, \Delta I)$	$\rho(\Delta C, L)$	$\rho(\Delta C, \Delta P)$
Data	(-0.3714)	(0.4362)	(0.0746)	(-0.4196)
Base Model	0.1258	0.3074	0.0345	-0.3406
	$\rho(\Delta C, r)$	$\rho(\Delta I, \Delta P)$	$\rho(\Delta I, r)$	$\rho(\Delta P, r)$
Data	(-0.2511)	(-0.2633)	(-0.1922)	(0.6754)
Base Model	-0.0977	0.3158	-0.0081	0.6065

Note : this table shows selected moments generated from our baseline model with FN, EB and growth. "σ " denotes standard deviation, "Δ " refers to the first difference operator, and ρ is a coefficient of correlation. The variables Y, I, C, and L are the natural logs of these series. Moments in the data are computed for the sample 1960Q1-2007Q3 and are shown in parentheses.

Table 2.5 Conditional Cyclicality of the Price Markup to a Monetary Policy Shock.

	First Differences	HP Filtered Log-Levels
Base Model	0.3780	0.0396
LBI, FN	0.2385	-0.2484
LBW, FN	-0.1531	-0.7338
No EB, No FN	-0.9797	-0.9701
No EB, No FN, full indexation	-0.9797	-0.9682
LBW, No FN, full indexation	0.0584	-0.4284
No EB, FN	-0.9941	-0.9911
EB, No FN	0.1641	-0.4304

Note :This table shows statistics for the conditional cyclicality of the price markup, (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Table 2.6 Conditional Cyclicality of the Wage Markup to a Monetary Policy Shock.

	First Differences	HP Filtered Log-Levels
Base Model	-0.6942	-0.7417
LBI, FN	-0.6902	-0.7476
LBW, FN	-0.6518	-0.7140
No EB, No FN	-0.7668	-0.8156
No EB, No FN, full indexation	-0.8091	-0.8674
LBW, No FN, full indexation	-0.7538	-0.8588
No EB, FN	-0.7066	-0.7480
EB, No FN	-0.7688	-0.8212

Note :This table shows statistics for the conditional cyclicality of the wage markup (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Table 2.7 Conditional Cyclicality of the Labor Wedge to Monetary Policy Shock.

	First Differences	HP Filtered Log-Levels
Base Model	-0.7171	-0.7717
LBI, FN	-0.7288	-0.7991
LBW, FN	-0.6555	-0.7162
No EB, No FN	-0.7868	-0.8359
No EB, No FN, full indexation	-0.8236	0.8785
LBW, No FN, full indexation	-0.7764	-0.8726
No EB, FN	-0.7215	-0.7688
EB, No FN	-0.7964	-0.8451

Note :This table shows statistics for the conditional cyclicality of the labor wedge (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Table 2.8 Unconditional Cyclicality of the Price Markup to a Monetary Policy Shock.

	First Differences	HP Filtered Log-Levels
Base Model	-0.0809	-0.2567
LBI, FN	-0.1394	-0.3165
LBW, FN	-0.1781	-0.3468
No EB, No FN	-0.4006	-0.5839
No EB, No FN, full indexation	-0.3713	-0.5220
LBW, No FN, full indexation	-0.3005	-0.5151
No EB, FN	-0.1829	-0.3424
EB, No FN	-0.3336	-0.5480

Note :This table shows statistics for the conditional cyclicality of the price markup (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Table 2.9 Unconditional Cyclicality of the Wage Markup to a Monetary Policy Shock.

	First Differences	HP Filtered Log-Levels
Base Model	-0.5631	-0.6940
LBI, FN	-0.6054	-0.7483
LBW, FN	-0.5723	-0.7348
No EB, No FN	-0.6644	-0.8190
No EB, No FN, full indexation	-0.6725	-0.7548
LBW, No FN, full indexation	-0.6566	-0.7508
No EB, FN	-0.6263	-0.7770
EB, No FN	-0.6327	-0.7822

Note :This table shows statistics for the conditional cyclicality of the wage markup (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Table 2.10 Unconditional Cyclicality of the Labor Wedge to a Monetary Policy Shock.

	First Differences	HP Filtered Log-Levels
Base Model	-0.5511	-0.6901
LBI, FN	-0.6389	-0.7800
LBW, FN	-0.5203	-0.6873
No EB, No FN	-0.6775	-0.8256
No EB, No FN, full indexation	-0.6764	-0.7600
LBW, No FN, full indexation	-0.6374	-0.7129
No EB, FN	-0.6205	-0.7782
EB, No FN	-0.6195	-0.7541

Note :This table shows statistics for the conditional cyclicality of the labor wedge (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Table 2.11 Business Cycle Moments ($\psi_\Gamma = \psi_K = \psi_K = 0.5$).

Panel : A : Volatility

	$\sigma(\Delta C)$	$\sigma(\Delta I)$	$\sigma(\Delta L)$	$\sigma(\Delta P)$	$\sigma(r)$
Data	(0.0047)	(0.0202)	(0.0079)	(0.0065)	(0.0082)
Based Model	0.0032	0.0227	0.0079	0.0033	0.0042

Panel B : Correlation

	$\rho(\Delta Y, \Delta C)$	$\rho(\Delta Y, \Delta I)$	$\rho(\Delta Y, L)$	$\rho(\Delta Y, r)$
Data	(0.7542)	(0.9192)	(0.1105)	(-0.2456)
Base Model	0.6203	0.9605	0.0456	-0.1365
	$\rho(\Delta Y, \Delta P)$	$\rho(\Delta C, \Delta I)$	$\rho(\Delta C, L)$	$\rho(\Delta C, \Delta P)$
Data	(-0.3714)	(0.4362)	(0.0746)	(-0.4196)
Base Model	0.0803	0.4176	0.0319	-0.3210
	$\rho(\Delta C, r)$	$\rho(\Delta I, \Delta P)$	$\rho(\Delta I, r)$	$\rho(\Delta P, r)$
Data	(-0.2511)	(-0.2633)	(-0.1922)	(0.6754)
Base Model	-0.1437	0.2324	-0.0412	0.4926

Note : this table shows selected moments generated from our baseline model with FN, EB and growth. "σ " denotes standard deviation, "Δ " refers to the first difference operator, and ρ is a coefficient of correlation. The variables Y, I, C, and L are the natural logs of these series. Moments in the data are computed for the sample 1960Q1-2007Q3 and are shown in parentheses.

Table 2.12 Unconditional Cyclicality of the Price Markup to a Monetary Policy Shock ($\psi_\Gamma = \psi_K = \psi_K = 0.5$).

	First Differences	HP Filtered Log-Levels
Base Model	-0.0878	-0.2516
LBI, FN	-0.1155	-0.2728
LBW, FN	-0.1374	-0.2867
No EB, No FN	-0.3484	-0.5280
No EB, No FN, full indexation	-0.3247	-0.4817
LBW, No FN, full indexation	-0.2832	-0.4780
No EB, FN	-0.1464	-0.2886
EB, No FN	-0.3099	-0.5161

Note :This table shows statistics for the conditional cyclicality of the price markup (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Table 2.13 Unconditional Cyclicality of the Wage Markup to a Monetary Policy Shock ($\psi_\Gamma = \psi_K = \psi_K = 0.5$).

	First Differences	HP Filtered Log-Levels
Base Model	-0.5599	-0.6913
LBI, FN	-0.5736	-0.7137
LBW, FN	-0.5552	-0.7045
No EB, No FN	-0.6287	-0.7755
No EB, No FN, full indexation	-0.6498	-0.7422
LBW, No FN, full indexation	-0.6434	-0.7433
No EB, FN	-0.5799	-0.7248
EB, No FN	-0.6205	-0.7613

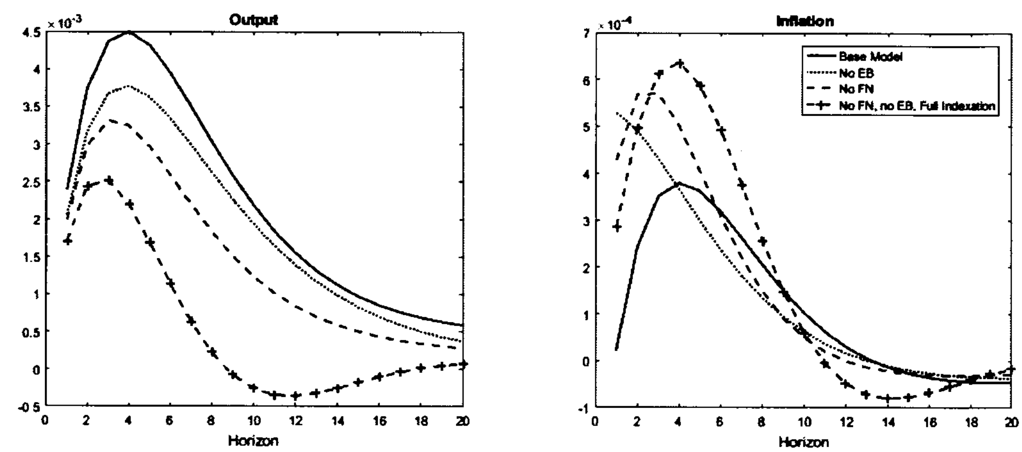
Note :This table shows statistics for the conditional cyclicality of the wage markup (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Table 2.14 Unconditional Cyclicality of the Labor Wedge to a Monetary Policy Shock ($\psi_\Gamma = \psi_K = \psi_K = 0.5$).

	First Differences	HP Filtered Log-Levels
Base Model	-0.5500	-0.6926
LBI, FN	-0.5823	-0.7304
LBW, FN	-0.5292	-0.6859
No EB, No FN	-0.6390	-0.7833
No EB, No FN, full indexation	-0.6509	-0.7470
LBW, No FN, full indexation	-0.6351	-0.7299
No EB, FN	-0.5721	-0.7261
EB, No FN	-0.6199	-0.7533

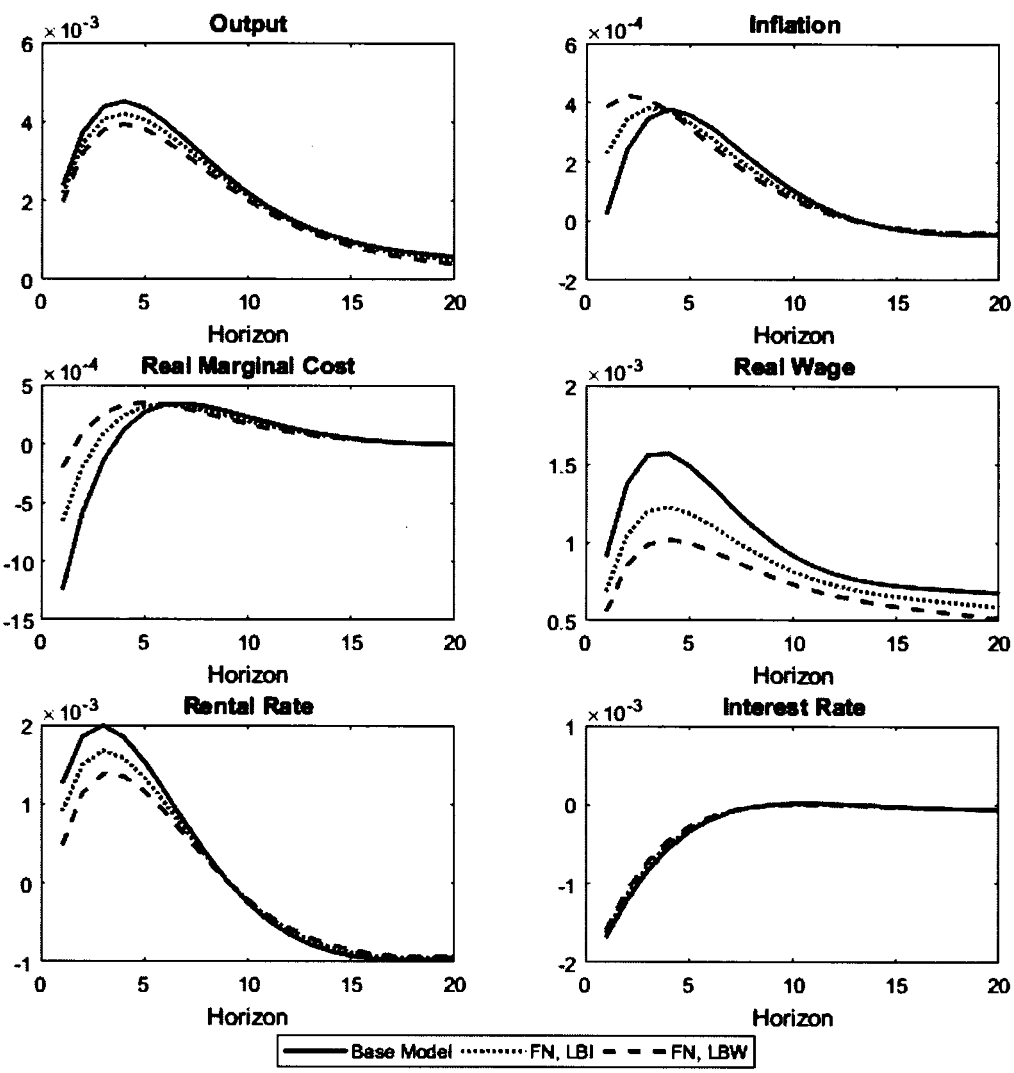
Note :This table shows statistics for the conditional cyclicality of the labor wedge (correlation with output) for different versions of the model and for different filtering methods. FN :firms networking; EB : extended borrowing with working capital financing all inputs; LBI : limited borrowing working capital financing only intermediate goods; LBW : limited borrowing with working capital financing only wages.

Figure 2.1 Output and Inflation Responses to a Monetary Policy Shock.



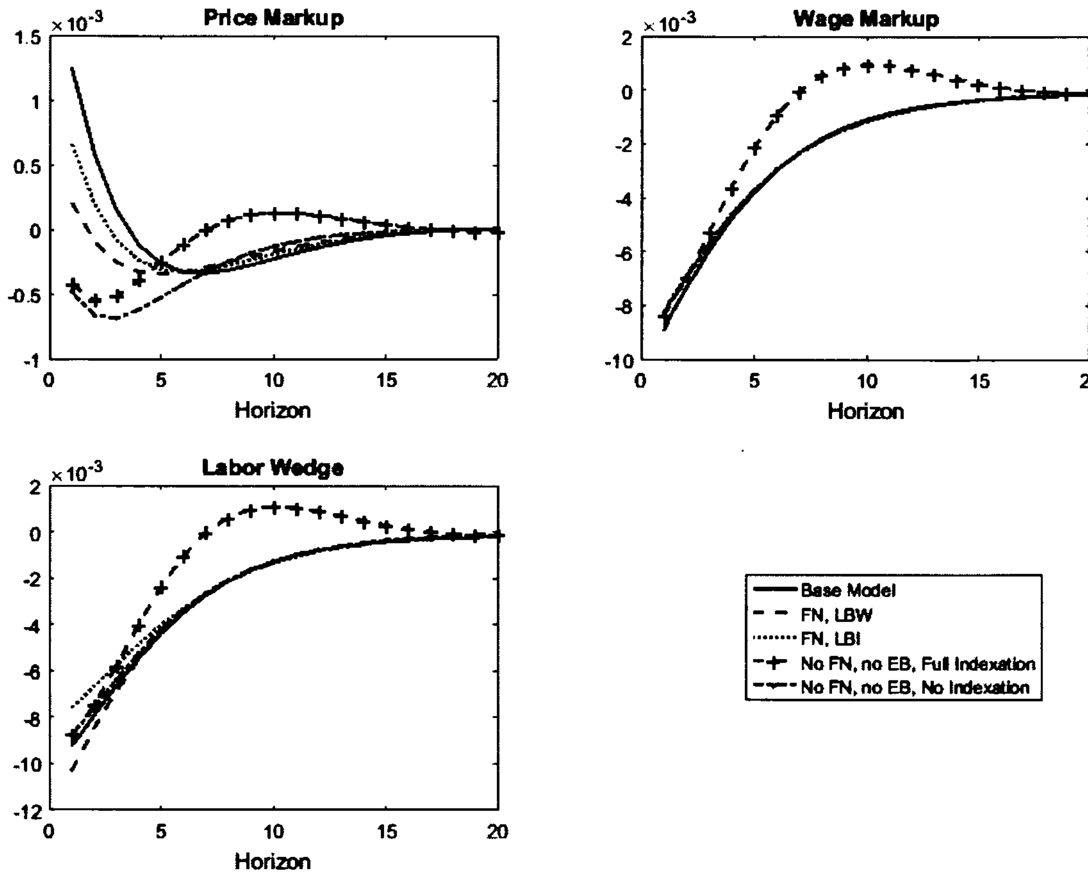
Note : This figure plots the impulse responses of output, inflation, and the price level to a monetary policy shock. The solid lines show the responses in the baseline calibrated model. The dashed lines show responses when there is no firms networking ("No FN"). The dotted lines show responses when there is no extended borrowing ("No EB"). The dashed lines with "+" show responses when there is no firms networking and no extended borrowing, but prices and wages are fully indexed to the lagged inflation rate ("No FN, No EB, Full Backward Indexation").

Figure 2.2 Output, Inflation and Real Marginal Cost Responses to a Monetary Policy Shock.



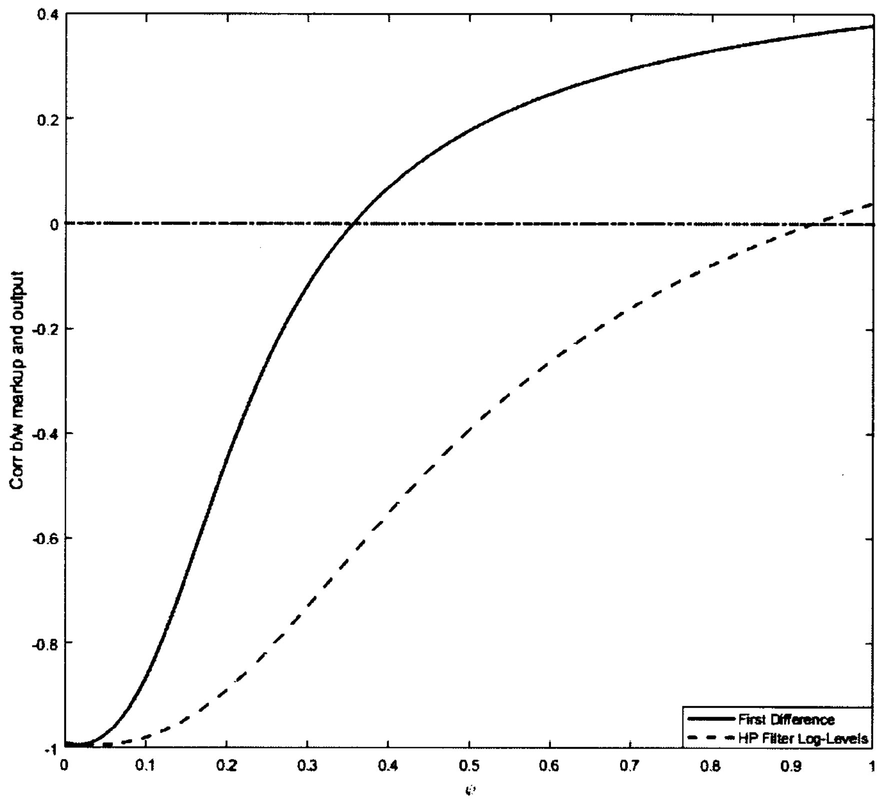
Note : This figure plots the impulse responses of output, inflation, and real marginal cost to a monetary policy shock. The solid lines show the responses in the baseline calibrated model. The dotted lines show responses when there is firms networking and limited borrowing with working capital financing only intermediate goods. ("FN, LBI").The dashed lines show responses when there is firms networking and limited borrowing with working capital financing only wages. ("FN, LBW").

Figure 2.3 The Price Markup, Wage Markup, and the Labor Wedge Responses to a Monetary Policy Shock.



