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RÉSUMÉ

Cette thèse se compose de quatre articles (chapitres) distincts. Il étudie les effets macroéconomiques de l'inflation tendancielle positive (trend d'inflation positif) et ses implications sur les coûts en bien-être. Pour ce faire, elle utilise un modèle Néo-Keynésien de type d'équilibre général dynamique stochastique et s'appuie sur différentes spécifications du trend d'inflation positif.

Le premier article examine le comportement cyclique des markups sur les prix et les salaires dans les modèles Néo-Keynésiens ainsi que leur rôle dans l'explication des effets de la dynamique des chocs lorsque l'inflation tendancielle est positive. Cette dernière est modélisee comme étant constante et égale à la cible d'inflation. Les résultats révèlent que quand le trend d'inflation passe de 0% à 4% et de 2% à 4%, le markup des salaires joue un rôle significatif dans la propagation des effets de la dynamique des chocs. En outre, l'interaction entre le trend d'inflation positif et le choc à l'efficience marginale d'investissement a un impact plus important sur la cyclicité de markup des salaires que sur celui des prix.

Dans le deuxième article, nous étudions les coûts en bien-être liés aux changements de politique monétaire et du trend d'inflation positif dans l'économie américaine d'après-guerre. Les résultats indiquent que les réformes de la politique monétaire et la variation du trend d'inflation ont joué un rôle essentiel dans la réduction de la volatilité des variables macroéconomiques dans les années 80. Par ailleurs, les coûts en bien-être y relatifs sont plus faibles dans la période post-1980 par rapport à la période pre-1980. Enfin, lorsque le trend d'inflation et la croissance exogène sont combinés à la rigidité nominale des salaires à la Calvo, réagir à l'écart de production (output gap) se traduit par des pertes équivalentes à la consommation plus importantes.

Dans le troisième article, nous examinons comment le trend d'inflation affecte-t-elle la dynamique des variables macroéconomique pour entraîner des effets sur le bien-être. A cet effet, le trend d'inflation positif est modélisé comme variable dans le temps, suivant un processus AR (1) stationnaire et très persistant. Les résultats montrent que les coûts en bien-être d'une inflation tendancielle variable dans le temps sont plus importants que ceux du trend d'inflation constant et positif. En outre, lorsque le trend d'inflation augmente, l'interaction entre les contrats salariaux échelonnés de Calvo et la croissance tendacielle génère une dispersion inefficiente des salaires. Ainsi, les salaires deviennent plus dispersés, affectent la demande de consommation, la demande du travail et la production, et ont des effets beaucoup plus importants sur les coûts en bien-être que la dispersion des prix. Enfin, l'analyse de sensibilité révèle que les contrats nominaux de Calvo et les coûts en bien-être y relatifs sont très sensibles aux variations du trend d'inflation et des paramètres clés du modèle.

Dans le quatrième article, nous élargissons l'analyse précédente aux contrats nominaux échelonnés de Taylor et introduisons les frictions financières ainsi qu'une spécification asymétrique du trend d'inflation positif variable dans le temps. Les résultats indiquent que les coûts en bien-être sont plus faibles et modestes dans le modèle de Taylor et sont moins sensibles aux variations du trend d'inflation et des paramètres clés du modèle contrairement au modèle de Calvo. En outre, la rigidité nominale des salaires et la dispersion des salaires sont des facteurs déterminants du mécanisme de transmission de la dynamique affectant les variables macroéconomiques pour générer les coûts en bien-être dans les deux modèles. Par ailleurs, deux changements significatifs ont été introduits dans la spécification du modèle de référence. D'abord, les frictions financières ont été ajoutées puis le trend d'inflation modélisé comme un processus AR(1) asymétrique. Les résultats montrent qu'avec les frictions financières, les coûts en bien-être sont plus élevés dans le modèle de Taylor que dans celui de Calvo. Ensuite, avec un processus AR(1) asymétrique du trend d'inflation, ces coûts sont élevés par rapport à ceux du processus symétrique dans les deux modèles. Enfin, l'analyse de sensibilité indique que le modèle des contrats nominaux de Taylor offre une alternative pertinente à ceux de Calvo pour évaluer les propriétés de bien-être dans les modèles Néo-Keynésiens.