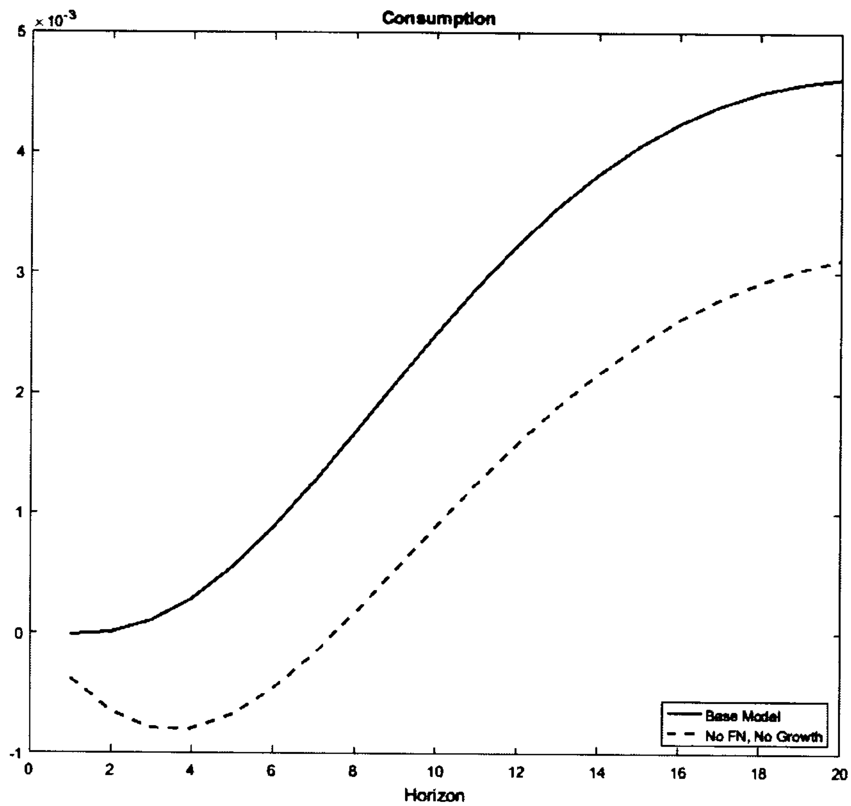
Note : This figure plots the impulse responses of the price markup, the wage markup, and the labor wedge to a monetary policy shock. The solid lines show the responses in the baseline calibrated model. The dotted lines show responses when there is firms networking and limited borrowing with working capital financing only intermediate goods. ("FN, LBI"). The dashed lines show responses when there is firms networking and limited borrowing with working capital financing only wages ("FN, LBW"). The dashed lines with "+" show responses when there is no firms networking and no extended borrowing, but prices and wages are fully indexed to the lagged inflation rate ("No FN, No EB, Full Indexation"). The dashed lines with "." show responses when there is no firms networking, no extended borrowing no indexation ("No FN, No EB, no Indexation").

Figure 2.4 Extent of Working Capital and the Cyclicality of the Price Markup.



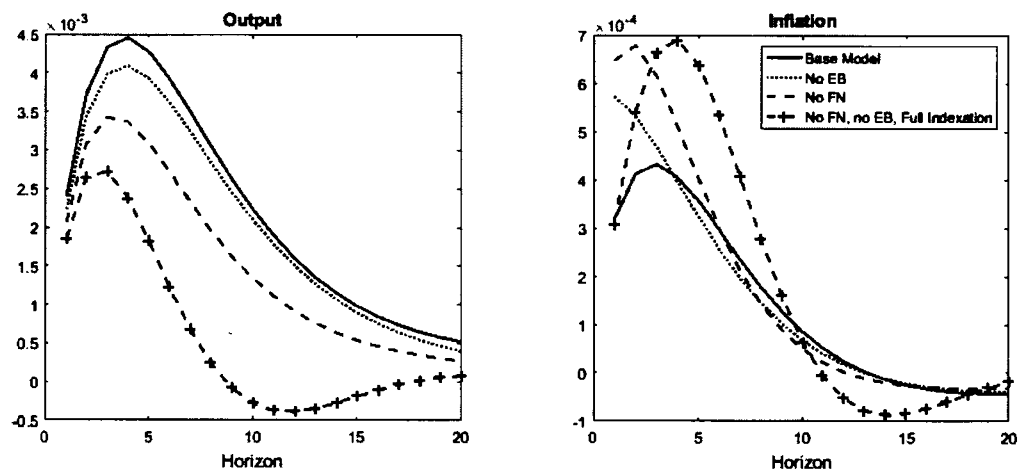
Note : This figure plots the correlation between the price markup and output in first log-differences (solid line) and HP filtered log-levels (dashed line) as a function of the value of ψ, where we assume that $\psi_\Gamma = \psi_K = \psi_L = \psi$. In other words, the parameter ψ measures the fraction of factor payments that have to be financed with working capital, assuming that this fraction is the same for all three factors of production. The dashed-dotted line is drawn at zero to facilitate determining the threshold value of ψ capable of delivering a procyclical markup.

Figure 2.5 Consumption Responses to a MEI Shock.



Note : This figure plots the responses of consumption to a MEI shock for the baseline model and the model with no firms networking and no growth

Figure 2.6 Output and Inflation Responses to a Monetary Policy Shock ($\psi_\Gamma = \psi_K = \psi_L = 0.5$).



Note : This figure plots the impulse responses of output and inflation to a monetary policy shock for $\psi_\Gamma = \psi_K = \psi_L = 0.5$. The solid lines show the responses in the baseline calibrated model. The dashed lines show responses when there is no firms networking ("No FN"). The dotted lines show responses when there is no extended borrowing ("No EB"). The dashed lines with "+" show responses when there is no firms networking and no extended borrowing, but prices and wages are fully indexed to the lagged inflation rate ("No FN, No EB, Full Backward Indexation").

CHAPITRE III

THE BUSINESS CYCLE IN AN ESTIMATED DSGE MODEL WITH PRODUCTION NETWORKS AND WORKING CAPITAL

Abstract

In this paper we use Bayesian methods to estimate a medium-scale DSGE model that features production networks and an extended working capital channel. We offer evidence which strongly supports a network view of the production process. It also suggests that firms use working capital to finance a substantial fraction of their outlays for intermediate inputs, capital services and labor. These findings hold whether news shocks are included or not. Relative to a standard model which abstracts from these refinements, a comparison of the marginal likelihood statistics computed by modified harmonic mean estimation speaks clearly to the relative advantage and fit of our benchmark model. Compared to the standard model, we find that production networks and working capital significantly alter the impulse responses of key variables to marginal efficiency of investment (MEI), TFP, wage markup and monetary policy shocks. In spite of standard preferences, our benchmark model is not prone to the "comovement problem".

JEL classification : E31, E32, E37.

Keywords : Bayesian estimation ; Production networks ; Extended working capital ; Investment shocks ; Business cycle comovements ; Source of business cycles.

3.1 Introduction

It is well known that DSGE models with time-separable preferences encounter difficulties accounting for business cycle comovements between consumption and other key variables such as output, investment and hours when an investment shock is the leading source of business cycle fluctuations. Less well known are their difficulties to account for comovements between inflation, interest rates, consumption and other variables. Central to these anomalies is a negative response of consumption that lasts for more than a year following a positive investment shock. Missing from the literature, however, is an estimated DSGE model with standard preferences that better accounts for these comovements. Our paper fills this gap.

We estimate via Bayesian methods a DSGE model that modifies the consensus medium-scale New Keynesian framework (e.g. see Smets and Wouters, 2007; Justiniano and Primiceri, 2008; Justiniano, Primiceri, and Tambalotti, 2010, 2011)) along three dimensions while keeping standard preferences. [1] Firstly, our model incorporates production networks wherein firms are interconnected through input-output linkages. Secondly, firms use working capital to defray some or all of their outlays for intermediate inputs, capital services and labor before the proceeds from the sale of output are received. Thirdly, the monetary authority sets the nominal interest rate according to a Taylor rule that includes a response of nominal interest rates to deviations of inflation and output growth from steady state instead of a reaction to inflation, the level and the growth rate of output from their flexible wage and price values without markup shocks. Our evidence supports a network view of the production process and an extended use of working capital by firms to finance a substantial fraction of their factor payments.

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1. Hereafter, we refer to Justiniano, Primiceri and Tambalotti as JPT.

These three modifications can be justified as follows. First, we combine production networks and real per capita output growth stemming from neutral and investment-specific technology to strengthen the positive income effect and reduce the negative substitution effect on consumption induced by an investment shock, and this to overcome some anomalous comovements between consumption growth and other key variables found in existing medium-scale DSGE models (Ascari, Phaneuf, and Sims, 2016a). Second, extended working capital helps our model generate a hump-shaped response of inflation and a rising price markup on impact of a negative shock to the nominal interest rate as recent evidence in Nekarda and Ramey (2013) seems to suggest. Third, we use a Taylor rule that includes a response of interest rates to deviations of output growth from steady state (Erceg and Levin, 2003) to avoid a state of indeterminacy and allow a direct comparison between our *benchmark* model which includes all three modifications and a *standard* model that abstracts from the first two.

We first estimate the benchmark and standard models with unanticipated shocks only. But in a later part of the paper, we also estimate a version of the benchmark model that builds on the distinction between unanticipated and news shocks(Jaimovich and Rebelo, 2009; Schmitt-Grohé and Uribe, 2012). The first two questions we address are the following. Does firms networking provide a plausible description of the U.S. production process as a whole? Second, what are the factor payments, if any, that require the use of working capital and to what extent? We report Bayesian estimates of the relevant parameters for the years 1960 :Q1-2008 :Q4. Our point estimate of the share of intermediate goods in gross output is 0.56, with a confidence interval ranging from 0.45 to 0.67. These estimates strongly support a network view of the production process. We also find that firms borrow working capital to defray a fraction of their outlays for production factors, the fraction varying between 43 and 50 percent depending on the input.

Firms networking has the following implications. Relative to the standard model, its presence substantially magnifies the effects of a TFP shock, which then has sizeable effects on aggregate fluctuations despite it is nearly two times smaller than in the standard model. Secondly, relative to the standard model, production networking downsizes the responses of output, consumption, investment and hours following a shock to the marginal efficiency of investment (MEI). As we later show, this is mainly the consequence of nominal wages being more flexible in the benchmark model (Calvo probability of wage non-reoptimization of 0.56 in the benchmark compared to 0.72 in the standard model). While firms networking effectively flattens the slope of the New Keynesian Phillips Curve, more flexible nominal wages allow real wages to grow faster following a positive MEI shock in the benchmark model. The increase in hours is then smaller, and so are the increases in output, consumption and investment. Firms networking also alters the responses of variables to a wage markup shock, producing a flip in the signs of the responses of output, consumption, investment and hours from positive in the standard model to negative in the benchmark model. Increased nominal wage flexibility is a key element producing the flip in the signs of the responses. Extended working capital helps generate a hump-shaped response of inflation and a rising price markup on impact of a negative shock to the nominal interest rate, something the standard model is unable to do. The benchmark model an unconditional countercyclical price markup.

Another point of interest pertains to the ability of alternative models to explain the correlations between consumption growth, investment growth, output growth and hours. In the data, the contemporaneous correlations between these variables are positive, while the cross-correlations are generally positive and decreasing at lags and leads. JPT (2011; Figure 3) report a negative unconditional contemporaneous correlation between consumption growth and investment growth, and unconditional cross-correlations that are positive and increasing at lags and consistently negative at leads. Ascari, Phaneuf, and Sims (2016a) provide a detailed analysis of the sources of the comovement problem in medium-scale New Keynesian models. Using the Hicksian decomposition proposed by King (1991), they show that existing models are prone to anomalous comovements because the positive income effect on consumption induced by a positive investment shock is not strong enough to overturn the negative substitution effect. As a result, the response of consumption is negative on impact of a positive investment shock. They show that combining firms networking and economic growth can generate a stronger income effect that results into a positive response of consumption on impact of an investment shock. An open question, however, is whether this mechanism is strong enough empirically to overcome the comovement problem.

We find that both our benchmark and standard models imply a mildly positive unconditional contemporaneous correlation between the growth rates of consumption and investment and cross-correlations profiles that are broadly consistent with the data. However, the benchmark model generates correlations between consumption, output, investment and hours which are generally closer to the data. We obtain this result in spite of standard (i.e. time-separable) preferences. So far in the literature, solutions to the comovement problem have generally involved non-standard preferences (Jaimovich and Rebelo, 2009 ; Khan and Tsoukalas, 2011 ; Furlanetto and Seneca, 2014).

Since our standard model and the model estimated by JPT are similar except for our different specification of the Taylor rule, a natural question is : why is it that our standard model does not suffer from the comovement problem ? JPT find a negative response of consumption on impact of a positive MEI shock whereas in our standard model this response is positive. In JPT (2011, Table 1), the parameter governing the response of interest rates to deviations of inflation from steady state is 1.7. This parameter is 1.39 in our standard model. So the monetary authority responds more agressively to inflation if, as in JPT, the Taylor rule incorporates reactions to both output growth and the output gap. Furthermore, while in JPT the point estimate of the parameter governing the response of the nominal interest rate to the output gap is fairly modest at 0.05, a positive MEI shock in their model is followed by a relatively large and highly persistent positive response of the output gap. Therefore, in the model estimated by JPT, monetary policy is significantly less accommodative than in our standard model which explains why consumption falls in their model on impact of a MEI shock and not in our standard model.

That said, the reason for choosing a Taylor rule admitting a response to deviations of output growth from steady state is the following. When trying to estimate the benchmark model with a Taylor rule featuring both output growth and the output gap, we are unable to obtain a unique rational expectations equilibrium. Interestingly, the indeterminacy result in our benchmark model seems broadly consistent with the analysis in Christiano, Trabandt, and Walentin (2011). Working from a price-setting model accounting for firms networking and working capital, these authors show that adhering to the Taylor principle may actually lead to indeterminacy if the share of materials in gross output is high enough and the working capital channel is strong enough. To sustain this claim, Christiano et al. use a Taylor rule responding to inflation and the output gap.

When estimating the benchmark model with a Taylor rule responding to deviations of output growth from steady state, we are able to achieve determinacy. The model is not subject to the comovement problem. But the mechanism at work to arrive at this result in the benchmark model is very different than that in the standard model. Two factors do not favour an increase in consumption following a

MEI shock in the benchmark model. One is that nominal wages are more flexible, which has for effect of downsizing the increase in consumption following a MEI shock. The other is that the response of monetary policy to inflation is stronger in the benchmark model (1.58 compared to 1.39 in the standard model), implying a less accommodative policy. Yet, the response of consumption is positive on impact of a MEI shock in the benchmark model. The key mechanism leading to this result is the one we have described before : the interaction between firms networking and economic growth strengthens the positive income effect of a MEI shock on consumption, which helps overturn the negative substitution effect induced by the MEI shock.

We give some attention to other anomalous comovements, overlooked so far in the literature. These anomalies pertain to the correlations between inflation, interest rates, output growth, consumption growth, investment growth and the level of hours. In the data, the contemporaneous correlations and cross-correlations at lags and leads between inflation (or the nominal interest rate) and these other variables are negative. In JPT, the unconditional contemporaneous correlations are positive instead of negative. Moreover, the unconditional cross-correlations at lags and leads between inflation and consumption growth are positive instead of negative.

By contrast, our benchmark model implies negative unconditional contemporaneous correlations between inflation, consumption growth and output growth. It also implies negative unconditional cross-correlations between inflation and consumption growth at lags and leads, consistent with the data. It also performs better than the standard model accounting for the correlations between the nominal interest rate, consumption growth, output growth, investment growth and the level of hours.

When looking at the sources of business cycle fluctuations through the lens of our estimated models, we find that the MEI shock drives the largest fraction of the variance of output growth, investment growth, inflation and interest rates either at business cycle or low frequencies. The contribution of the MEI shock to business cycle fluctuations is however smaller in the benchmark model. While this shock accounts for 65 percent of the variance of output growth at business cycle frequencies in the standard model, it contributes to 49 percent in the benchmark model. The MEI shock is also the leading source of the variance of hours at business cycle frequencies with 53 percent compared to 71 percent in the standard model. Smets and Wouters (2007) report that the wage markup shock explains about half of the forty-quarter ahead forecasting error variance of output growth. We find no evidence that the wage markup shock is a key driver of business cycle fluctuations.

According to our benchmark and standard models, the MEI shock is also the key source of inflation variability. We find that this shock explains nearly 47 percent of the cyclical variance of inflation in both models. JPT (2011) find instead that the price markup shock explains 39 percent of the cyclical variance of inflation, followed by the neutral technology shock with 37 percent. The MEI shock contributes to only 10 percent of the variance of inflation. We return to this point later in the paper.

A final question concerns the relative importance of unanticipated and news shocks. We follow the approach in Schmitt-Grohé and Uribe (2012). The news component is driven by innovations announced four and eight quarters in advance. Schmitt-Grohé and Uribe report evidence suggesting that news shocks explain the bulk of business cycle fluctuations. Khan and Tsoukalas (2012) dispute these findings based on estimation of a New Keynesian model. Their model abstracts from production networks and working capital. They report that news shocks have a relatively small effect on aggregate fluctuations, except for the anticipated wage markup shock which explains about 60 percent of the variance of hours and inflation at low frequencies.

We find that the benchmark model with unanticipated and news shocks statistically outperforms the standard model with unanticipated shocks only. At the same time, the data prefer the benchmark model with unanticipated shocks only to the benchmark model with unanticipated and news shocks. If anything, when accounting for news shocks, the unanticipated MEI shock explains a higher percentage of the variance of output growth at business cycle frequencies. Thus, there is no case based on our benchmark model with news to argue that news shocks play a significant role in generating business cycle fluctuations.

The rest of the paper is organized as follows. Section 2 describes our model. Section 3 discusses our estimation procedure through Bayesian methods. Section 4 presents and analyzes our main results. Section 5 looks at the sources of business cycles with unanticipated shocks only and news shocks added to the benchmark model. Section 6 concludes.

3.2 The Model

This section describes our model. It features imperfectly competitive labor and goods markets, Calvo's (1983) wage and price contracts, consumer habit formation, investment adjustment costs and variable capital utilization (Christiano, Eichenbaum, and Evans, 2005). It also includes several types of disturbances (Smets and Wouters, 2007; Justiniano and Primiceri, 2008) and trend growth in neutral and investment-specific technology (JPT, 2010, 2011; Ascari, Phaneuf, and Sims, 2016b). To this standard medium-size New Keynesian model we add production networks and an extended working capital channel. The inertial Taylor rule includes reactions to deviations of inflation and output growth from their steady-state values.

3.2.1 Gross Output

Gross output, X_t, is produced by a perfectly competitive firm using a continuum of intermediate goods, X_{jt}, $j \in (0,1)$ and the following CES production technology :

$$X_t = \left(\int_0^1 X_{jt}^{\frac{1}{1+\lambda_{p,t}}} dj \right)^{1+\lambda_{p,t}}, \tag{3.1}$$

where $\lambda_{p,t}$ is the desired price markup over marginal cost which is assumed to follow an ARMA (1,1) process (see also Smets and Wouters, 2007; JPT, 2011) :

$$\lambda_{p,t} = (1 - \rho_p) \lambda_p + \rho_p \lambda_{p,t-1} + \varepsilon_p - \theta_p \varepsilon_{p,t-1}, \tag{3.2}$$

λ_p denoting the steady-state desired markup and ε_p is an *i.i.d.* $N\left(0, \sigma_p^2\right)$ price-markup shock.

Profit maximization and a zero-profit condition for gross output leads to the following downward sloping demand curve for the intermediate good j

$$X_{jt} = \left(\frac{P_{jt}}{P_t} \right)^{-\frac{(1+\lambda_{p,t})}{\lambda_{p,t}}} X_t, \tag{3.3}$$

where P_{jt} is the price of good j and P_t is the aggregate price index :

$$P_t = \left(\int_0^1 P_{jt}^{-\frac{1}{\lambda_{p,t}}} dj \right)^{-\lambda_{p,t}}. \tag{3.4}$$

3.2.2 Intermediate Goods Producers and Price Setting

A monopolist produces intermediate good j according to the following production function :

$$X_{jt} = \max\left\{ A_t \Gamma_{jt}^{\phi} \left(\widehat{K}_{jt}^{\alpha} L_{jt}^{1-\alpha}\right)^{1-\phi} - \Upsilon_t F, 0\right\}, \tag{3.5}$$

where A_t denotes an exogenous non-stationary level of neutral technology. Its growth rate, $z_t \equiv \ln\left(\frac{A_t}{A_{t-1}}\right)$, follows a stationary AR(1) process,

$$z_t = (1-\rho_z)\, g_z + \rho_z z_{t-1} + \varepsilon_{z,t}, \tag{3.6}$$

where g_z is the steady-state growth rate of neutral technology, and $\varepsilon_{z,t}$ is an i.i.d. $N(0,\sigma_z^2)$ neutral technology shock. Γ_{jt} denotes the intermediate inputs, $\widehat{K}_{jt}$ the capital services, and L_{jt} the labor input used by the j^{th} producer. Υ_t represents a growth factor originating from two distinct sources : neutral and investment-specific technology. F is a fixed cost, such that profits are zero in the steady state and ensuring that the existence of balanced growth path.

The stochastic growth factor is given by the following composite technological process :

$$\Upsilon_t = A_t^{\frac{1}{(1-\phi)(1-\alpha)}} {V_t^I}^{\frac{\alpha}{1-\alpha}}, \tag{3.7}$$

where V_t^I denotes investment-specific technological progress (hereafter IST). When production networks are absent from the model, i.e. $\phi = 0$, this reverts to the conventional stochastic growth factor in a model with growth in neutral and investment-specific productivity. Under this restriction, intermediates are irrelevant for production, and the model reduces to the standard New Keynesian model. Interestingly, from 3.7, it is evident that a higher value of ϕ amplifies the effects of stochastic growth in neutral productivity on output and its components. For a given level of stochastic growth in neutral productivity, the economy will grow faster the larger is the share of intermediates in production. As later shown by our estimation, this has a significant impact on the size of neutral technology shocks needed to generate sizeable aggregate fluctuations in the benchmark model relative to the standard model. IST progress is non-stationary and its growth rate, $v_t^I \equiv \ln\left(\frac{V_t^I}{V_{t-1}^I}\right)$, follows a stationary AR(1) process : $\mathrm{v}_t^I = (1-\rho_v)\, g_v + \rho_v v_{t-1}^I + \eta_t^I$,where g_v is the steady-state growth rate of the IST process and η_t^I is an i.i.d. $N\left(0, \sigma_{\eta^I}^2\right)$ IST shock.

The firm gets to choose its price, P_{jt}, as well as quantities of intermediates, capital services, and labor input. It is subject to Calvo (1983) pricing, where each period there is a $(1-\xi_p)$ probability that a firm can re-optimize its price. Regardless of whether a firm is given the opportunity to adjust its price, it will choose inputs to minimize total cost, subject to the constraint of producing enough to meet demand. The cost minimization problem of a typical firm is :

$\min_{\Gamma_t, \widehat{K}_t, L_t}(1-\psi_\Gamma+\psi_\Gamma R_t)P_t\Gamma_{jt} + (1-\psi_K+\psi_K R_t)R_t^k\widehat{K}_{jt} + (1-\psi_L + \psi_L R_t)W_t L_{jt}$,subject to :

$$A_t\Gamma_{jt}^{\phi}\left(\widehat{K}_{jt}^{\alpha}L_{jt}^{1-\alpha}\right)^{1-\phi} - \Upsilon_t F \geq \left(\frac{P_{jt}}{P_t}\right)^{-\theta} X_t, \tag{3.8}$$

where R_t^k is the nominal rental price of capital services (i.e. the product of utilization, u_t, and physical capital, K_t), W_t is the nominal wage index, and ψ_Γ, ψ_K and ψ_L are the fractions of factor payments financed through short-term loans at the gross nominal interest rate R_t. We define $\Psi_{l,t} = (1-\psi_l+\psi_l R_t)$, for $l = \Gamma, K, L$. Solving the cost minimization problem yields the following real marginal cost :

$$mc_t = \overline{\phi} A_t^{(1-\alpha)(\phi-1)}\Psi_{\Gamma,t}^{\phi}\left[\left(\Psi_{K,t}r_t^k\right)^{\alpha}(\Psi_{L,t}w_t)^{(1-\alpha)}\right]^{1-\phi}, \tag{3.9}$$

and demand functions for intermediate input and primary factor inputs :

$$\Gamma_{jt} = \phi\frac{mc_t}{\Psi_{\Gamma,t}}\left(X_{jt} + \Upsilon_t F\right), \tag{3.10}$$

$$K_{jt} = \alpha\left(1-\phi\right)\frac{mc_t}{\Psi_{K,t}r_t^k}\left(X_{jt}+\Upsilon_t F\right), \tag{3.11}$$

$$L_{jt} = (1-\alpha)(1-\phi)\frac{mc_t}{\Psi_{L,t}w_t}\left(X_{jt}+\Upsilon_t F\right), \tag{3.12}$$

where $\overline{\phi} \equiv \phi^{-\phi}\left(1-\phi\right)^{\phi-1}\left(\alpha^{-\alpha}\left(1-\alpha\right)^{\alpha-1}\right)^{1-\phi}$, $mc_t = \frac{MC_t}{P_t}$, is the real marginal cost which is common to all firms, r_t^k is the real rental price on capital services, and w_t is the real wage.

Intermediate firms allowed to reoptimize their price choose a price P_t^*, and those not allowed to reoptimize index to lagged inflation, π_{t-1}, and/or steady-state inflation, π. The price-setting rule is given by

$$P_{jt}\begin{cases} = P_{jt}^* & \text{with probability } 1-\xi_p \\ = P_{j,t-1}\pi_{t-1}^{\iota_p}\pi^{1-\iota_p} & \text{with probability } \xi_p \end{cases}, \tag{3.13}$$

where ι_p is the degree of price indexation to past inflation. When reoptimizing its price, a firm j chooses a price that maximizes the present discounted value of future profits, subject to (3.3) and to cost minimization :

$$\max_{P_{jt}} \quad E_t\sum_{t=0}^{\infty}\xi_p^s\beta^s\frac{\Lambda_{t+s}}{\Lambda_t}\left[P_{jt}X_{j,t+s}\Pi_{t,t+s}^p - MC_{t+s}X_{j,t+s}\right], \tag{3.14}$$

where β is the discount factor, Λ_t is the marginal utility of nominal income to the representative household that owns the firm, ξ_P^s is the probability that a wage chosen in period t will still be in effect in period $t+s$, $\Pi_{t,t+s}^p = \Pi_{k=1}^s\pi^{1-\iota_p}\pi_{t+k-1}^{\iota_p}$ is the cumulative price indexation between t and $t+s-1$, and MC_{t+s} is the nominal marginal cost.

Solving the problem yields the following optimal price :

$$E_0\sum_{s=0}^{\infty}\xi_p^s\beta^s\lambda_{t+s}^r X_{jt+s}\frac{1}{\lambda_{p,t+s}}\left(p_t^*\frac{\Pi_{t,t+s}^p}{\pi_{t+1,t+s}} - \left(1+\lambda_{p,t+s}\right)mc_{t+s}\right) = 0, \tag{3.15}$$

where λ_t^r is the marginal utility of an additional unit of real income received by the household, $p_t^* = \frac{P_{jt}}{P_t}$ is the real optimal price and $\pi_{t+1,t+s} = \frac{P_{t+s}}{P_t}$ is the cumulative inflation rate between $t+1$ and $t+s$.

3.2.3 Households and Wage Setting

There is a continuum of households, indexed by $i \in [0,1]$, who are monopoly suppliers of labor. They face a downward-sloping demand curve for their particular type of labor given in (3.23). Each period, there is a fixed probability, $(1-\xi_w)$, that households can reoptimize their nominal wage. As in As in Erceg, Henderson, and Levin (2000), utility is separable in consumption and labor. State-contingent securities insure households against idiosyncratic wage risk arising from staggered wage-setting. Households are then identical along all dimensions other than labor supply and wages.

The problem of a typical household, omitting dependence on i except for these two dimensions, is :

$$\max_{C_t, L_{it}, K_{t+1}, B_{t+1}, I_t, Z_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t b_t \left(\ln\left(C_t - hC_{t-1}\right) - \eta \frac{{L_{it}}^{1+\chi}}{1+\chi} \right), \tag{3.16}$$

subject to the following budget constraint,

$$P_t \left(C_t + \frac{I_t}{V_t^I} + \frac{a(u_t)K_t}{V_t^I} \right) + \frac{B_{t+1}}{R_t} \leq W_{it}L_{it} + R_t^k u_t K_t + B_t + \Pi_t + T_t, \tag{3.17}$$

and the physical capital accumulation process,

$$K_{t+1} = \vartheta_t \left(1 - S\left(\frac{I_t}{I_{t-1}} \right) \right) I_t + (1-\delta)K_t. \tag{3.18}$$

b_t in the utility function is an exogenous intertemporal preference shock. C_t is real consumption and h is a parameter determining internal habit. L_{it} denotes hours and χ is the inverse Frisch labor supply elasticity. I_t is investment, and $a(u_t)$ is a resource cost of utilization, satisfying $a(1) = 0$, $a'(1) = 0$, and $a''(1) > 0$. This resource cost is measured in units of physical capital. W_{it} is the nominal wage paid to labor of type i, B_t is the stock of nominal bonds that the household enters the period with. Π_t denotes the distributed dividends from firms. T_t is a lump sum transfer from the government. $S\left(\frac{I_t}{I_{t-1}}\right)$ is an investment adjustment cost, satisfying $S(.) = 0$, $S'(.) = 0$, and $S''(.) > 0$, δ is the depreciation rate and ϑ_t is a stochastic MEI shock.

The intertemporal preference shock, b_t, follows the AR(1) process :

$$\ln b_t = \rho_b \ln b_{t-1} + \varepsilon_t^b, \tag{3.19}$$

where ε_t^b is an i.i.d. $N(0, \sigma_b^2)$ preference shock. The MEI shock, ϑ_t, follows the AR(1) process :

$$\ln \vartheta_t = \rho_I \ln \vartheta_{t-1} + \varepsilon_t^I, \quad 0 \leq \rho_I < 1, \tag{3.20}$$

where ε_t^I is an i.i.d. $N(0, \sigma_{\varepsilon^I}^2)$ MEI shock.

3.2.4 Employment Agencies

A large number of competitive employment agencies combine differentiated labor skills into a homogeneous labor input sold to intermediate firms, according to :

$$L_t = \left(\int_0^1 L_{it}^{\frac{1}{1+\lambda_{w,t}}} di\right)^{1+\lambda_{w,t}}, \tag{3.21}$$

where $\lambda_{w,t}$ is the stochastic desired markup of wage over the household's marginal rate of substitution. The desired wage markup follows an ARMA(1,1) process :

$$\lambda_{w,t} = (1 - \rho_w)\lambda_w + \rho_w \lambda_{w,t-1} + \varepsilon_w - \theta_w \varepsilon_{w,t-1}, \tag{3.22}$$

where λ_w is the steady-state wage markup and ε_w is an *i.i.d.* $N(0, \sigma_w^2)$ wage-markup shock.

Profit maximization by the perfectly competitive employment agences implies the following labor demand function :

$$L_{it} = \left(\frac{W_{it}}{W_t}\right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} L_t, \tag{3.23}$$

where W_{it} is the wage paid to labor of type i and W_t is the aggregate wage index :

$$W_t = \left(\int_0^1 W_{it}^{-\frac{1}{\lambda_{w,t}}} di\right)^{-\lambda_{w,t}}. \tag{3.24}$$

3.2.5 Wage setting

Households set wages in a staggered fashion. Each period, a household can reoptimize its wage with probability $1-\xi_w$. Households not allowed to reoptimize their wages index to lagged and/or steady-state inflation. The wage-setting rule is then given by :

$$W_{it} = \begin{cases} W_{it}^* & \text{with probability } 1-\xi_w \\ W_{i,t-1}\left(\pi e^{\frac{1}{(1-\alpha)(1-\phi)}g_z + \frac{\alpha}{(1-\alpha)}g_v}\right)^{1-\iota_w}\left(\pi_{t-1} e^{\frac{1}{(1-\alpha)(1-\phi)}z_{t-1} + \frac{\alpha}{(1-\alpha)}v_{t-1}^I}\right)^{\iota_w} & \text{with probability } \xi_w, \end{cases} \tag{3.25}$$

where W_{it}^* is the reset wage. When allowed to reoptimize its wage, the household chooses the nominal wage that maximizes the present discounted value of flow utility flow (3.16) subject to demand schedule (3.23). From the first-order condition, we the have the following optimal wage rule :

$$E_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \frac{\lambda_{t+s}^r L_{it+s}}{\lambda_{w,t+s}} \left[w_t^* \frac{\Pi_{t,t+s}^w}{\pi_{t+1,t+s}} - (1+\lambda_{w,t+s}) \frac{\eta \varepsilon_{t+s}^h L_{it+s}^{\chi}}{\lambda_{t+s}^r}\right] = 0, \tag{3.26}$$

where ξ_w^s is the probability that a wage chosen in period t will still be in effect in period $t+s$, $\Pi_{t,t+s}^w = \Pi_{k=1}^s \left(\pi e^{\frac{1}{(1-\alpha)(1-\phi)}g_z + \frac{\alpha}{(1-\alpha)}g_v}\right)^{1-\iota_w}\left(\pi_{t+k-1} e^{\frac{1}{(1-\alpha)(1-\phi)}z_{t-k+1} + \frac{\alpha}{(1-\alpha)}v_{t-k+1}^I}\right)^{\iota_w}$ is the cumulative wage indexation between t and $t+s-1$, and ι_w is the degree of wage indexing to past inflation. Given our assumption on preferences and wage-setting, all updating households will choose the same optimal reset wage, denoted in real terms by $w_t^* = \frac{W_{it}}{P_t}$.

3.2.6 Monetary and Fiscal Policy

Monetary policy is set according to a Taylor rule wherein the Fed smooths variations in the nominal interest and responds to deviations of inflation (π_t) from steady state inflation (π) and to deviations of growth rate of GDP ($\widehat{Y}_t/\widehat{Y}_{t-1}$) from trend growth ($g_{\widehat{Y}}$):

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi} \left(\frac{\widehat{Y}_t}{\widehat{Y}_{t-1}} g_{\widehat{Y}}^{-1}\right)^{\alpha_{\Delta\widehat{y}}}\right]^{1-\rho_R} \varepsilon_t^r, \tag{3.27}$$

where R is the steady-state nominal interest rate, ρ_R is the interest-rate smoo-ting parameter, α_π and $\alpha_{\Delta\widehat{y}}$ are control parameters, and ε_t^r is an i.i.d. $N(0, \sigma_r^2)$ monetary policy shock.

Fiscal policy is fully Ricardian. The government finances its budget deficit by issuing short-term bonds. Public spending is a time-varying fraction of final output, Y_t :

$$G_t = \left(1 - \frac{1}{g_t}\right) Y_t, \tag{3.28}$$

where g_t is the government spending shock that follows the AR(1) process :

$$\ln g_t = (1 - \rho_g)\ln g + \rho_g \ln g_{t-1} + \varepsilon_{g,t}. \tag{3.29}$$

where g is the steady-state level of government spending and $\varepsilon_{g,t}$ is an i.i.d. $N(0, \sigma_v^2)$ government spending shock.

3.2.7 Market-Clearing and Equilibrium

Market-clearing for capital services, labor, and intermediate inputs requires that $\int_0^1 \widehat{K}_{jt}dj = \widehat{K}_t$, $\int_0^1 L_{jt}dj = L_t$, and $\int_0^1 \Gamma_{jt}dj = \Gamma_t$.

Gross output can be written as :

$$X_t = A_t\Gamma_t^{\phi}\left(K_t^{\alpha}L_t^{1-\alpha}\right)^{1-\phi} - \Upsilon_t F. \tag{3.30}$$

Value added, Y_t, is related to gross output, X_t, by

$$Y_t = X_t - \Gamma_t, \tag{3.31}$$

where Γ_t denotes total intermediates. Real GDP is given by

$$\widehat{Y}_t = C_t + \frac{I_t}{V_t^I} + G_t. \tag{3.32}$$

The resource constraint of the economy is :

$$\frac{1}{g_t}Y_t = C_t + \frac{I_t}{V_t^I} + \frac{a(u_t)K_t}{V_t^I} \tag{3.33}$$

3.2.8 Log-Linearization

Economic growth in our model stems from neutral and investment-specific technological change. Therefore, output, consumption, intermediates and the real wage all inherit trend growth $g_{\Upsilon,t} \equiv \frac{\Upsilon_t}{\Upsilon_{t-1}}$. In turn, the capital stock and investment grow at the rate $g_I = g_K = g_{\Upsilon,t}g_{v,t}$. Solving the model requires detrending variables, which is done by removing the joint stochastic trend, $\Upsilon_t = A_t^{\frac{1}{(1-\phi)(1-\alpha)}} V_t^{I\,\frac{\alpha}{1-\alpha}}$, and taking a log-linear approximation of the stationnary model around the non-stochastic steady state. The full set of equilibrium conditions can be found in the Appendix .

3.3 Model Estimation

This section begins with a description of the data and econometric procedure used for the estimation of our benchmark and standard models. Then we explain the reasons behind our specification of the Taylor rule. Next, we compare estimates of shock and non-shock parameters from the two models. Finally, we assess the empirical fit of both models.

3.3.1 Data and Estimation Procedure

We use Bayesian methods to characterize the posterior distribution of the structural parameters. The posterior distribution combines the likelihood function with prior information. The likelihood is based on eight observable variables. They are real per capita GDP growth, real per capita consumption growth, real per capita investment growth, real wage growth, the per capita log of hours worked, the inflation rate, the federal funds rate, and the change in the relative price of investment. The data are quarterly and span the period from 1960 :Q1 to 2008 :Q4. Consumption is measured by the sum of consumer expenditures on non-durables and services. Investment is the sum of expenditures on consumer durables and private domestic investment. Wages are defined as the compensation per hour in the non-farm business sector. Inflation is measured by the log-difference of the consumption deflator (e.g. see JPT, 2010; 2011). The relative price of investment is the ratio of the implied investment deflator to the consumption deflator.

The observables are expressed in percentages and are linked to variables in the model by the following measurement equations :

$$\begin{bmatrix} GDPgrowth \\ Consumptiongrowth \\ Investmentgrowth \\ Realwagegrowth \\ hoursworked \\ Inflation \\ Federalfundsrate \\ Relativepriceofinvestmentgrowth \end{bmatrix} = \begin{bmatrix} \widehat{gdp}_t - \widehat{gdp}_{t-1} + \widehat{g}_{\Upsilon,t} \\ \widehat{c}_t - \widehat{c}_{t-1} + \widehat{g}_{\Upsilon,t} \\ \widehat{i}_t - \widehat{i}_{t-1} + \widehat{g}_{\Upsilon,t} \\ \widehat{w}_t - \widehat{w}_{t-1} + \widehat{g}_{\Upsilon,t} \\ \widehat{L}_t \\ \widehat{\pi}_t \\ \widehat{R}_t \\ -\widehat{v}_t^I \end{bmatrix} + \begin{bmatrix} \overline{g}_\Upsilon \\ \overline{g}_\Upsilon \\ \overline{g}_\Upsilon \\ \overline{g}_\Upsilon \\ \overline{\pi} \\ \overline{g}_\Upsilon \\ \overline{R} \\ \overline{g}_v \end{bmatrix} \tag{3.34}$$

where $gdp_t = \frac{GDP_t}{\Upsilon_t}$, $c_t = \frac{C_t}{\Upsilon_t}$, $i_t = \frac{I_t}{\Upsilon_t}$ and $w_t = \frac{W_t}{\Upsilon_t}$. The parameters $\overline{g}_\Upsilon$, $\overline{L}$, $\overline{\pi}$, $\overline{R}$ and $\overline{g}_v$ are related to the model's steady state as follow : $\overline{g}_\Upsilon = 100 \log g_\Upsilon$, $\overline{L} = 100 \log L$, $\overline{\pi} = 100 \log \pi$, $\overline{R} = 100 \log R$ and $\overline{g}_v = 100 \log g_v$. The symbol ^ over a variable denotes that it is measured as a log-deviation from steady state.

3.3.2 Calibrated Parameters and Prior Distributions of Parameters

We calibrate some parameters. We assign them values commonly used in the literature. The depreciation rate of capital is set at $\delta = 0.025$, implying an annualized rate of depreciation of 10 percent. The steady-state ratio of government spending to GDP is set at 0.21, corresponding to the average ratio of government spending to GDP in the data. The elasticities of substitution between differentiated goods and skills, θ and σ, are both set at 10, which is fairly common in the literature.

Priors for the other parameters can be found in Table 3.1 and 3.2. The prior distributions are the same in the benchmark and standard models. These priors are in line with those of JPT (2011). The benchmark model has four more parameters relative to the standard model. They are the share of intermediate inputs in gross output, ϕ, and the cost percentage financed through working capital by type of factor, ψ_Γ, ψ_K, and ψ_L. We use a Beta prior for each of these parameters with mean 0.5 and standard deviation 0.1.

3.3.3 The Taylor Rule

We estimate first the benchmark model using a Taylor rule embedding a systematic response of the nominal interest rate to deviations of inflation from steady state and deviations of the level and growth rate of output from their values at flexible wages and prices (Smets and Wouters 2007, JPT, 2010, 2011). We are unable to obtain a unique rational expectations equilibrium, preventing a direct comparison between our benchmark model and other estimated New Keynesian models that have used a mixed output growth/output gap rule.

The failure of our benchmark model to achieve determinacy with a mixed rule seems broadly consistent with the analysis in Christiano, Trabandt, and Walentin (2011). Christiano et al. argue that adding production networking and working capital to an otherwise standard sticky-price model without capital accummulation can lead to indeterminacy with the central bank strictly adhering to the Taylor principle. This will happen if the working capital channel is strong enough and the share of materials in gross output is high enough. To prove their point, Christiano et al. assume a Taylor rule admitting a reaction to inflation and the output gap. However, whether combining working capital and production networking actually overturn the wisdom of implementing the Taylor principle remains an open question. Evidence from our benchmark model with a mixed Taylor rule supports this conclusion.

The absence of a consensus about the specification of the Taylor rule leads us to reestimate our benchmark model with a different policy rule. We retain an inertial Taylor rule incorporating a systematic response of the nominal interest to deviations of inflation and output growth from steady state. Erceg and Levin (2003) argue that this rule better fits the data. (McCallum, 2001 ; Orphanides and Williams, 2006 ; Orphanides and Van Norden, 2002) support this specification on the grounds that output growth is easier to observe than the output gap. Coibion and Gorod- nichenko (2010) argue that a Taylor rule with a response to the output gap does not accurately describe how the Fed has set nominal interest rates since the chairmanship of Paul Volcker. They endorse a specification with output growth, arguing that the distinction between the output gap and output growth is important for the timing of interest rate decisions since the output gap evolves slowly while the growth rate of GDP changes more rapidly. Working from a New Keynesian model with positive trend inflation, Coibion and Gorodnichenko (2011) find that a Taylor rule reacting to the output gap represents a greater threat to determinacy than one reacting to output growth. Finally, Sims (2013) shows that output growth ought to be preferred to the output gap based on welfare considerations.

These considerations lead us to estimate the benchmark and standard models with an inertial Taylor rule reacting to deviations of inflation and output growth from steady state. As the remainder of the section makes clear, we are then able to achieve determinacy of the equilibrium in both models, allowing a direct comparison between the two.