Mots-clés : Modèle Néo-Keynésien d'Équilibre Général Dynamique Stochastique, Dispersion des Prix, Inflation Tendancielle variable dans le temps, Croissance tendacielle, Dispersion des Salaires

ABSTRACT

This thesis consists of four separate papers. It investigates the macroeconomic effects of positive trend inflation and its welfare implications using a medium-scale New Keynesian DSGE model that features positive trend inflation, trend growth, and roundabout production structure. In the first paper, we examine the cyclical behavior of price and wage markups in the New Keynesian models and their role in explaining the dynamics of shocks when trend inflation is positive. We model non-zero trend inflation as constant and equal to the fixed inflation target. The results show that when raising trend inflation from 0% to 4% and 2% to 4%, wage markup is more important than price markup in explaining shocks dynamics effects. We further find that the interaction between positive trend inflation and marginal investment shock has more significant cyclical effects on the wage markup than on the price markup.

The second paper investigates the welfare costs related to changes in monetary policy and trend inflation in the Postwar U.S. economy. The results show that monetary policy reforms and changes in trend inflation play an essential role in reducing macroeconomic variables volatility in the post-1980s. However, welfare costs are smaller in the post-1980s period compared to the pre-1980s period. Finally, we find that when trend inflation and trend productivity growth are combined with nominal wage rigidity, reacting to the output gap results in more significant consumption-equivalent losses.

In the third paper, We examine how shifting trend inflation affects macroeconomic dynamics to bring about welfare effects. We model positive trend inflation as time-varying, and a stationary and highly persistent AR(1) process. The results show that welfare costs of shifting trend inflation are more extensive than those associated with constant trend inflation. We further find that the interaction between staggered wage contracts trend growth generates inefficient wage dispersion when trend inflation rises. Thus, wages become more dispersed, affect consumption, labor, and output, and have much larger effects on welfare costs than price dispersion. Finally, our robustness exercises show that Calvo's nominal contracts and welfare costs are too responsive to trend inflation levels and variations in key model's parameters. This last observation motivated the last article.

In the fourth paper, we extend the previous analysis to Taylor's staggered nominal contracts. We find that welfare costs are smaller and modest in the Taylor model and are immune to variation in trend inflation level, unlike the Calvo model. Meanwhile, wage rigidity and wage dispersion are key determinant factors in the transmission mechanism to bring about welfare costs in the two models. Furthermore, we introduce two significant changes in the benchmark model specifications. We first add a cost channel and then model an asymmetric trend inflation AR(1) process. The results show that welfare costs are higher in introducing a cost channel in the Taylor model than without financial frictions. However, we notice a different result in the Calvo model. In addition, welfare costs with an asymmetric trend inflation process are high compared to the symmetrical process. Finally, robustness check exercises provide evidence that Taylor's nominal contracts model offers a relevant alternative to Calvo's model in assessing the New Keynesian model's welfare proprieties.

Keywords: Medium-scale New Keynesian DSGE model, Price Dispersion, Shifting Trend Inflation, Trend Growth, Wage Dispersion

INTRODUCTION

Cette thèse examine les effets de l'inflation tendancielle non-nulle sur la dynamique des variables macroéconomiques et les coûts en bien-être. Les chapitres qui la constituent, abordent les questions centrales de recherche suivantes : L'inflation tendancielle non nulle affecte-t-elle la dynamique des variables macroéconomiques ? Le canal de transmission passe-t-il par une dispersion des prix ou des salaires ? Comment cela affecte-t-il les coûts en bien-être ?

Pour répondre à ces préoccupations, ce travail recourt à la modélisation Néo-Keynésienne de type équilibre général dynamque stochastique à échelle moyenne (DSGE) et s'appuie sur différentes spécifications du trend d'inflation positif. A cet effet, deux hypothéses de base sont formulées : a) la Banque Centrale fixe un objectif d'inflation non-nulle. b) Par manque d'engagement à poursuivre une cible d'inflation fixe, celle-ci varie (voire le trend d'inflation change ou se comporte comme un choc exogène).

Dans la littérature, différentes formes de modéliser l'inflation tendancielle sont proposées. Notons que l'inflation affiche une variation à basse fréquence ou composante tendancielle. Ainsi, comme le soulignent Stock and Watson (2007) et Cogley and Sbordone (2008), cette composante tendancielle (inflation tendancielle) est le moteur d'une grande partie de la dynamique de l'inflation et, en particulier, de sa persistance. Dans cette perspective, elle est cruciale car elle peut affecter la pente de la courbe de Phillips et la politique monétaire optimale. Il n'y a pratiquement pas de théorie à son sujet (Monti et al., 2017), et la plupart des modèles l'ignorent (Clarida et al., 2000) ou l'expliquent par des changements exogènes de la cible d'inflation (Ascari and Sbordone, 2014; Ascari et al., 2018).

Par ailleurs, une littérature abondante a préconisé la modélisation de l'inflation tendancielle comme un choc très persistant, un moyen pour expliquer la forte inflation des années 70 et la dynamique de son évolution au cours des périodes d'après. Elle a examiné ses implications pour différents aspects de la dynamique macroéconomique (Kozicki and Tinsley, 2001; Ireland, 2007; Cogley and Sbordone, 2008; Cogley et al., 2009) et des coûts en bien-être (Nakata, 2014). Ces deux types de modélisaton du trend d'inflation sont retenus dans cette thèse et les lignes qui suivent résument les différents chapitres.

Le chapitre 1 se concentre sur l'examen de l'effet de trend d'inflation constant et positif sur la dynamique des variables macroéconomiques. Plus particulièrement, il étudie le comportement cyclique de markup des prix (Bils, 1987; Nekarda and Ramey, 2013) et de markup des salaires (Gali, Gertler and Lopez-Salido, 2007), et examine leur rôle dans l'explication des effets dynamiques des chocs dans les mdoèles Néo-Keynésiens. Le modèle utilisé s'inspire de Ascari, Phaneuf and Sims (2018). Il constitue le modèle de base pour ce chapitre voire modèle de référence pour le reste du travail. Il incorpore le trend d'inflation non-nulle, les rigidités nominales, les frictions réelles, la croissance exogène qui tire son origne de la croissance technologique neutre et de celle spécifique à l'investissement, et la structure de production 'roundabout'. Dans ce chapitre, ce modèle est exploité pour documenter les sources de la dynamique des markups des prix et des salaires.

Les résultats indiquent que la corrélation contemporaine entre le markup des prix et l'output est procyclique à la suite de choc technologique neutre dans le modèle à prix rigide. Elle est contra-cyclique en réponse au choc à l'efficience marginale d'investment. Et face au choc de politique monétaire, elle est contra-cylique. Ces résultats se maintiennent pour le modèle à salaires rigides, à l'exception du choc technologique neutre, où la corrélation entre le markup des salaires et l'ouput est contra-cyclique. Ils sont aussi observés dans le modèle à prix rigide et à salaires rigides. Par ailleurs, lorsque le trend d'inflation passe de 0% à 4% et de 2% à 4%, l'interaction entre le choc à l'efficience marginale d'investissement et le trend d'inflation affecte la dynamique de markup des salaires plus que celle des prix et produit des effets cycliques assez importants. La contribution majeure de ce chapitre est d'avoir documenté la cyclicité de markup des salaires (Gali et al., 2007).

Le chapitre 2 examine le rôle de la politique monétaire dans la réalisation de la stabilité macroéconomique pendant la Grande Modération (Clarida et al., 2000), et étend cet examen aux implications sur le bien-être. Plus particulièrement, il tente de répondre à la préoccupation suivante : dans quelle mesure les changements de politique monétaire et du trend d'inflation positif affectent-ils le coût de l'inflation dans l'économie américaine d'après-guerre ? Pour ce faire, le modèle de référence est augmenté d'une règle de politique mixte (Coibion and Gorodnichenko, 2011), laquelle comporte une réponse à l'inflation, à la croissance de la production et à l'écart de production (output gap) tel que modélisé dans Rudebusch and Swanson (2012). La période de l'étude est divisée en années avant et après le début des années 80 et la fonction de réaction de la Fed dans le modèle est calibrée sur la base des estimations de Smets and Wouters (2007) et Coibion and Gorodnichenko (2011).

Les résultats révèlent que les coûts de l'inflation sont plus élevés dans la période pre-1980s que dans la période post-1980s. Par ailleurs, réagir fortement à l'output gap peut entraîner des coûts en bien-être plus élevés que réagir à la croissance de la production. Enfin, la croissance tendancielle de productivité et le trend d'inflation positif associés à la rigidité nominale des salaires font que la dispersion des salaires joue un rôle important dans la détermination des coûts de l'inflation. La principale contribution de ce chapitre est lorsque le trend d'inflation positif et la croissance de productivité sont combinés avec la rigidité nominale des salaires à la Calvo, cibler l'output gap est très coûteux en termes de bien-être (Sims, 2013) .