3.3.4 Posterior Distributions of Parameters

Table 3.3 and 3.4 presents the posterior mean of non-shock (Panel A) and shock parameters (Panel B) estimated from our benchmark and standard models along with their 90 percent confidence intervals. The estimates from the standard model are broadly consistent with those reported by Smets and Wouters (2007) and JPT (2010, 2011).

Among the parameters of interest are the share of intermediate inputs in gross output, ϕ, and the cost percentage of factors financed by working capital, ψ_Γ, ψ_K, and ψ_L. The point estimate of the share of intermediate goods in gross output is 0.56, with a confidence interval ranging from 0.45 to 0.67. This estimate supports a network view of the production process. Interestingly, it is in the range of values assigned to this parameter in the literature (e.g.see Basu, 1995; Huang, Liu, and Phaneuf, 2004; Dotsey and King, 2006; Christiano, Trabandt, and Walentin, 2011)..

The point estimates of the share of factor payments financed by working capital are $\psi_K = 0.5, \psi_\Gamma = 0.49$ and $\psi_L = 0.43$. Hence, firms make an extended use of working capital to finance a significant fraction of payments to intermediate inputs, capital services and labor. This contrasts with the assumption usually made that firms borrow funds from financial intermediaries to pay the wage bill before the proceeds from the sale of output are received.

In the standard model, the point estimates of ξ_p and ξ_w are 0.72. In the benchmark model, they respectively are 0.725 and 0.56. Therefore, the benchmark model is characterized by greater nominal wage flexibility relative to the standard model. Another significant difference in the estimates from the two models pertains to the standard deviation of the neutral technology shock which is 0.404 in the benchmark model compared to 0.756 in the standard model, a reduction of 47 percent in the size of the neutral technology shock. Meanwhile, the estimated AR(1) parameter of the stochastic process generating the growth rate of z_t is almost the same in both models. In JPT (2011), the estimated standard deviation of the neutral technology shock is 0.943.

Increased nominal wage flexibility in the benchmark model is the consequence of production networks, for if we remove firms networking and reestimate the model with working capital only, the estimates of ξ_p and ξ_w are 0.74 and 0.72, with a standard deviation of the neutral technology shock of 0.755.

Following the intuition in (e.g. see Basu, 1995), the interaction between sticky prices and firms networking acts as a "multiplier for price stickiness", resulting from strategic complementarity in price setting. The benchmark model is then able to fit the data with less nominal wage rigidity. Yet, another effect of production networks is to amplify the effects of neutral technology shocks on output. The neutral technology shock affects output directly via the production function, and indirectly through its effect on intermediate inputs, so the benchmark model can generate sizeable aggregate fluctuations with much smaller neutral technology shocks.

Another notable difference between the estimates from our benchmark and standard models pertains to the parameter governing the response of the nominal interest rate in the Taylor rule to the deviation of inflation from steady state. In the standard model, the point estimate of α_π is 1.39, while in the benchmark model it is 1.58. Meanwhile, the estimates of $\rho_I, \alpha_{\Delta y}$ and σ_r are nearly the same in both models. These estimates hence suggest that monetary policy is less accommodative in our benchmark model, a point to which we return later when we discuss how consumption responds to a MEI shock.

3.4 Results

This section compares the results from our estimated benchmark and standard models. First, we compare the fit of the two models. Second, we look at some basic business cycle moments in the data and those implied by the two models. Third, we compare the impulse responses of key macroeconomic variables to monetary policy, neutral technology, MEI and wage-markup shocks from both models. Fourth, we ask whether our estimated models are prone to the comovement problem by looking at the theoretical unconditional cross-correlograms of consumption growth, investment growth, output growth and hours and those in the data. Fifth, we look at the actual correlations between inflation, interest rates, consumption growth, output growth, investment growth and hours and those implied by the two models.

3.4.1 Comparing the Fit of the Benchmark and Standard Models

We assess the relative fit of the estimated benchmark and standard models by computing the Bayes factor, $BF_{B,S}$, given by :

$$BF_{B,S} = \frac{p(Y_T|M_B)}{p(Y_T|M_S)}, \tag{3.35}$$

where $p(Y_T|M_B)$ and $p(Y_T|M_S)$ are the marginal densities of the benchmark model, M_B, and the standard model, M_S, evaluated at the sample of observations, Y_T.[2] The resulting log marginal densities are log $p(Y_T|M_B) = -1431.26$ and log $p(Y_T|M_S) = -1447.75$. Kass and Raftery (1995) propose that a value of 2 log $\text{BF}_{1,2}$ exceeding 10 strongly speaks in favour of model 1 over model 2. The value of 2 log $\text{BF}_{B,S}$ is 33. Based on this criterion, the benchmark model is thus stron-

2. The log marginal densities are approximated using harmonic mean along the lines of Geweke (1999).

gly preferred to the standard model in direct proportion to the degree to which it predicts the observed data.

We also perform an identifiability test proposed by Iskrev (2010). This test allows identification of DSGE models by testing the rank of the Jacobian matrix J of the mapping from Θ to m_T, Θ being the vector of parameters of interest and m_T being a vector collecting the parameters that determine the first two moments in the data. Based on this test, we find that the parameters of the benchmark and standard models are well identified.

3.4.2 Business Cycle Moments

Table 3.5 reports business cycle moments in the data and those implied by our estimated benchmark and standard models. Panel A reports the standard deviations of the eight variables used in the estimation and their first-order autocorrelations. Panel B presents the relative volatilities of output growth along with the contemporaneous correlations between output growth and the other seven variables.

Both models somewhat overestimate the volatilities of output growth, consumption growth, investment growth and hours, something which is common to other multi-shock New Keynesian models (e.g. see JPT, 2010, 2011). They generate positive autocorrelations for all variables, accounting particularly well for the high autocorrelations of hours, inflation and the nominal interest rate.

The benchmark model provides a relatively close account of the relative volatilities of output growth. It does reasonably well accounting for contemporaneous correlations between output growth and other variables. In particular, it implies unconditional contemporaneous correlations between output growth and consumption growth and between output growth and investment growth which are very close to the data, the later significantly exceeding the former as in the data. Real wage growth is weakly procyclical unconditionally both in the models and in the data. The benchmark model, unlike the standard model, accounts for the negative comovements of inflation and output growth and the nominal interest rate and output growth. Both models, however, correctly predict that the comovement between output growth and the relative price of investment is negative.

3.4.3 Impulse Responses

Figures 1-3 offer a different perspective on the comparability of the posterior estimates of our benchmark and standard models based on impulse responses of selected variables to the following four types of shocks : monetary policy, neutral technology, wage markup and MEI.[3] When looking at these figures, what immediately strikes the eye is that production networking and extended working capital significantly alter several impulse responses.

Figure 3.1 displays the responses of key variables to a one-percent negative shock to the nominal interest rate. Production networking and working capital significantly affect the responses of inflation, the price markup and real marginal cost. The standard model does not deliver a hump-shaped response of inflation. The price markup falls and the real marginal cost rises on impact of the policy shock. By contrast, the benchmark model produces a hump-shaped response of inflation, as well as a positive response of the price markup and a negative response of real marginal cost on impact of the policy shock. Evidence in Nekarda and Ramey (2013) suggests that a negative shock to the nominal interest generates an increase in the price markup.

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3. We do not report the impulse responses to government spending, investment-specific, price markup and preference shocks because they do not drive any of our main results.

Phaneuf, Sims, and Victor (2015) offer a detailed analysis of the reasons why firms networking and extended working capital can generate a hump-shaped response of inflation and a mildly procyclical price markup conditioned on a monetary policy shock. Firms networking induces strategic complementarity into price setting, and is thus isomorphic to prices being stickier. Inflation is less sensitive to changes in real marginal cost by a factor of proportionality reflecting the share of intermediate inputs in production. The inflation response is then smaller and more persistent. Extended working capital helps obtaining a hump-shaped response of inflation. Because of working capital, the nominal interest rate has a direct effect on marginal cost. With a falling interest rate, the marginal cost drops initially with working capital, generating a rise of the price markup on impact the shock.

The impulse responses to a neutral technology shock are displayed in Figure 3.2. The increases of output, consumption and investment following a positive neutral technology shock are stronger in the benchmark model, although the standard deviation of the neutral technology shock is nearly two times smaller than in the standard model. Note also that the wage markup and the labor wedge, that both react positively on impact of a TFP shock in the standard model, respond negatively on impact of this shock in the benchmark model.

Figure 3.3 shows that the responses of output, consumption, investment and hours to a positive wage markup shock are positive in the standard model. The benchmark model implies opposite signs in the responses of these variables. Smets and Wouters (2007, Figure 3) also report negative responses of output and hours and positive responses of inflation and the interest rate to a positive wage markup shock. Two factors are mainly responsible for the flip in the signs of the responses of output, consumption, investment and hours in the benchmark model : the smaller estimates of ξ_w and θ_w, the MA parameter of the wage markup shock generating process. If in the benchmark model we assume that $\xi_w = 0.72$ and

$\theta_w = 0.99$, as in the standard model, we find that the signs of the responses flip to positive.

A positive MEI shock in Figure 3.4 has a strong impact on investment, with a peak response of investment which is nearly two times larger than that of a TFP shock. However, the increases in output, consumption, investment and hours are smaller following a MEI shock in the benchmark model. At first sight, this could seem seem surprising since firms networking should amplify the effects of shocks by flattening the slope of the New Keynesian Phillips Curve. While this is indeed the case in our benchmark model, we also find that nominal wages are significantly more flexible in the benchmark model ($\xi_w = 0.557$ vs 0.72 in the standard model).

The increased flexibility of nominal wages in the benchmark model accounts for the smaller effects of a MEI shock on output, consumption, investment and hours. With more flexible nominal wages, the real wage actually grows faster following a positive MEI shock. As a result, hours increase less, and also output, consumption and investment. Figure 3.5 supports this claim. We display the responses of output, consumption, investment and hours to a MEI shock in three alternative models : the standard model, the benchmark model, and a version of the benchmark model with a Calvo probability of wage non-reoptimization of 0.72 as estimated in the standard model. The lower estimate of ξ_w in the benchmark model makes up for much of the difference between the impulse responses in the two models.

To briefly summarize the results reported in this subsection, we have shown that production networks and an extended working capital channel significantly alter several impulse responses of key macroeconomic variables to monetary policy, neutral technology, MEI and wage-markup shocks.

3.4.4 The Comovement Problem

Figure 3.6 presents the cross-correlograms of the variables used in the estimation, and compares the cross-correlations at lags and leads found in the data with the unconditional cross-correlations implied by the benchmark and standard models. Here, we look at the so-called comovement problem. For this, we compare the contemporaneous and cross-correlations between the growth rates of output, consumption and investment, and the level of hours.

The unconditional contemporaneous correlation and cross-correlations at lags and leads between output growth and consumption growth implied by the benchmark and standard models are very close to the data. The benchmark model predicts that the unconditional contemporaneous comovement of consumption growth and investment growth, and that of consumption growth and hours are both positive and consistent with the data. Furthermore, the signs and profiles of the unconditional cross-correlations implied by the benchmark model are broadly consistent with the data. The standard model does relatively well along these dimensions, but the benchmark model provides a somewhat bettter account of the cross-correlations between consumption growth and hours. In JPT (2011, Figure 3), the unconditional contemporaneous correlation and cross-correlations between consumption growth and investment growth are at odd with the data. Specifically, the contemporaneous correlation between consumption growth and investment growth is negative, while the cross-correlations are positive and increasing at lags and consistently negative at leads.

These findings can be interpreted in light of the analysis in Barro and King (1984). These authors argue that non-TFP shocks, like an investment shock, will not be able to generate business cycle comovements of output, consumption, investment, and hours that are consistent with the data. Consider for example how variables respond to an investment shock in the standard neoclassical framework. A positive shock to the marginal productivity of investment increases the rate of return on capital, giving households the incentive to save (invest) more in the present and postpone consumption for the future. Consumption hence falls after the shock. In turn, lower consumption increases the marginal utility of income, shifting labor supply to the right along a fixed labor demand schedule. Hours and output rise, while the real wage and labor productivity fall. As a result, the investment shock generates an investment boom accompanied by a short-run fall in consumption. Insofar as the key disturbance driving business cycle fluctuations is an investment shock, the unconditional correlation between consumption and investment will be negative. The model will also imply anomalous comovements between consumption and hours.

Macroeconomic models built from microeconomic foundations and including nominal rigidities and other sources of real inertia need not automatically imply counterfactual comovements of consumption and other aggregate variables conditional on non-productivity shocks. That said, since the core of such models is the neoclassical benchmark, the intuition provided by Barro and King is potentially still valid. As it happens, existing medium-scale New Keynesian models which identify MEI shocks as the key source of business cycles have been prone to these anomalies. This is not the case of our benchmark and standard models. We return to key reasons why below.

3.4.5 Inflation, Interest Rates and Markups

Another dimension, overlooked so far in the literature, along which medium-scale New Keynesian models encounter some difficulties, is their inability to account for the correlations between inflation, the nominal interest rate and variables such as output growth, consumption growth, investment growth and the level of hours. The contemporaneous correlations and cross-correlations at lags and leads between inflation (the nominal interest rate) and output growth, consumption growth, investment growth and the level of hours are all negative in the data. The benchmark model does significantly better than the standard model accounting for the contemporaneous correlations and cross-correlations between these variables.

Note in particular that the benchmark model produces negative unconditional contemporaneous correlations between inflation, consumption growth and output growth. It also implies negative unconditional cross-correlations between inflation and consumption growth at lags and leads consistent with the data. In comparison, JPT (2011, Figure 3) report positive unconditional contemporaneous correlations between inflation, consumption growth and output growth. Moreover, the unconditional cross-correlations at lags and leads between inflation and consumption growth are positive instead of negative.

We have previously seen that the response of price markup is positive on impact of a monetary policy shock in our benchmark model. Table 3.6 reports the unconditional contemporaneous correlations between first-differenced output and the first-difference of the price markup, the wage markup and the labor wedge from our estimated benchmark and standard models. The price markup, the wage markup and the labor are all countercyclical unconditionally, the price markup being somewhat more countercyclical and the wage markup less countercyclical in the benchmark model.

3.4.6 Consumption Response to a MEI Shock

We identify the reasons why the standard and benchmark models are not affected by anomalous comovements between consumption growth and other variables including investment growth and inflation. The key factor is the positive response of consumption following a positive MEI shock. In JPT (2011, Figure 1), the response of consumption is negative following a positive MEI shock.

The mechanisms which generate a positive response of consumption are very different in the two models. Our standard model is very similar to that estimated by JPT, except for the Taylor rule. In JPT, the parameter governing the reaction of interest rates to deviations of inflation from steady state is 1.7 (JPT, 2011, Table 1). In comparison, in our standard model this parameter is 1.39. So, the central bank responds more agressively to inflation if the Taylor rule includes both the output gap and output growth. Furthermore, while in JPT the point estimate of the parameter determining the response of interest rates to the output gap is 0.05, a positive MEI shock generates a positive response of the output gap which is large and highly persistent.[4] Therefore, monetary policy is significantly more accommodative in our standard model, which explains why the response of consumption is positive following a positive MEI shock.

Our benchmark model also is not affected by the comovement problem. However, in this case the mechanism leading to a positive response of consumption to a positive MEI shock is very different. As we have seen earlier, nominal wages are much more flexible in the benchmark model. Greater nominal wage flexibility reduces the positive response of consumption to a MEI shock. Furthermore, in the benchmark model the interest rate response to inflation is stronger (1.58 vs 1.39),

4. This is based on our computation of the response of the output gap to a positive MEI shock using the JPT model.

meaning that monetary policy is less accommodative. In spite of this, the response of consumption to a MEI shock implied by the benchmark model is positive since the income effect induced by the interaction between production networking and economic growth is sufficiently strong to overturn the negative substitution effect of the shock on consumption.

Figure 3.7 displays the response of consumption to a MEI shock in four different models : *i*) the JPT (2011) model, *ii*) our standard model, *iii*) our benchmark model and *iv*) a modified version of the benchmark model with $\xi_w = 0.72$. In JPT's model, consumption falls for more than a year following a positive MEI shock, which leads to the anomalous business cycle comovements involving consumption growth and other variables we have described before. In the standard and benchmark models, consumption rises following a positive MEI shock. But the increase is stronger in the standard model. The response of consumption generated by the modified benchmark model confirms that with a Calvo probability of wage non-reoptimization that would be the same as in the standard model, the benchmark model would deliver a response of consumption that would exceed that in the standard model.

3.5 Sources of Business Cycles

This section provides a quantitative evaluation of the sources of business cycle fluctuations based on our estimated benchmark and standard models. We also report estimation results from a modified version of our benchmark model that includes unanticipated and news shocks.

3.5.1 Unanticipated Shocks Only

Table 3.7 reports the variance decomposition of forecast errors at business cycle frequencies for the benchmark model (Panel A) and standard model (Panel B). We have also computed the unconditional variance decomposition for both models, which we do not report for the sake of brevity.

In the benchmark model, the forecast errors at business cycle frequencies of output, investment, hours, inflation and interest rates due to the MEI shock are 49 percent, 69 percent, 53 percent, 47 percent and 57 percent, respectively. These percentages are generally higher for the standard model. For example, the MEI shock explains 65 percent of the cyclical variance of output, consistent with the evidence of JPT (2011). As explained earlier, the lower contribution of the MEI shock for the benchmark model is mainly the consequence of increased nominal wage flexibility and its downsizing effects on the response of output, investment and hours. The unconditional variance decomposition leads to a similar conclusion, with the exception that the wage markup shock explains 63 percent of the variance of hours in the benchmark model compared to 27 percent in the standard model. Therefore, the wage markup shock in our benchmark model is a leading source of fluctuations only for hours and at very low frequencies.

How do our results compare to those of others ? Smets and Wouters (2007) report that the neutral technology shock accounts for 32 percent of the variance of output growth at the horizon of 10 quarters, this percentage decreasing as the horizon extends beyond 10 quarters. The wage markup shock explains 21, 38 and 51 percent of the variance of output, hours and inflation, respectively, at an horizon of 10 quarters. These numbers increase to 48, 67 and 58 percent, respectively, based on the unconditional variance decomposition. Meanwhile, the investment shock accounts for respectively 19, 19 and 4 percent of the variance of output, hours and inflation at the horizon of 10 quarters, all three percentages decreasing as the horizon exceeds 10 quarters.

Justiniano and Primiceri (2008) estimate a New Keynesian model allowing for time variation in the volatility of structural innovations. They find that the investment shock accounts for about half of the variance of GDP growth. JPT (2010) report a similar finding using a time-invariant DSGE model similar to that of Smets and Wouters, but with a different measurement for some of the observables.

Chari, Kehoe, and McGrattan (2009) dispute the key role played by wage markup shocks on the grounds that they are dubiously structural, being subject to alternative interpretations and not invariant with respect to policy. On the other hand, Schmitt-Grohé and Uribe (2012) dispute the prominent role assigned to unanticipated investment shocks on the grounds that Justiniano and Primiceri (2008) omit the relative price of investment as an observable. They report evidence suggesting that unanticipated investment shocks account for no more than 21 percent of the unconditional variance of output and only 3 percent of the variance of hours.

Our results are closer to those reported by JPT (2011). However, there is one important difference between our results and theirs. They identify the price markup shock at 39 percent and the neutral technology shock at 37 percent as the two main sources of inflation volatility, the MEI shock explaining only 10 percent. By contrast, both our benchmark and standard models imply that the MEI shock is the main source of inflation volatility, explaining about 47 percent of its variance. Our different treatment of the Taylor rule explains the higher contribution of the MEI shock to the variance of inflation in the standard model.

3.5.2 Unanticipated and News Shocks

Now, a legitimate question is whether we have been able to successfully identify the main sources of business cycle fluctuations by restricting disturbances to unanticipated shocks only? In other words, are our main results affected if news shocks are added to our benchmark model? We follow Schmitt-Grohé and Uribe (2012) and estimate a version of our benchmark model that includes both unanticipated and news shocks. The news components are driven by innovations announced four and eight quarters in advance. Interestingly, we find that accounting for news shocks has a relatively negligible impact on the estimates of the structural parameters of the model. We still find empirical support for the network view of the production process and an extended use of working capital by firms. Futhermore, the unconditional contemporaneous and cross-correlations between key variables are essentially unaffected by adding news shocks to the benchmark model.

The benchmark model is preferred to the model with news on the basis of the Bayes factor $\text{BF}_{BU,BN}$, which denotes the ratio of the marginal likelihood of the benchmark model to that of the model with news. The estimated models imply an estimate of $2 \log \text{BF}_{BU,BN} = 22$, suggesting that the benchmark model is strongly preferred by the data to the model with news. The benchmark model with news, however, is preferred to the standard model since $2 \log \text{BF}_{BN,S} = 11$.

Table 3.8 reports the variance decomposition of forecast errors at business cycle frequencies for the benchmark model with news. Panel A of the table reports the contribution of unanticipated shocks, while Panel B reports that of news shocks. Two main observations can be made from this table. First, adding news shocks to the benchmark model does not affect our reading of the main sources of business cycle fluctuations, with unanticipated MEI shocks contributing to a higher fraction of the variance of output (54 percent), investment (77 percent) and hours (56 percent). The MEI shock is also the main shock driving the variances of inflation and interest rates, although its contribution is somewhat smaller in the model with news shocks.

A second observation is that news shocks account in total for a fairly modest percentage of business cycle fluctuations. Except for consumption and the relative price of investment with 32 and 23 percent, respectively, the cumulative percentages of news shocks on other variables such as output, investment, wage growth, hours, inflation and interest rates are under 20 percent. Furthermore, no single news shock stands out as a key driver of aggregate fluctuations.

How do our results compare to those of others? Schmitt-Grohé and Uribe (2012) dispute the fact that unanticipated investment shocks are the leading source of business cycle fluctuations. Instead, they convey evidence suggesting that news shocks explain 41 percent of the unconditional variance of output growth, 52 percent of the variance of consumption growth, 31 percent of the variation in investment, and 67 percent of the unconditional variance of hours. In the last case, they estimate that four-quarter anticipated markup shocks explain 62 percent of the variance of hours. Chari, Kehoe, and McGrattan (2009) have also reported that wage markup shocks explain a large fraction of the unconditional variance of hours (67 percent). A huge difference, however, is that almost the totality of movements in hours due to wage markup shocks in Schmitt-Grohé and Uribe is attributable to its anticipated component, not to its unanticipated component. Schmitt-Grohé and Uribe reach this conclusion through estimation of a DSGE model that includes non-standard preferences *à la* Jaimovich and Rebelo (2009), real frictions, and imperfect competition in labor markets. Nominal wages (and prices) are perfectly flexible.

Khan and Tsoukalas (2012) dispute these findings based on estimation of a multi-shock version of the model in Christiano, Eichenbaum, and Evans (2005). Their model abstracts from firms networking and working capital. Their evidence about the importance of news shocks for aggregate fluctuations is mixed. While they report that news shocks are the main driver of the unconditional variance of output, investment and interest rates, they find that the anticipated wage markup shock explains 60 percent of the variance of hours and inflation. When we look at unconditional variances from our estimated benchmark model with news, we find that the unanticipated MEI shock is the key shock accounting for the variance of output (45 percent), investment (74 percent), inflation (44 percent) and interest rates (56 percent). As Schmitt-Grohé and Khan and Tsoukalas, we also find that news shocks explain a substantial fraction of the variance of hours (about 60 percent), with the important difference however that the anticipated wage markup shock accounts for 29 percent of this variance and the anticipated MEI shock for 24 percent. Therefore, we do not find a case where news shocks play a significant role generating business cycle fluctuations.

3.6 Conclusion

There has been a resurgence of interest lately into the macroeconomic consequences of production networking in the terminology used recently by Christiano (2015). In this paper, we have brought production networking as well as a possible extended use of working capital by firms into an otherwise state-of-the-art medium-size New Keynesian model which we have estimated using a Bayesian procedure.

Evidence from this model strongly supports of a network view of the production process and the use by firms of working capital to finance a fraction between 40 and 50 percent of their outlays of intermediate inputs, capital services and labor, and this whether news shocks are taken into account or not in the estimation. Despite the use of standard preferences, a model incorporating these features better accounts for business cycle comovements between consumption, output, investment, hours, inflation and interest rates than previous DSGE models.

Unlike several claims in the literature to the contrary, we do not find evidence of a key role for wage markup shocks in accounting for aggregate fluctuations at business cycle frequencies. The bulk of business cycle fluctuations is here explained by shocks that are considered "structurally reliable" based on the Chari, Kehoe, and McGrattan (2009) criticism of medium-scale New Keynesian models.

Table 3.1 Prior densities : structural parameters.

Parameter	Description	Density	Mean	Std
α	Capital share	Normal	0.30	0.05
ι_p	Price indexation	Beta	0.50	0.15
ι_w	Wage indexation	Beta	0.50	0.15
g_y	SS technology growth rate	Beta	0.50	0.15
g_ν	IST growth rate	Beta	0.50	0.10
h	Consumption habit	Beta	0.50	0.10
$\log L$	SS hour	Beta	0.50	0.15
$100\,(\pi - 1)$	SS quarterly inflation	Beta	0.50	0.10
$100\,(\beta^{-1} - 1)$	Discount factor	Normal	0.00	0.50
χ	Inverse Frisch elasticity	Gamma	2.00	0.75
ξ_p	Calvo prices	Beta	0.66	0.10
ξ_w	Calvo wages	Beta	0.66	0.10
σ_a	Capital utilization costs	Gamma	5.00	0.10
κ	Investment adjustment costs	Gamma	4.00	1.00
ψ_K	Payment to capital	Beta	0.50	0.10
ψ_L	Payment to labor	Beta	0.50	0.10
ψ_Γ	Payment to interm. input	Beta	0.50	0.10
ϕ	Intermediate input share	Beta	0.50	0.10
α_π	Taylor rule inflation	Normal	1.70	0.30
$\alpha_{\Delta y}$	Taylor rule output growth	Norma	0.13	0.05
ρ_I	Taylor rule smooting	Beta	0.60	0.20

Table 3.2 Prior densities : shock parameters.

Parameter	Description	Density	Mean	Std
ρ_z	Neutral technology	Beta	0.40	0.20
ρ_g	Government spending	Beta	0.60	0.20
ρ_I	IST	Beta	0.20	0.10
ρ_p	Price markup	Beta	0.60	0.20
ρ_w	Wage markup	Beta	0.60	0.20
ρ_b	Preference	Beta	0.60	0.20
ρ_ϑ	MEI	Beta	0.60	0.20
θ_p	Price markup MA	Beta	0.50	0.20
θ_w	Wage markup MA	Beta	0.50	0.20
σ_r	Monetary policy	Inverse gamma	0.10	1.00
σ_z	Neutral technology	Inverse gamma	0.50	1.00
σ_g	Government spending	Inverse gamma	0.50	1.00
σ_I	IST	Inverse gamma	0.50	1.00
σ_p	Price markup	Inverse gamma	0.10	1.00
σ_w	Wage markup	Inverse gamma	0.10	1.00
σ_b	Preference	Inverse gamma	0.10	1.00
σ_ϑ	MEI	Inverse gamma	0.50	1.00

Table 3.3 Posterior estimates : structural parameters.

Parameter	Description	Benchmark			Standard		
		Mean	10th	90th	Mean	10th	90th
α	Capital share	0.165	0.155	0.175	0.148	0.139	0.157
ι_p	Price indexation	0.193	0.088	0.296	0.134	0.049	0.212
ι_w	Wage indexation	0.115	0.057	0.168	0.177	0.098	0.253
g_y	SS technology growth rate	0.386	0.347	0.426	0.389	0.350	0.428
g_ν	IST growth rate	0.227	0.188	0.266	0.227	0.188	0.266
h	Consumption habit	0.913	0.888	0.940	0.922	0.903	0.943
$\log L$	SS hour	0.060	-0.753	0.866	0.030	-0.784	0.831
$100\,(\pi - 1)$	SS quarterly inflation	0.718	0.597	0.841	0.684	0.550	0.813
$100\,(\beta^{-1} - 1)$	Discount factor	0.119	0.051	0.185	0.128	0.058	0.197
χ	Inverse Frisch elasticity	2.731	1.619	3.791	3.435	2.099	4.758
ξ_p	Calvo prices	0.725	0.688	0.764	0.722	0.684	0.760
ξ_w	Calvo wages	0.557	0.475	0.639	0.719	0.678	0.759
σ_a	Capital utilization costs	5.554	3.834	7.212	5.660	3.984	7.310
κ	Investment adjustment costs	2.997	1.957	3.990	2.926	1.928	3.902
ψ_K	Payment to capital	0.498	0.336	0.665	n/a	n/a	n/a
ψ_L	Payment to labor	0.426	0.263	0.585	n/a	n/a	n/a
ψ_Γ	Payment to interm. input	0.486	0.323	0.654	n/a	n/a	n/a
ϕ	Interm. input share	0.559	0.452	0.667	n/a	n/a	n/a
α_π	Taylor rule inflation	1.583	1.388	1.771	1.388	1.187	1.579
$\alpha_{\Delta y}$	Taylor rule output growth	0.244	0.171	0.319	0.245	0.169	0.317
ρ_I	Taylor rule smoothing	0.811	0.782	0.841	0.804	0.774	0.835

Table 3.4 Posterior estimates : shock parameters.

		Benchmark			Standard		
Parameter	Description	Mean	10th	90th	Mean	10th	90th
ρ_z	Neutral technology	0.321	0.216	0.425	0.311	0.210	0.411
ρ_g	Government spending	0.995	0.991	0.999	0.995	0.991	0.999
ρ_I	IST	0.284	0.179	0.395	0.301	0.188	0.414
ρ_p	Price markup	0.980	0.962	0.998	0.982	0.966	0.998
ρ_w	Wage markup	0.969	0.955	0.982	0.947	0.931	0.964
ρ_b	Preference	0.379	0.226	0.528	0.292	0.172	0.412
ρ_ϑ	MEI	0.878	0.829	0.927	0.912	0.875	0.953
θ_p	Price markup MA	0.759	0.664	0.861	0.672	0.551	0.795
θ_w	Wage markup MA	0.834	0.769	0.900	0.989	0.981	0.998
σ_r	Monetary policy	0.234	0.214	0.255	0.231	0.211	0.251
σ_z	Neutral technology	0.404	0.336	0.472	0.755	0.693	0.820
σ_g	Government spending	0.344	0.315	0.373	0.344	0.316	0.373
σ_I	IST	0.602	0.550	0.652	0.602	0.552	0.653
σ_p	Price markup	0.203	0.173	0.232	0.216	0.184	0.247
σ_w	Wage markup	0.262	0.229	0.294	0.338	0.307	0.369
σ_b	Preference	0.155	0.127	0.183	0.172	0.145	0.198
σ_ϑ	MEI	4.825	3.607	5.982	4.451	3.432	5.492

Table 3.5 Business cycle statistics.

Panel A

	Standard deviation			Autocorrelation		
Variable	Data	Benchmark	Standard	Data	Benchmark	Standard
Output growth	0.91	1.31	1.35	0.28	0.67	0.68
Consumption growth	0.48	0.66	0.59	0.32	0.63	0.53
Investment growth	3.36	5.32	5.67	0.23	0.71	0.75
Wage growth	4.07	6.75	7.63	0.13	0.54	0.35
Hours	0.65	0.91	0.81	0.98	0.99	0.98
Inflation	0.65	0.75	0.75	0.79	0.81	0.81
Interest rate	0.82	0.89	0.89	0.95	0.94	0.95
Relative price	0.59	0.62	0.63	0.19	0.28	0.30

Panel B

	Standard deviation relative to output			Correlation with output growth		
Variable	Data	Benchmark	Standard	Data	Benchmark	Standard
Consumption growth	0.53	0.50	0.44	0.57	0.52	0.45
Investment growth	3.72	4.06	4.20	0.88	0.88	0.91
Wage growth	4.49	5.15	5.65	0.05	0.13	0.16
Hours	0.72	0.70	0.60	0.16	0.47	0.33
Inflation	0.72	0.57	0.56	-0.33	-0.01	0.24
Interest rate	0.91	0.68	0.66	-0.21	-0.08	0.14
Relative price	0.65	0.48	0.47	-0.11	-0.05	-0.04

Note : The moments are generated using the parameter estimates for the benchmark and the standard models.

Moments in the data are computed for the sample 1960Q1-2008Q4.

Table 3.6 Cyclical markups and labor wedge

Model/Variable	Price markup	Wage markup	Labor wedge
Benchmark	-0.23	-0.67	-0.56
Standard	-0.17	-0.87	-0.82

Note : This table shows the correlation between output, price markup, wage markup and labor wedge measured in first difference for the benchmark and the standard models at the mean of the posterior distribution.

Table 3.7 Variance decomposition at business cycle frequencies (6-32).

Panel A : Benchmark

Variable/shock	MON	TFP	GOV	IST	PMU	WMU	PRF	MEI
Output growth	3.53	17.89	2.94	0.39	9.28	12.09	5.31	48.57
Consumption growth	0.50	21.96	1.03	0.08	1.78	12.51	60.99	1.14
Investment growth	3.59	9.91	0.04	0.59	8.94	7.19	0.49	69.26
Wage growth	1.42	42.31	0.01	0.01	33.45	20.60	0.91	1.30
Hours	3.35	9.56	1.82	0.20	8.56	20.13	3.26	53.11
Inflation	2.19	17.67	0.27	0.23	20.41	10.76	1.85	46.61
Interest rate	23.12	6.16	0.36	0.31	7.74	3.61	1.76	56.94
Relative price	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00

Panel B : Standard

Variable/shock	MON	TFP	GOV	IST	PMU	WMU	PRF	MEI
Output growth	3.78	14.93	3.08	0.45	5.36	2.21	5.25	64.95
Consumption growth	0.69	19.23	1.21	0.04	0.67	4.18	73.00	0.99
investment growth	3.67	8.88	0.02	0.61	5.33	1.23	0.11	80.16
Wage growth	0.02	53.00	0.01	0.05	19.98	26.03	0.03	0.88
Hours	3.82	8.66	1.80	0.29	6.45	4.36	3.27	71.35
Inflation	2.17	27.56	0.43	0.49	17.43	4.31	1.29	46.32
Interest rate	23.30	8.10	0.49	0.55	5.29	1.84	1.28	59.16
Relative price	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00

Note : This table shows the variance decomposition in percentage for the benchmark and the standard model at the mean of the posterior distribution. The shocks are MON : Monetary, TFP : Neutral technology, IST : Investment specific technology, PMU : price markup, PRF : preference, MEI : marginal efficiency of investment shock.

Table 3.8 Variance decomposition at business cycle frequencies (6-32) : benchmark model with news shocks.

Panel A :Non anticipated shocks.

Variable/shock	MON	TFP	GOV	IST	PMU	WMU	PRF	MEI	TOT
Output growth	3.27	15.65	1.31	0.32	3.88	5.21	3.01	54.37	87.02
Consumption growth	1.04	25.65	0.72	0.11	1.07	5.32	31.86	2.25	68.02
investment growth	2.78	7.03	0.01	0.47	3.35	3.05	0.13	77.18	93.99
Wage growth	1.24	42.28	0.01	0.01	20.19	19.38	0.24	0.97	84.32
Hours	3.12	7.70	0.78	0.16	3.71	7.92	1.73	55.68	80.80
Inflation	3.32	18.68	0.12	0.13	14.87	8.27	0.72	42.14	88.26
Interest rate	23.65	6.77	0.17	0.20	5.68	3.17	0.69	52.30	92.62
Relative price	0.00	0.00	0.00	77.34	0.00	0.00	0.00	0.00	77.34

Panel B : Anticipated shocks.

Variable/shock (News)	MON	TFP	GOV	IST	PMU	WMU	PRF	MEI	TOT
Output growth	0.82	1.50	1.17	0.91	1.59	4.73	0.55	1.71	12.98
Consumption growth	0.38	7.86	0.35	7.54	3.63	7.55	0.82	3.84	31.98
investment growth	0.00	1.01	0.02	0.55	0.62	2.23	0.61	0.97	6.01
Wage growth	0.02	4.06	0.02	2.77	3.72	1.75	1.24	2.10	15.68
Hours	0.39	1.73	0.67	1.11	1.54	8.70	1.12	3.94	19.20
Inflation	0.02	1.30	0.16	3.05	1.13	1.75	2.46	1.87	11.74
Interest rate	0.06	0.68	0.23	1.99	0.44	0.70	1.67	1.61	7.38
Relative price	0.00	0.00	0.00	0.00	12.04	0.00	10.61	0.00	22.66

Note : This table shows the variance decomposition in percentage in percentage for the benchmark model with news shocks. News shocks are the sum of four- and eight-quarter-ahead components.

Figure 3.1 Impulse responses to a monetary policy shock.

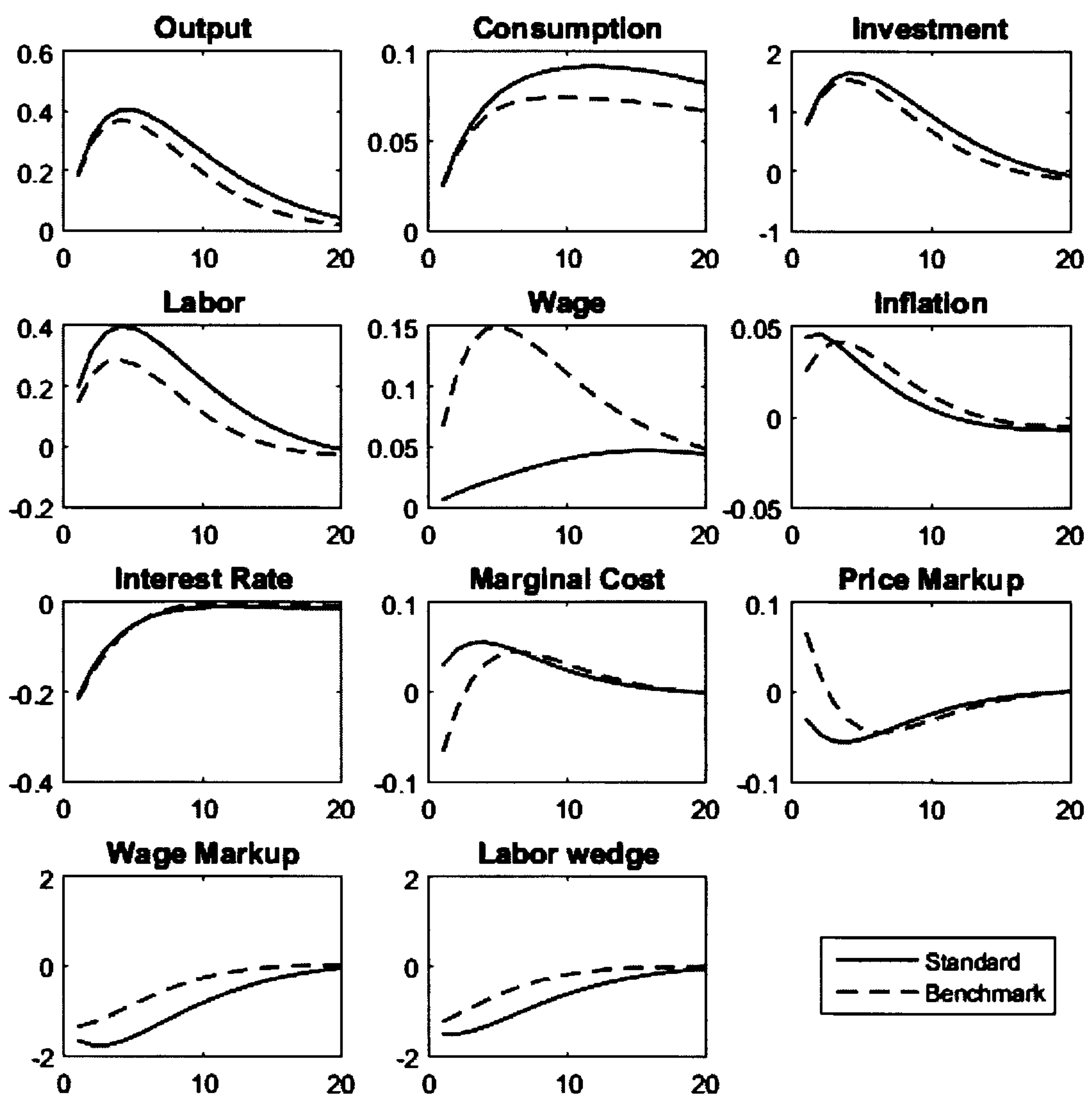


Figure 3.2 Impulse responses to a neutral technology shock.

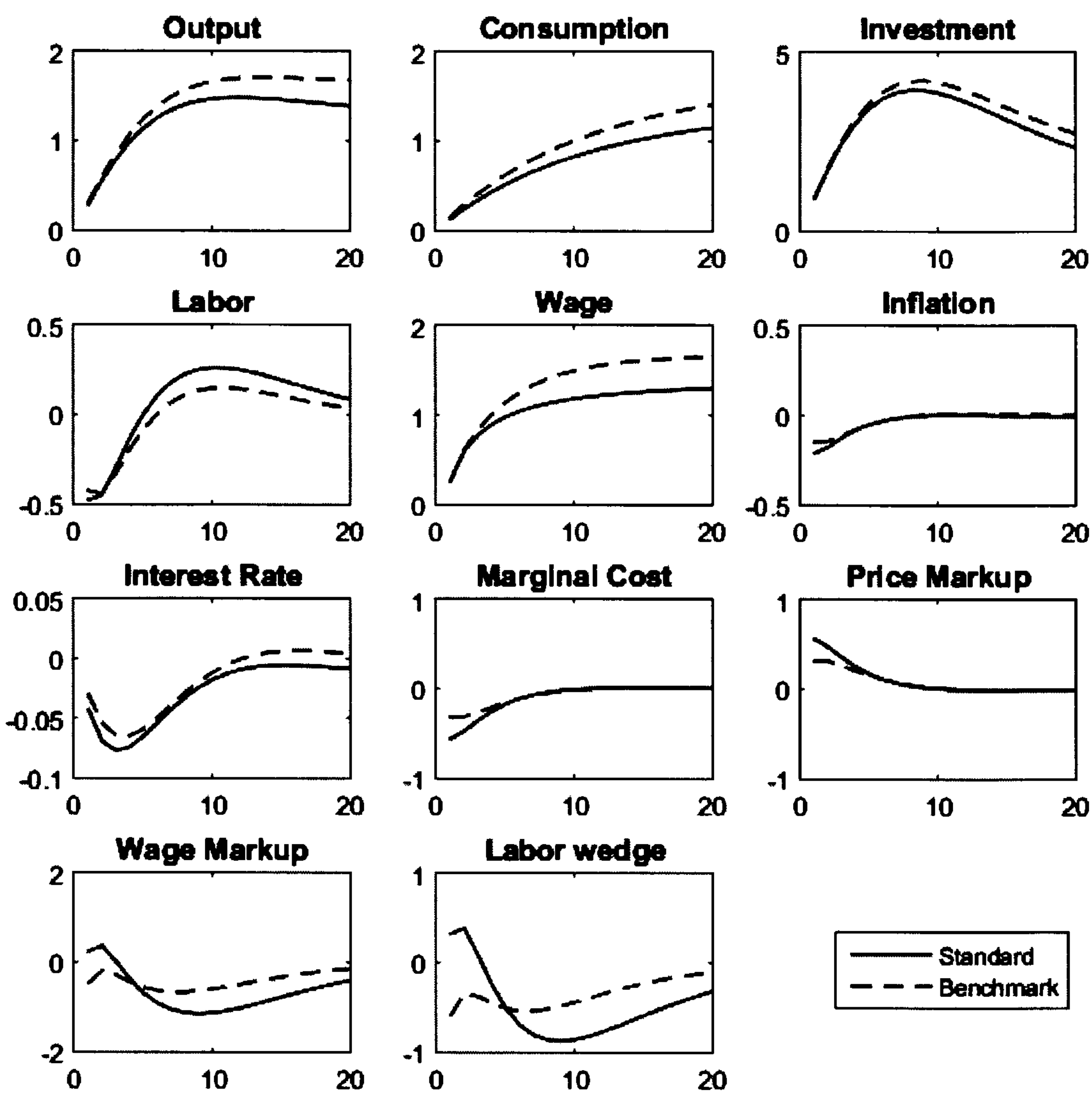


Figure 3.3 Impulse responses to a wage markup shock.

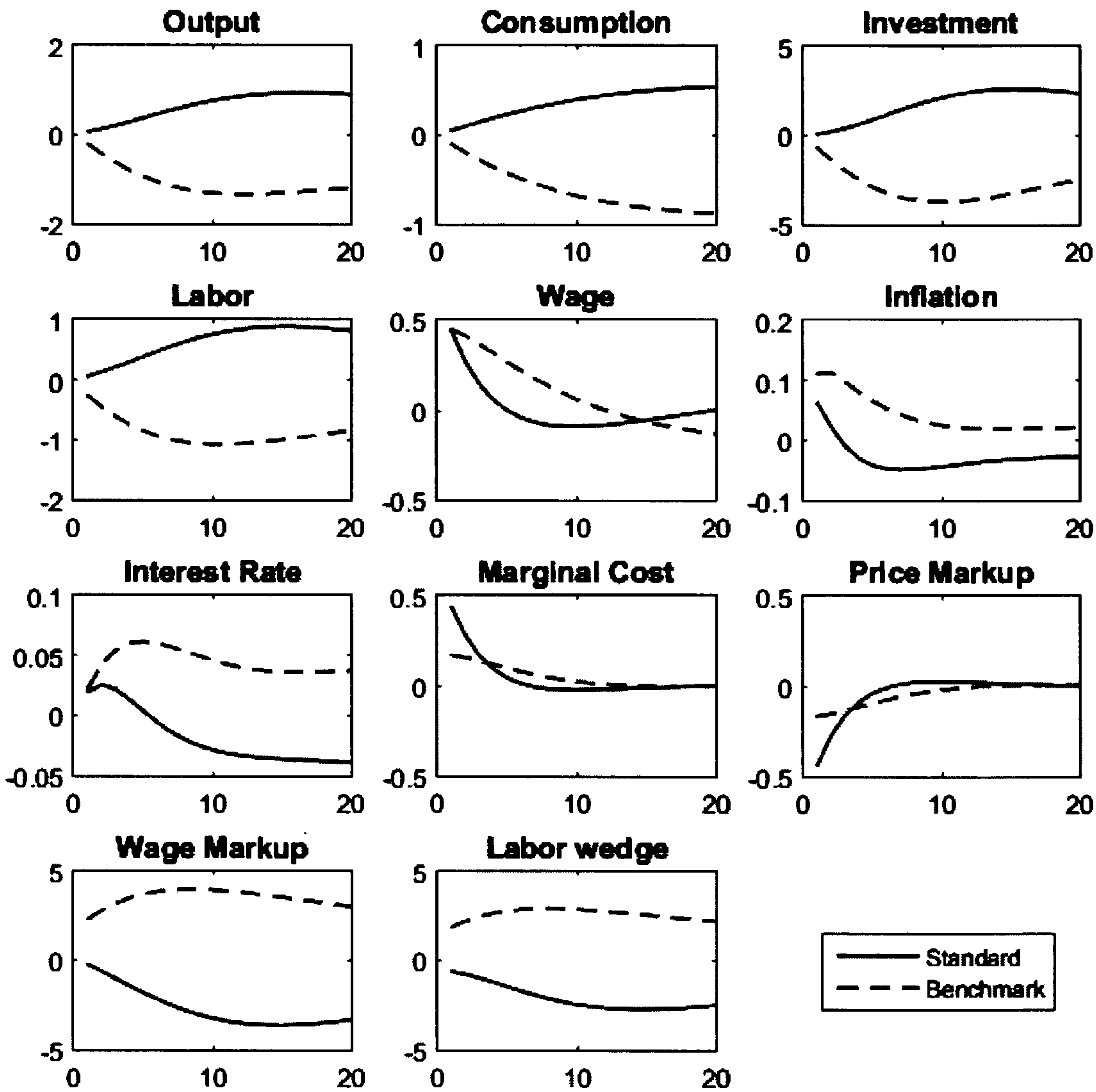


Figure 3.4 Impulse responses to a MEI shock

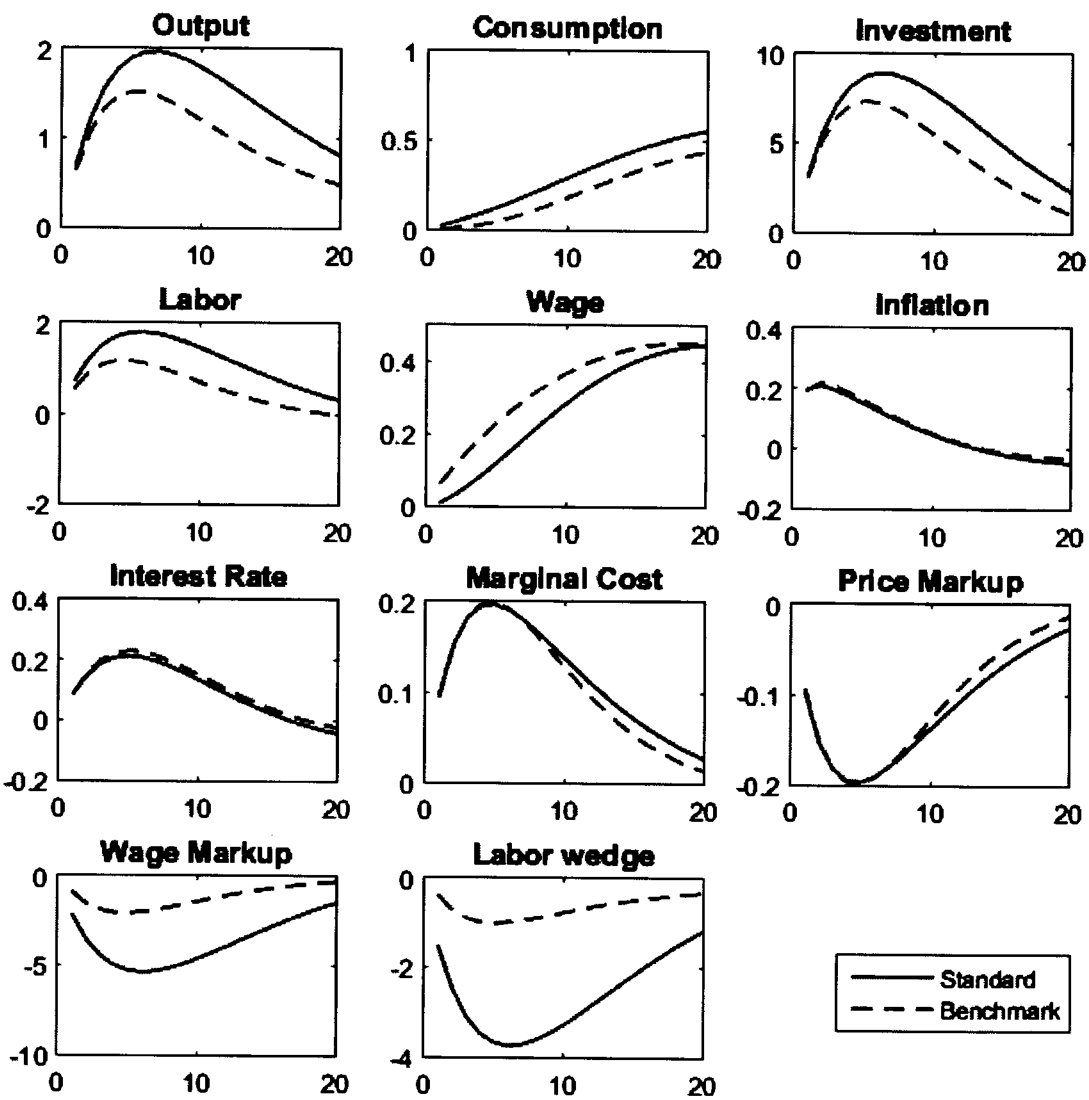


Figure 3.5 Impulse responses to a MEI shock : benchmark vs standard.

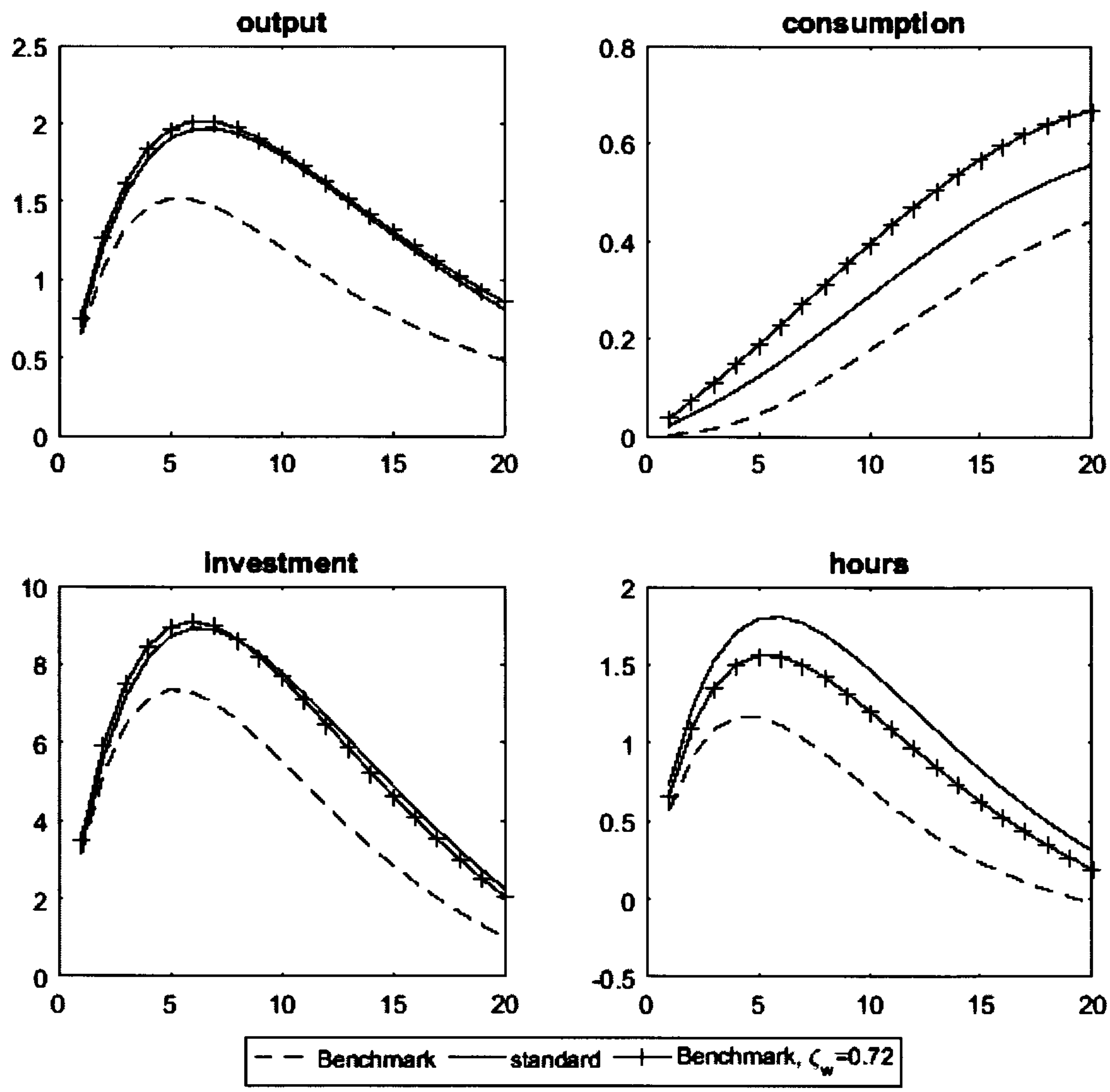


Figure 3.6 Cross-correlograms observed in the data, the standard and the bechmark model.

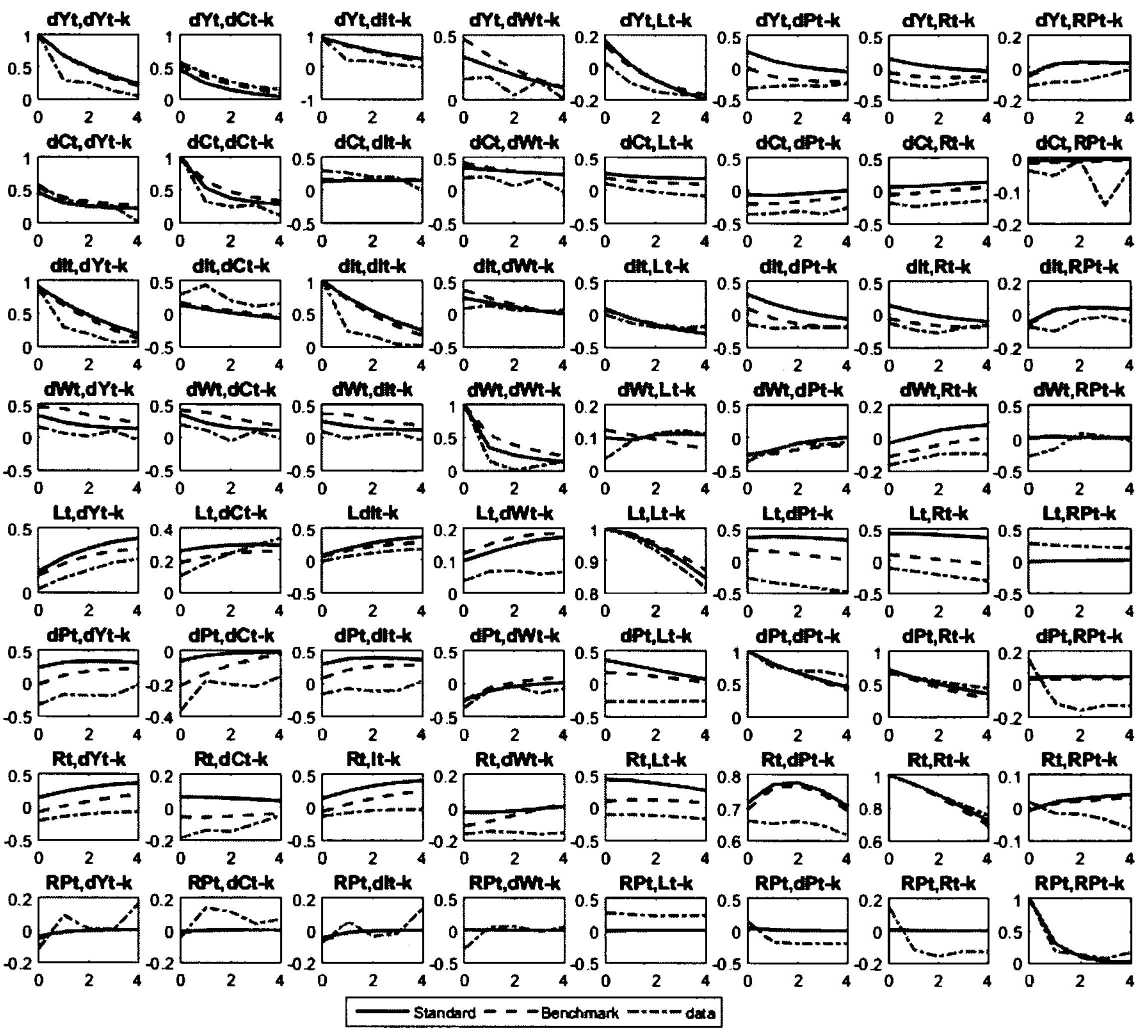
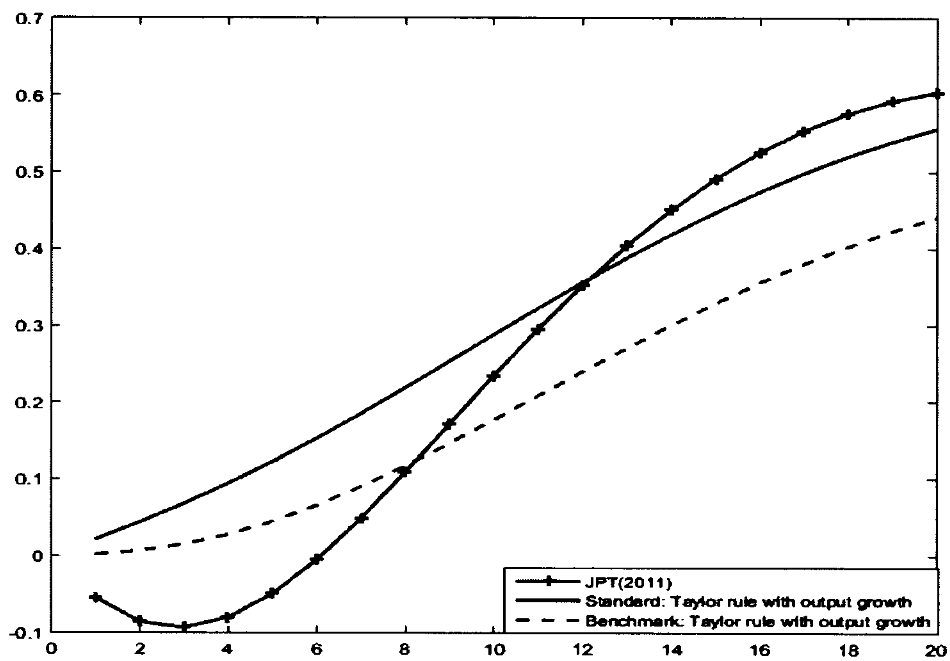


Figure 3.7 Impulse responses function of consumption to a MEI shock : comparing alternative models.



APPENDIX A

LONG-RUN INFLATION AND THE DISTORTING EFFECTS OF STICKY WAGES AND TECHNICAL CHANGE

A.1 Data and sources

The data used are from the BEA and they cover the period 1960:I-2007:III. They are generated as follows.$C^n_{nd,t}$, $C^n_{s,t}$, D^n_t, and $I^n_{f,t}$ represent nominal non-durable consumption, services consumption, expenditure on durables, and fixed investment. $P_{nd,t}$, $P_{s,t}$, $P_{d,t}$, and $P_{f,t}$ denote the corresponding price indexes. Nominal consumption and nominal investment are given by:

$$C^n_t = C^n_{nd,t} + C^n_{s,t}, \tag{A.1}$$

$$I^n_t = D^n_t + I^n_{f,t}. \tag{A.2}$$

$g_{nd,t}$, $g_{s,t}$, $g_{d,t}$, and $g_{f,t}$ are the real growth rates of the series:

$$g_{nd,t} = \ln C^n_{nd,t} - \ln C^n_{nd,t-1} - (\ln P_{nd,t} - \ln P_{nd,t-1}), \tag{A.3}$$

$$g_{s,t} = \ln C^n_{s,t} - \ln C^n_{s,t-1} - (\ln P_{s,t} - \ln P_{s,t-1}), \tag{A.4}$$

$$g_{d,t} = \ln C^n_{t,t} - \ln D^n_{t,t-1} - (\ln P_{d,t} - \ln P_{d,t-1}), \tag{A.5}$$

$$g_{f,t} = \ln I^n_{f,t} - \ln I^n_{f,t-1} - (\ln P_{f,t} - \ln P_{f,t-1}). \tag{A.6}$$

The real growth rate of non-durable and services consumption is the share-weighted growth rates of the real component series:

$$g_{c,t} = \left(\frac{C^n_{nd,t-1}}{C^n_{t-1}}\right) g_{nd,t} + \left(\frac{C^n_{s,t-1}}{C^n_{t-1}}\right) g_{s,t}. \tag{A.7}$$

Similarly, the real growth rate of investment is the share-weighted growth rates of the real components:

$$g_{i,t} = \left(\frac{D^n_{t-1}}{I^n_{t-1}}\right) g_{d,t} + \left(\frac{I^n_{f,t-1}}{I^n_{t-1}}\right) g_{f,t}. \tag{A.8}$$

The log-level real series is computed by cumulating the growth rates starting from a base of 1. They are put levels by exponentiating the log-levels. They are re-scaled so that the real and nominal series are equal in the third quarter of 2009. The price indexes for consumption and investment are computed as the ratios of the nominal to the real series. The relative price of investment is the ratio of the implied price index for investment goods to the price index for consumption goods. The average growth rate of the relative price from the period 1960:I-2007:III is -0.00472. This implies a calibration of $g_I = 1.00472$.

We compute aggregate output in a similar way. Define nominal output as the sum of the nominal components:

$$Y^n_t = C^n_{nd,t} + C^n_{s,t} + D^n_t + I^n_{f,t}. \tag{A.9}$$

The growth rate of real GDP is calculated by using the share-weighted real growth rates of the constituent series:

$$g_{y,t} = \left(\frac{C^n_{nd,t-1}}{Y^n_{t-1}}\right) g_{nd,t} + \left(\frac{C^n_{s,t-1}}{Y^n_{t-1}}\right) g_{s,t} + \left(\frac{D^n_{t-1}}{Y^n_{t-1}}\right) g_{d,t} + \left(\frac{I^n_{f,t-1}}{Y^n_{t-1}}\right) g_{f,t}. \tag{A.10}$$

Then, we cumulate to get in log-levels, and exponentiate to get in levels. The price deflator is the ratio between the nominal and real series. The average growth rate of the price index over the period 1960:I-2007:III is 0.008675. This implies $\pi^* = 1.0088$ or 3.52% annualized.

Real per capita GDP is computed by subtracting from the log-level the log civilian non-institutionalized population. The average growth rate of the resulting output per capita series over the period is 0.005712. The standard deviation of output growth over the period is 0.0078. The calculations above imply that $g_Y = 1.005712$ or 2.28% a year. Given the calibrated growth of IST from the relative price of investment data ($g_I = 1.00472$), we then pick g_A to generate the appropriate average growth rate of output. This implies $g_z = 1.0022$ or a measured TFP growing at about 1% per year.

To get the parameters governing the shock processes, we proceed as follows. Given trend inflation of $\pi^* = 1.0088$, we pick σ_I, σ_z, and σ_r so that our baseline model matches the actual volatility of output growth of 0.0078 of our sample period.

A.2 Equilibrium Conditions: Model with Stochastic Trends

The set of equilibrium conditions in the model with stochastic trend:

$$\widetilde{\lambda}_t^r = \frac{1}{\widetilde{C}_t - b g_{\Upsilon,t}^{-1} \widetilde{C}_{t-1}} - E_t \frac{\beta b}{g_{\Upsilon,t+1} \widetilde{C}_{t+1} - b\widetilde{C}_t} \tag{A1}$$

$$\widetilde{r}_t^k = \gamma_1 + \gamma_2 (u_t - 1) \tag{A2}$$

$$\widetilde{\lambda}_t^r = \widetilde{\mu}_t \left(1 - \frac{k}{2}\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_{\Upsilon,t} - g_\Upsilon\right)^2 - \kappa\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_{\Upsilon,t} - g_\Upsilon\right)\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_{\Upsilon,t}\right) \tag{A3}$$

$$+\beta E_t g_{\Upsilon,t+1}^{-1} \widetilde{\mu}_{t+1} \kappa \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_{\Upsilon,t+1} - g_\Upsilon\right)\left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_{\Upsilon,t+1}\right)^2 \tag{A4}$$

$$\widetilde{\mu}_t = \beta E_t \widetilde{\lambda}^r_{t+1} g^{-1}_{\Upsilon,t+1} g^{-1}_{I,t} \left(\widetilde{r}^k_{t+1} u_{t+1} - \left(\gamma_1 (u_{t+1} - 1) + \frac{\gamma_2}{2} (u_{t+1} - 1)^2 \right) \right) \quad \text{(A5)}$$

$$+\beta(1-\delta) E_t \widetilde{\mu}_{t+1} g^{-1}_{\Upsilon_{t+1}} g^{-1}_{I,t} \quad \text{(A6)}$$

$$\widetilde{\lambda}^r_t = \beta E_t g^{-1}_{\Upsilon_{t+1}} R_t \pi^{-1}_{t+1} \widetilde{\lambda}^r_{t+1} \quad \text{(A7)}$$

$$\widetilde{w}^*_t = \frac{\sigma}{\sigma - 1} \frac{f_{1,t}}{\widetilde{f}_{2,t}} \quad \text{(A8)}$$

$$f_{1,t} = \eta \left(\frac{\widetilde{w}_t}{\widetilde{w}^*_t} \right)^{\sigma(1+\chi)} L^{1+\chi}_t + \beta \xi_w E_t \pi^{\sigma(1+\chi)}_{t+1} \left(\frac{\widetilde{w}^*_{t+1}}{\widetilde{w}^*_t} \right)^{\sigma(1+\chi)} g^{\sigma(1+\chi)}_{\Upsilon,t+1} f_{1,t+1} \quad \text{(A9)}$$

$$\widetilde{f}_{2,t} = \widetilde{\lambda}^r_t \left(\frac{\widetilde{w}_t}{\widetilde{w}^*_t} \right)^{\sigma} L_t + \beta \xi_w E_t \pi^{\sigma-1}_{t+1} \left(\frac{\widetilde{w}^*_{t+1}}{\widetilde{w}^*_t} \right)^{\sigma} g^{\sigma-1}_{\Upsilon,t+1} \widetilde{f}_{2,t+1} \quad \text{(A10)}$$

$$\widetilde{\widetilde{K}}_t = g_{I,t} g_{\Upsilon,t} \alpha \frac{mc_t}{\widetilde{r}^k_t} \left(v^p_t \widetilde{Y}_t + F \right) \quad \text{(A11)}$$

$$L_t = (1-\alpha) \frac{mc_t}{\widetilde{w}_t} \left(v^p_t \widetilde{Y}_t + F \right) \quad \text{(A12)}$$

$$p^*_t = \frac{\theta}{\theta - 1} \frac{x^1_t}{x^2_t} \quad \text{(A13)}$$

$$x^1_t = \widetilde{\lambda}^r_t mc_t \widetilde{Y}_t + \xi_p \beta \pi^{\theta}_{t+1} x^1_{t+1} \quad \text{(A14)}$$

$$x^2_t = \widetilde{\lambda}^r_t \widetilde{Y}_t + \xi_p \beta \pi^{\theta-1}_{t+1} x^2_{t+1} \quad \text{(A15)}$$

$$1 = \xi_p \pi^{\theta-1}_t + (1-\xi_p) p^{*1-\theta}_t \quad \text{(A16)}$$

$$\widetilde{w}^{1-\sigma}_t = \xi_w g^{\sigma-1}_{\Upsilon,t} \widetilde{w}^{1-\sigma}_{t-1} \pi^{\sigma-1}_t + (1-\xi_w) \widetilde{w}^{*1-\sigma}_t \quad \text{(A17)}$$

$$\widetilde{Y}_t = \widetilde{\widetilde{K}}^{\alpha}_t L^{1-\alpha}_t g^{-\alpha}_{\Upsilon,t} g^{-\alpha}_{I,t} - F \quad \text{(A18)}$$

$$\widetilde{Y}_t = \widetilde{C}_t + \widetilde{I}_t + g^{-1}_{\Upsilon,t} g^{-1}_{I,t} \left(\gamma_1 (u_t - 1) + \frac{\gamma_2}{2} (u_t - 1)^2 \right) \widetilde{K}_t \quad \text{(A19)}$$

$$\widetilde{K}_{t+1} = \left(1 - \frac{\kappa}{2} \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_{\Upsilon,t} - g_{\Upsilon} \right)^2 \right) \widetilde{I}_t + (1-\delta) g^{-1}_{\Upsilon,t} g^{-1}_{I,t} \widetilde{K}_t \quad \text{(A20)}$$

$$\frac{R_t}{R} = \left(\left(\frac{\pi_t}{\pi} \right)^{\alpha_\pi} \left(\frac{\widetilde{Y}_t}{\widetilde{Y}_{t-1}} \frac{g_{\Upsilon,t}}{g_{\Upsilon}} \right)^{\alpha_y} \right)^{1-\rho_i} \left(\frac{R_{t-1}}{R} \right)^{\rho_i} \varepsilon^r_t \quad \text{(A21)}$$

$$\widetilde{\widetilde{K}}_t = u_t \widetilde{K}_t \tag{A22}$$

$$v_t^p = (1-\xi_p) p_t^{*-\theta} + \xi_p \pi_t^{\theta} v_{t-1}^p \tag{A23}$$

$$v_t^w = (1-\xi_w) \left(\frac{\widetilde{w}_t^*}{\widetilde{w}_t}\right)^{-\sigma(1+\chi)} + \xi_w \left(\frac{\widetilde{w}_{t-1}}{\widetilde{w}_t g_{\Upsilon,t}}\right)^{-\sigma(1+\chi)} \pi_t^{\sigma(1+\chi)} v_{t-1}^w \tag{A24}$$

$$\widetilde{V}_t^c = \ln\left(\widetilde{C}_t - b g_{\Upsilon,t}^{-1} \widetilde{C}_{t-1}\right) + \beta g_{\Upsilon,t+1} E_t \widetilde{V}_{t+1}^c \tag{A25}$$

$$V_t^n = -\eta \frac{L_t^{1+\chi}}{1+\chi} v_t^w + \beta E_t V_{t+1}^n \tag{A26}$$

$$V_t = \widetilde{V}_t^c + \widetilde{V}_t^n + \Psi_t \tag{A27}$$

$$\Psi_t = \frac{\beta}{1-\beta} \ln g_{\Upsilon,t+1} + \beta \Psi_{t+1} \tag{A28}$$

$$z_t = g_z + \varepsilon_{z,t} \tag{A29}$$

$$v_t^I = g_I + \varepsilon_I \tag{A30}$$

$$g_{\Upsilon_t} = \left(\frac{A_t}{A_{t-1}}\right)^{\frac{1}{1-\alpha)}} \left(\frac{V_t^I}{V_{t-1}^I}\right)^{\frac{\alpha}{1-\alpha}} \tag{A31}$$

APPENDIX B

INFLATION, OUTPUT AND MARKUP DYNAMICS WITH PURELY FORWARD-LOOKING WAGE AND PRICE SETTERS

B.1 Full Set of Equilibrium Conditions

This appendix lists the full set of equilibrium conditions:

$$\widetilde{\lambda}_t^r = \frac{1}{\widetilde{C}_t - bg_\Upsilon^{-1}\widetilde{C}_{t-1}} - E_t\frac{\beta b}{g_\Upsilon \widetilde{C}_{t+1} - b\widetilde{C}_t} \tag{B1}$$

$$r_t^k = \gamma_1 + \gamma_2(Z_t - 1) \tag{B2}$$

$$\widetilde{\lambda}_t^r = \widetilde{\mu}_t\vartheta_t\left(1 - \frac{k}{2}\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}}g_\Upsilon - g_\Upsilon\right)^2 - \kappa\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}}g_\Upsilon - g_\Upsilon\right)\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}}g_\Upsilon\right) + \ldots$$
$$\beta E_t g_\Upsilon^{-1}\widetilde{\mu}_{t+1}\vartheta_{t+1}\kappa\left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t}g_\Upsilon - g_\Upsilon\right)\left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t}g_\Upsilon\right)^2 \text{ (B3)}$$

$$g_I g_\Upsilon \widetilde{\mu}_t = \beta E_t\widetilde{\lambda}_{t+1}^r\left(\widetilde{r}_{t+1}^k Z_{t+1} - \left(\gamma_1(Z_{t+1} - 1) + \frac{\gamma_2}{2}(Z_{t+1} - 1)^2\right)\right) + \beta(1-\delta)E_t\widetilde{\mu}_{t+1} \tag{B4}$$

$$\widetilde{\lambda}_t^r = \beta g_\Upsilon^{-1}E_t(1 + i_t)\pi_{t+1}^{-1}\widetilde{\lambda}_{t+1}^r \tag{B5}$$

$$\widetilde{w}_t^* = \frac{\sigma}{\sigma - 1}\frac{f_{1,t}}{\widetilde{f}_{2,t}} \tag{B6}$$

$$\widetilde{f}_{1,t} = \eta \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*} \right)^{\sigma(1+\chi)} L_t^{1+\chi} + \beta \xi_w E_t (\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*} \right)^{\sigma(1+\chi)} g_\Upsilon^{\sigma(1+\chi)} \widetilde{f}_{1,t+1} \quad \text{(B7)}$$

$$\widetilde{f}_{2,t} = \widetilde{\lambda}_t^r \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*} \right)^{\sigma} L_t + \beta \xi_w E_t (\pi_{t+1})^{\sigma-1} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*} \right)^{\sigma} g_\Upsilon^{\sigma-1} \widetilde{f}_{2,t+1} \quad \text{(B8)}$$

$$\widetilde{\widetilde{K}}_t = g_I g_\Upsilon \alpha (1-\phi) \frac{mc_t}{\widetilde{r}_t^k} \left(s_t \widetilde{X}_t + F \right) \quad \text{(B9)}$$

$$L_t = (1-\alpha)(1-\phi) \frac{mc_t}{\widetilde{w}_t} \left(s_t \widetilde{X}_t + F \right) \quad \text{(B10)}$$

$$\widetilde{\Gamma}_t = \phi mc_t \left(s_t \widetilde{X}_t + F \right) \quad \text{(B11)}$$

$$p_t^* = \frac{\theta}{\theta - 1} \frac{x_t^1}{x_t^2} \quad \text{(B12)}$$

$$x_t^1 = \widetilde{\lambda}_t^r mc_t \widetilde{X}_t + \xi_p \beta \left(\frac{1}{\pi_{t+1}} \right)^{-\theta} x_{t+1}^1 \quad \text{(B13)}$$

$$x_t^2 = \widetilde{\lambda}_t^r \widetilde{X}_t + \xi_p \beta \left(\frac{1}{\pi_{t+1}} \right)^{1-\theta} x_{t+1}^2 \quad \text{(B14)}$$

$$1 = \xi_p \left(\frac{1}{\pi_t} \right)^{1-\theta} + (1-\xi_p) p_t^{*1-\theta} \quad \text{(B15)}$$

$$\widetilde{w}_t^{1-\sigma} = \xi_w g_\Upsilon^{\sigma-1} \left(\frac{\widetilde{w}_{t-1}}{\pi_t} \right)^{1-\sigma} + (1-\xi_w) \widetilde{w}_t^{*1-\sigma} \quad \text{(B16)}$$

$$\widetilde{Y}_t = \widetilde{X}_t - \widetilde{\Gamma}_t \quad \text{(B17)}$$

$$s_t \widetilde{X}_t = \widetilde{A}_t \widetilde{\Gamma}_t^{\phi} \widetilde{\widetilde{K}}_t^{\alpha(1-\phi)} L_t^{(1-\alpha)(1-\phi)} g_\Upsilon^{\alpha(\phi-1)} g_I^{\alpha(\phi-1)} - F \quad \text{(B18)}$$

$$\widetilde{Y}_t = \widetilde{C}_t + \widetilde{I}_t + g_\Upsilon^{-1} g_I^{-1} \left(\gamma_1 (Z_t - 1) + \frac{\gamma_2}{2} (Z_t - 1)^2 \right) \widetilde{K}_t \quad \text{(B19)}$$

$$\widetilde{K}_{t+1} = \vartheta_t \left(1 - \frac{\kappa}{2} \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Upsilon - g_\Upsilon \right)^2 \right) \widetilde{I}_t + (1-\delta) g_\Upsilon^{-1} g_I^{-1} \widetilde{K}_t \quad \text{(B20)}$$

$$\frac{1+i_t}{1+i} = \left(\left(\frac{\pi_t}{\pi} \right)^{\alpha_\pi} \left(\frac{\widetilde{Y}_t}{\widetilde{Y}_{t-1}} \right)^{\alpha_y} \right)^{1-\rho_i} \left(\frac{1+i_{t-1}}{1+i} \right)^{\rho_i} \varepsilon_t^r \quad \text{(B21)}$$

$$\widetilde{\widetilde{K}}_t = Z_t \widetilde{K}_t \quad \text{(B22)}$$

$$s_t = (1-\xi_p) p_t^{*-\theta} + \xi_p \left(\frac{1}{\pi_t} \right)^{-\theta} s_{t-1} \quad \text{(B23)}$$

Equation B1 defines the real multiplier on the flow budget constraint.B2 is the optimality condition for capital utilization. B3 and B4 are the optimality conditions for the household choice of investment and next period's stock of capital, respectively. The Euler equation for bonds is given by B5. B6 - B8 describe optimal wage setting for households given the opportunity to adjust their wages. Optimal factor demands are given by equations B9 - B11. Optimal price setting for firms given the opportunity to change their price is described by equations B12 - B14. The evolutions of aggregate inflation and the aggregate real wage index are given by B15 and B16, respectively. Net output is gross output minus intermediates, as given by B17. The aggregate production function is B18. The aggregate resource constraint is B19, and the law of motion for physical capital is given by B20. The Taylor rule for monetary policy is B21. Capital services are defined as the product of utilization and physical capital, as in B22. The law of motion for price dispersion is B23.

APPENDIX C

THE BUSINESS CYCLE IN AN ESTIMATED DSGE MODEL WITH PRODUCTION NETWORKS AND WORKING CAPITAL

C.1 Full Set of Log-linearized Equilibrium Conditions

For each trending variable M_t, we define $\widehat{m}_t = \log \widetilde{M}_t - \log \widetilde{M}$, where $\widetilde{M}_t$ represents the corresponding stationary variable and $\widetilde{M}$ its steady state.

$$\widehat{x}_t = \frac{\widetilde{X}+F}{\widetilde{X}}\left[\phi\widehat{\gamma}_t + \alpha\left(1-\phi\right)\left(k_t - \widehat{g}_{\Upsilon,t} - \widehat{g}_{I,t}\right) + (1-\alpha)(1-\phi)\widehat{L}_t\right] \tag{C1}$$

$$k_t = \widehat{g}_{\Upsilon,t} + \widehat{g}_{I,t} + \widehat{mc}_t - \frac{R\psi_K}{\Psi_K}\widehat{R}_t - \widehat{r}_t^k + \frac{\widetilde{X}}{\widetilde{X}+F}\widehat{x}_t \tag{C2}$$

$$\widehat{L}_t = \widehat{mc}_t - \frac{R\psi_L}{\Psi_L}\widehat{R}_t - \widehat{w}_t + \frac{\widetilde{X}}{\widetilde{X}+F}\widehat{x}_t \tag{C3}$$

$$\widehat{\gamma}_t = \widehat{mc}_t - \frac{R\psi_\Gamma}{\Psi_\Gamma}\widehat{R}_t + \frac{\widetilde{X}}{\widetilde{X}+F}\widehat{x}_t \tag{C4}$$

$$\widehat{y}_t = \frac{\widetilde{X}}{\widetilde{X}-\widetilde{\Gamma}}\widehat{x}_t - \frac{\widetilde{\Gamma}}{\widetilde{X}-\widetilde{\Gamma}}\widehat{\gamma}_t \tag{C5}$$

$$\widehat{\pi}_t = \frac{1}{1+\iota_p\beta}\iota_p\widehat{\pi}_{t-1} + \frac{\beta}{1+\iota_p\beta}E_t\widehat{\pi}_{t+1} + \kappa_p\widehat{mc}_t + \kappa_p\frac{\lambda_p}{1+\lambda_p}\widehat{\lambda}_{p,t} \tag{C6}$$

$$\widehat{\lambda}_t^r = \left\{ \begin{array}{c} \frac{h\beta g_\Upsilon}{(g_\Upsilon - h\beta)(g_\Upsilon - h)} E_t \widehat{c}_{t+1} - \frac{g_\Upsilon^2 + h^2\beta}{(g_\Upsilon - h\beta)(g_\Upsilon - h)} \widehat{c}_t + \frac{hg_\Upsilon}{(g_\Upsilon - h\beta)(g_\Upsilon - h)} \widehat{c}_{t-1} + \\ + \frac{\beta h g_\Upsilon}{(g_\Upsilon - h\beta)(g_\Upsilon - h)} E_t \widehat{g}_{\Upsilon,t+1} - \frac{hg_\Upsilon}{(g_\Upsilon - h\beta)(g_\Upsilon - h)} \widehat{g}_{\Upsilon,t} + \frac{(g_\Upsilon - h\beta\rho_b)}{(g_\Upsilon - h\beta)} \widehat{b}_t \end{array} \right\} \tag{C7}$$

$$\widehat{\lambda}_t^r = \widehat{R}_t - E_t \widehat{\pi}_{t+1} + E_t \widehat{\lambda}_{t+1}^r - E_t \widehat{g}_{\Upsilon,t+1} \tag{C8}$$

$$\widehat{r}_t^k = \sigma_a \widehat{u}_t \tag{C9}$$

$$\widehat{\mu}_t = \left\{ \begin{array}{c} \left[1 - \beta(1-\delta) g_\Upsilon^{-1} g_I^{-1} E_t \left(\widehat{\lambda}_{t+1}^r + \widehat{r}_{t+1}^k - \widehat{g}_{\Upsilon,t+1} - \widehat{g}_{I,t+1} \right) \right] \\ + \beta g_\Upsilon^{-1} g_I^{-1} (1-\delta) E_t \left(\widehat{\mu}_{t+1} - \widehat{g}_{\Upsilon,t+1} - \widehat{g}_{I,t+1} \right) \end{array} \right\} \tag{C10}$$

$$\widehat{\lambda}_t^r = \left\{ \begin{array}{c} \left(\widehat{\mu}_t + \widehat{\vartheta}_t \right) - \kappa \left(g_\Upsilon g_I \right)^2 \left(\widehat{i}_t - \widehat{i}_{t-1} + \widehat{g}_{\Upsilon,t} + \widehat{g}_{I,t} \right) \\ + \kappa\beta \left(g_\Upsilon g_I \right)^2 E_t \left(\widehat{i}_{t+1} - \widehat{i}_t + \widehat{g}_{\Upsilon,t+1} + \widehat{g}_{I,t+1} \right) \end{array} \right\} \tag{C11}$$

$$\widehat{k}_t = \widehat{u}_t + \widehat{\overline{k}}_t \tag{C12}$$

$$E_t \widehat{\overline{k}}_{t+1} = \left(1 - (1-\delta) g_\Upsilon^{-1} g_I^{-1} \right) \left(\widehat{\vartheta} + \widehat{i}_t \right) + (1-\delta) g_\Upsilon^{-1} g_I^{-1} \left(\widehat{\overline{k}}_t - \widehat{g}_{\Upsilon,t} - \widehat{g}_{I,t} \right) \tag{C13}$$

$$\left\{ \begin{array}{c} \widehat{w}_t = \frac{1}{1+\beta} \widehat{w}_{t-1} + \frac{\beta}{(1+\beta)} E_t \widehat{w}_{t+1} - \kappa_w \left(\widehat{w}_t - \chi \widehat{L}_t - \widehat{b}_t + \widehat{\lambda}_t^r \right) + \frac{1}{1+\beta} \iota_w \widehat{\pi}_{t-1} \\ - \frac{1+\beta\gamma_w\iota_w}{1+\beta} \widehat{\pi}_t + \frac{\beta}{1+\beta} E_t \widehat{\pi}_{t+1} + \frac{\iota_w}{1+\beta} \widehat{g}_{\Upsilon,t-1} - \frac{1+\beta\iota_w}{1+\beta} \widehat{g}_{\Upsilon,t} + \frac{\beta}{1+\beta} E_t \widehat{g}_{\Upsilon,t+1} + \kappa_w \widehat{\lambda}_{w,t} \end{array} \right\} \tag{C14}$$

$$\widehat{R}_t = (1-\rho_i) \left[\alpha_\pi \widehat{\pi}_t + \alpha_y \left(\widehat{gdp}_t - \widehat{gdp}_{t-1} \right) \right] + \rho_i \widehat{R}_{t-1} + \widehat{\varepsilon}_t^r \tag{C15}$$

$$\widehat{gdp}_t = \widehat{y}_t - \frac{r^k \widetilde{K}}{\widetilde{Y}} g_\Upsilon^{-1} g_I^{-1} \widehat{u}_t \tag{C16}$$

$$\frac{1}{g}\widehat{y}_t = \frac{1}{g}\widehat{g}_t + \frac{\widetilde{C}}{\widetilde{Y}}\widehat{c}_t + \frac{\widetilde{I}}{\widetilde{Y}}\widehat{I}_t + \frac{r^k K}{\widetilde{Y}} g_\Upsilon^{-1} g_I^{-1} \widehat{u}_t \tag{C17}$$

$$\widehat{g}_{\Upsilon,t} = \frac{1}{(1-\phi)(1-\alpha)}\widehat{z}_t + \frac{\alpha}{1-\alpha}\widehat{\nu}_t \tag{C18}$$

$$\widehat{g}_{I,t} = \widehat{\nu}_t \tag{C19}$$

$$\widehat{b}_t = \rho_b \widehat{b}_{t-1} + \varepsilon_{t,b} \tag{C20}$$

$$\widehat{\vartheta}_t = \rho_\vartheta \widehat{\vartheta}_{t-1} + \varepsilon_{\vartheta,t} \tag{C21}$$

$$\widehat{\lambda}_{p,t} = \rho_p \widehat{\lambda}_{p,t-1} + \varepsilon_{p,t} - \theta_p \varepsilon_{p,t-1} \tag{C22}$$

$$\widehat{\lambda}_{w,t} = \rho_w \widehat{\lambda}_{w,t-1} + \varepsilon_{w,t} - \theta_w \varepsilon_{w,t-1} \tag{C23}$$

$$\widehat{g}_t = \rho_g \widehat{g}_{t-1} + \varepsilon_{g,t} \tag{C24}$$

$$\widehat{z}_t = \rho_z \widehat{z}_{t-1} + \varepsilon_{z,t} \tag{C25}$$

$$\widehat{\nu}_t = \rho_\nu \widehat{\nu}_{t-1} + \varepsilon_{\nu,t} \tag{C26}$$

BIBLIOGRAPHY

[1] Altig, D., Christiano, L., Eichenbaum, M., Linde, J., 2011. "Firm-Specific Capital, Nominal Rigidities, and the Business Cycle." *Review of Economic Dynamics,*14(2), 225-247.

[2] Amano, Robert, Steve Ambler, and Nooman Rebei. 2007. "The Macroeconomic Effects of Non-Zero Trend Inflation." *Journal of Money, Credit and Banking,* 39 (7):1821-1838.

[3] Amano, Robert, Kevin Moran, Stephen Murchison, and Andrew Rennison. 2009."Trend Inflation, Wage and Price Rigidities, and Productivity Growth. " *Journal of Monetary Economics,* 56:353-364.

[4] Ascari, G., 2004. "Staggered Prices and Trend Inflation: Some Nuisances." *Review of Economic Dynamics,* 7, 642-67.

[5] Ascari, G., Ropele, T., 2007. "Optimal Monetary Policy Under Low Trend Inflation." *Journal of Monetary Economics,* 54, 2568-2583.

[6] Ascari, G., Phaneuf, L., and Sims, E., 2015. "On the Welfare and Cyclical Implications of Moderate Trend Inflation. " *NBER* Working Paper No. 21392.

[7] Ascari, G., Phaneuf, L., and Sims, E., 2016. "Business Cycles, Investment Shocks, and the Barro-King Curse. " *NBER* Working Paper No. 22941.

[8] Bakhshi, H., Burriel-Llombart, P., Khan, H., and Rudolf, B., 2014. "The New Keynesian Phillips Curve under Trend Inflation and Strategic Complementarity. " *Journal of Macroeconomics,* 29(1), 37-59.

[9] Barattieri, A., Basu, S., Gottschalk, P., 2014. "Some Evidence on the Importance of Sticky Wages. " *American Economic Journal: Macroeconomics,* 6(1), 70-101.

[10] Barro, R.J., King, R.J., 1984. "Time-Separable Preferences and Intertemporal-Substitution Models of Business Cycles. " *Quaterly Journal of Economics,* 99(4).

[11] Basu, S., 1995. "Intermediate Goods and Business Cycles: Implications for Productivity and Welfare." *American Economic Review,* 85(3), 512-531.

[12] Basu, S., Fernald, J., and Kimball, M.S., 2007. "Are Technology Improvements Contractionary?" *American Economic Review,* 96(5), 1418-1448.

[13] Basu, S., Kimball, M.S., 1997. "Cyclical Productivity with Unobserved Input Variation." *NBER,* Working Paper No. 5915.

[14] Berry, S., Levinsohn, J., and Pakes, A., 1995. "Automobile Prices in Market Equilibrium." *Econometrica: Journal of the Econometric Society* : 841- 890.

[15] Bernanke, B., Mihov, I., 1998. "Measuring Monetary Policy. " *Quaterly Journal of Economics,* 113(3), 869-902.

[16] Bils, M., Klenow, P.J., 2004. "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy,* 112(5), 947-985.

[17] Bils, M., Klenow P.J., Malin, B.A. 2016. "Resurrecting the Role of the Product Market Wedge in Recessions." *Tech. rep.*

[18] Broda, C., Weinstein, D.E., 2006. "Globalization and the Gains from Variety. " *The Quarterly journal of economics,* 121 (2):541 - 585.

[19] Calvo, G.A., 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics,* 12, 383-398.

[20] Chari, V.V., Kehoe, P.J., McGrattan, E.R., 1996. "Sticky Price Models of the Business Cycle: Can the Contract Multiplier Solve the Persistence Problem? " *NBER,* Working Paper No. 5805.

[21] Chari, V.V., Kehoe, P.J., McGrattan, E.R., 2000. "Sticky Price Models of the Business Cycle: Can the Contract Multiplier Solve the Persistence Problem? " *Journal of The Econometric Society: Econometrica,* 68(5), 1151-1179.

[22] Chari, V.V., Kehoe, P.J., McGrattan, E.R., 2009. "New Keynesian Models: Not Yet Useful for Policy Analysis. " *American Economic Journal: Macroeconomics,* 1(1), 242-266.

[23] Cho, J. O., Cooley, T. F., Phaneuf, L., 1997. "The welfare cost of nominal wage contracting. " *The Review of Economic Studies,* 64(3), 465-484.

[24] Chowdhury, I., Hoffmann, M., Schabert, A., 2006. "Inflation Dynamics and the Cost Channel of Monetary Transmission. " *European Economic Review,* 50, 995-1016.

[25] Christiano, L.J., Eichenbaum, M., and Trabandt, M., 2015."Understanding the Great Recession." *American Economic Journal: Macroeconomics,* 7(1):110-167.

[26] Christiano, L.J., Eichenbaum, M., and Trabandt, M., 2015."Unemployment and Business Cycles. Working Paper.

[27] Christiano, L.J., Trabandt, M., Walentin, K. 2011."DSGE Models for Monetary Policy Analysis." *Handbook of Monetary Economics,* edited by Benjamin Friedman and Michael Woodford. Elsevier, 285-367 .

[28] Christiano, L.J. 2015. "Comment on "Networks and the Macroeconomy: An Empirical Exploration. " *In NBER Macroeconomics Annual 2015,* Volume 30. University of Chicago Press.

[29] Christiano, L.J., Eichenbaum, M., 1992. "Effects and the Monetary Transmission Mechanism." *American Economic Review* (82):346-353.

[30] Christiano, L.J., Eichenbaum, M., Evans, C.L., 1997. "Sticky Price and Limited Participation Models of Money: A Comparison." *European Economic Review,* 41, 1201-1249.

[31] Christiano, L.J., Eichenbaum, M., Evans, C.L., 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy,* 113(1), 1-45.

[32] Cogley, T., Sbordone, A.M., 2008. "Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve" *American Economic Review,* 98(5), 2101-2126.

[33] Coibion, O., Gorodnichenko, Y., 2010. "When will the Fed raise interest rates? Reconciling Taylor Rule and Financial Market Forecasts. " *VOX CEPR's Policy Portal,* http://voxeu.org/article/when-will-fed-raise-interest-rates.

[34] Coibion, O., Gorodnichenko, Y., 2011. "Monetary Policy, Trend Inflation, and the Great Moderation: An Alternative Interpretation." *American Economic Review,* 101(1), 341-70.

[35] Coibion, O., Gorodnichenko, Y., and Wieland, J.F. 2012. "The Optimal Inflation Rate in New Keynesian Models: Should Central Banks Raise their Inflation Targets in Light of the ZLB? " *The Review of Economic Studies,* 79:1371-1406.

[36] Cooley, T.F., Prescott, E.C., 1995. "Economic Growth and Business Cycles." In, *Frontiers of Business Cycle Research,* edited by Cooley T.F., Princeton University Press.

[37] Del Negro, M., Schorfheide, F., Wouters, R. 2007. "On the Fit of New Keynesian Models. " *Journal of Business and Economic Statistics,* 25 (2):123-143.

[38] Dotsey, M., King, R.G., 2006. "Production, and Persistence." *Journal of the European Economic Association,* 4(5), 893-928.

[39] Eichenbaum, M., Jaimovich, N., and Rebelo, S., 2011. "Prices, Costs, and Nominal Rigidities." *The American Economic Review,* 101 (1):234-262.

[40] Erceg, Christopher J., Henderson, D.W, Levin, A.T. 2000. "Optimal Monetary Policy with Staggered Wage and Price Contracts." *Journal of Monetary Economics,* 46, 281-313.

[41] Erceg, C.J., Levin, A.T., 2003. "Imperfect credibility and inflation persistence." *Journal of Monetary Economics,* 50, 915-944.

[42] Fisher, J. 2006."The Dynamic Effects of Neutral and Investment-Specific Technology Shocks." *Journal of Political Economy,* 114(3):413-451.

[43] Francis, N., Ramey, V., 2005. "Is the Technology-Driven Business Cycle Hypothesis Dead? Shocks and Aggregate Fluctuations Revisited" *Journal of Monetary Economics,* 52(8):1379-1399.

[44] Furlanetto, F., Seneca, M., 2014. "New Perspectives on Depreciation Shocks as a Source of Business Cycle Fluctuations. " *Macroeconomic Dynamics,* 18 (6): 1209-1233.

[45] Geweke, J., 1999."Using Simulation Methods for Bayesian Econometric Models: Inference, Development, and Communication. " *Econometric Reviews,* 18 (1):1-73.

[46] Galí, J.,1999. "Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations? " *American Economic Review,* 89(1):249-271.

[47] Galí, J.,2003. "New Perspectives on Monetary Policy, Inflation, and the Business Cycle." In " *Advances in Economic Theory,* edited by M. Dewatripont, L. Hansen, and S. Turnovsky. Cambridge University Press, 151-197.

[48] Galí, J., Gertler, M., Lóopez-Salido, D, 2007. "Markups, Gaps, and the Welfare Costs of Business Fluctuations. " *Review of Economics and Statistic,* 89:44-59.

[49] Griffin, P., 1992. "The Impact of Affirmative Action on Labor: a Test of Some Implications of the Le Chatelier Principle. " *Review of Economics and Statistics,* 74:251-260.

[50] Greenwood, J., Hercowitz, Z., Huffman, G. W. (1988). Investment, capacity utilization, and the real business cycle. " *The American Economic Review,* 402-417.

[51] Greenwood, J., Hercowitz, Z., Krusell, P., 1997. "Long-run implications of investment-specific technological change. " *The American Economic Review,* 342-362.

[52] Greenwood, J., Hercowitz, Z., Krusell, P., 2000. "The Role of Investment-Specific Technological Change in the Business Cycle. " *European Economic Review,* 44 (1):91-115.

[53] Griffin, P. 1992. "The Impact of Affirmative Action on Labor: a Test of Some Implications of the Le Chatelier Principle" *Review of Economics and Statistics,* 74:251-260.

[54] Griffin, P. 1996. "Input Demand Elasticities for Heterogeneous Labor: Firm-Level Estimates and An Investigation Into the Effects of Aggregation" *Southern Economic Journal,* 62:889-901.

[55] Huang, Kevin X.D, Zheng Liu., 2002. "Staggered Contracts and Business Cycle Persistence. " *Journal of Monetary Economics,* 49:405-433.

[56] Huang, K.X.D., Liu, Z., Phaneuf, L., 2004. "Why Does the Cyclical Behavior of Real Wages Change over Time." *American Economic Review,* 94(4), 836-856.

[57] Iskrev, N., 2010. "Local Identification in DSGE Models. " *Journal of Monetary Economics,* 57 (2):189-202.

[58] Jaimovich, N., Rebelo, S. 2009. "Can News About the Future Drive the Business Cycle? " *The American Economic Review,* 99 (4):1097-1118.

[59] Justiniano, J., Primiceri, G.E., 2008. "The Time-Varying Volatility of Macroeconomic Fluctuations." *American Economic Review,* 98(3), 604-641.

[60] Justiniano, A., Primicieri, G.E., Tambalotti, A., 2010."Investment Shock and Business Cycles. " *Journal of Monetary Economics,* 57(2):132-145.

[61] Justiniano, A., Primicieri, G.E., Tambalotti, A., 2011. "Investment Shocks and the Relative Price of Investment." *Review of Economic Dynamics,* 14(1), 101-121.

[62] Khan, H., Tsoukalas, J., 2011. "Investment Shocks and the Comovement Problem. " *Journal of Economic Dynamics and Control,* 35 (1):115-130.

[63] Khan, H., Tsoukalas, J., 2012. "The Quantitative Importance of News Shocks in Estimated DSGE models." *Journal of Money, Credit and Banking,* 44(8), 1535-1561.

[64] King, R., 1991. "Value and Capital in the Equilibrium Business Cycle Program. " *In Value and Capital Fifty Years Later,* edited by L. McKenzie and S. Zamagni. London: MacMillan.

[65] McCallum, B. T. 2001. "Should Monetary Policy Respond Strongly to Output Gaps? " *American Economic Review,* 91 (2):258-262.

[66] Mankiw, N. G., Reis R. 2002. "Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve. " *Quarterly Journal of Economics,* 117:1295-1328.

[67] Nakamura, E., Steinsson, J., 2008. "Five Facts About Prices: A Reevaluation of Menu Cost Models." *Quaterly Journal of Economics,* 123(4), 1415-1464.

[68] Nakamura, E., Steinsson, J., 2010. "Monetary Non-Neutrality in a Multi-Sector Menu Cost Model." *Quaterly Journal of Economics,* 125(3), 961-1013.

[69] Nakamura, E., Steinsson, J., Sun, P., and Villar, D., 2017. "The Elusive Costs of Inflation: Price Dispersion during the U.S. Great In ation." *Quaterly Journal of Economics,* forthcoming.

[70] Nekarda, C., Ramey, V. 2013. "The Cyclical Behavior of the Price-Cost Markup. " *NBER,* Working Paper No. 19099.

[71] Nevo, A. 2001."Measuring Market Power in the Ready-to-Eat Cereal Industry. " *Econometrica,* 69 (2):307-342.

[72] Orphanides, A., Williams, J. C., 2006. "Inflation Targeting Under Imperfect Knowledge." *Economic Review-Federal Reserve Bank of San Francisco.*

[73] Phaneuf, L., Sims, E. R., Victor, J. G., 2015. "Inflation, Output, and Markup Dynamics with Forward-Looking Wage and Price Setters. " *NBER,* Working Paper No. 21599.

[74] Phaneuf, L., Victor. J. G. 2017. "The Business Cycle in an Estimated DSGE Model With Production Networks and Working Capital. Working Paper.

[75] Ravenna, F., Walsh, C., 2006. "Optimal Monetary Policy with the Cost Channel. " *Journal of Monetary Economics,* 53:199-216.

[76] Romer, C. D., Romer, D. H., 2004. "A New Measure of Monetary Shocks: Derivation and Implications. " *The American Economic Review,* 94(4), 1055-1084.

[77] Rotemberg, J. J., Woodford, M., 1993. "Dynamic General Equilibrium Models with Imperfectly Competitive Product Markets. " *NBER,* Working Paper No. 4502.

[78] Rotemberg, J.J., Woodford, M., 1997. "An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy." In: Rotemberg, J.J., Bernanke, B.S. (Eds.), *NBER Macroeconomics Annual 1997.* MIT Press, Cambridge, MA, pp. 297-346.

[79] Schmitt- Grohé, S., Uribe, M., 2012. "What's News in Business Cycles. " *Econometrica,* 80(6), 2733-2764.

[80] Sims, E., 2013. Growth or the Gap? "Which Measure of Economic Activity Should be Targeted in Interest Rate Rules? Working Paper.

[81] Smets, F., Wouters, R., 2007. "Shocks and Frictions in U.S. Business Cycles: a Bayesian DSGE Approach." *American Economic Review,* 97, 586-606.

Taylor, J.B., 1993. "Discretion versus Policy Rules in Practice" *Carnegie-Rochester Conference Series on Public Policy* 39:195-214.

[82] Tillmann, P., 2008. "Do interest Rates drive Inflation Dynamics? An Analysis of the Cost Channel of Monetary Transmission. " *Journal of Economic dynamics and Control,* 32(9), 2723-2744.

[83] Walsh, Carl E., 2005. "Labor Market Search, Sticky Prices, and Interest Rate Policies. " *Review of economic Dynamics,* 8 (4):829-849.

[84] Woodford, M., 2003. "Interest and Prices. Foundations of a Theory of Monetary Policy." *Princeton University Press,* Princeton, NJ.

[85] Woodford, M., 2007. "Interpreting Inflation Persistence: Comments on the Conference on Quantitative Evidence on Price Determination." *Journal of Money, Credit and Banking,* 39(s1), 203-210.

[86] Woodford, M., 2009. "Convergence in Macroeconomics: Elements of the New Synthesis. " *American Economic Journal: Macroeconomics,* 1(1), 267-279.

[87] Woodford, M., 2011. "Simple Analytics of the Government Expenditure Multiplier. " *American Economic Journal: Macroeconomics,* 3(1), 1-35.