Le chapitre 3 aborde les quesitons spécifiques de recherche suivantes : Comment l'inflation tendancielle positive affecte-t-elle la dynamique des variables macroéconomiques pour générer les coûts en bien-être ? Est-ce le canal de transmission passe-t-il primcipalement par la dispersion des prix ou des salaires ? Ce chapitre est basé sur des études récentes sur le trend d'inflation variable dans le temps lesquelles utilisent le modèle Néo-Kynésien standard avec contrats nominaux des prix à la Calvo pour examiner les coûts en bien-être (Nakata, 2014; Ha, 2018). Nous proposons une nouvelle perspective dans un modèle DSGE Néo-keynésien à échelle moyenne qui tient compte des rigidités nominales des prix et des salaires, du trend d'inflation variable dans le temps, de la croissance exogène, et de la structure de production roundabout. A cet effet, le trend d'inflation positif est modélisé comme variable dans le temps suivant un processus AR (1) stationnaire et très persistant (Nakata, 2014).

Les résultats offrent des nouvelles perspectives sur les effets de trend d'inflation variable sur la dynamique des variables macroéconomiques et les coûts en bien-être. Nous comparons d'abord les deux économies d'inflation tendancielle constante et variable dans le temps. Les résultats montrent que les coûts en bien-être conditionnés par les moyennes sont plus importants dans l'économie avec trend d'inflation variable que dans celle à trend d'inflation constant et positif. En examinant le rôle des rigidités nominales de prix ou des salaires sur le bien-être, il ressort que la fréquence d'ajustement des prix ne varie pas avec le niveau du trend d'inflation. Par conséquent, les coûts en bien-être sont modestes et moindres dans un environnement de rigidité nominale des prix. Par contre, dans un environnement de rigidité nominale des salaires, les pertes équivalentes à la consommation sont beaucoup plus importantes quand le trend d'inflation est plus élevé. Nous avons noté que le mécanisme de transmission passe principalement par l'interaction entre la croissance tendancielle et la rigidité nominale des salaires, quand le trend d'inflation augmente. De ce fait, les salaires sont plus dispersés ce qui affecte la demande de consommation des ménages, la main-d'œuvre et la production, et entraîne des coûts en bien-être plus importants. Cette analyse met en évidence plusieurs caractéristiques essentielles omises dans la plupart des études utilisant les contrats nominaux de Calvo sur les questions de bien-être, dont l'absence entraîne des coûts d'inflation modestes ou inférieurs, comme c'est le cas dans Nakata (2014); Ha (2018) et Lê et al. (2019).

Dans le chapitre précédent, l'analyse de sensibilité révèle que les coûts en bien-être basés sur les contrats nominaux de Calvo sont très sensibles aux variations du trend d'inflation et des paramètres clés du modèle. Ce fait jette un doute sur la capacité de ces contrats nominaux à évaluer les propriétés normatives des modèles Néo-Keynésien (Phaneuf and Victor, 2019b). Certains critiques préconisent l'utilisation d'autres classes de modèles dans lesquels ces coûts sont probablement plus faibles (Nakata, 2014; Nakamura et al., 2018). Au chapitre 4, nous enrichissons l'analyse du chapitre 3 en y ajoutant les contrats nominaux échelonnés de Taylor, les frictions finacières et une spécification asymétrique du processus AR(1) de trend d'inflation variable dans le temps.

L'analyse des moments du second ordre révèle que le trend d'inflation positif variable dans le temps améliore l'appariement des volatilités de l'inflation et des taux d'intérêt dans les données et fait mieux que dans le modèle avec trend d'inflation constant. Par ailleurs, les résultats indiquent que la dispersion des salaires joue un rôle déterminant dans le mécanisme de transmission qui affecte les coûts en bien-être dans les deux modèles lorsque l'inflation tendancielle augmente. Cependant, ces coûts sont plus faibles et modestes dans le modèle de Taylor et moins sensibles aux variations du trend d'inflation et des paramètres clés contrairement au modèle de Calvo. En outre, deux changements majeurs sont introduits dans les deux modèles : les frictions financières sous la forme d'un fonds de roulement étendu (extended working capital) et un processus AR(1) asymétrique du trend d'inflation. Avec ces changements, les coûts en bien-être avec frictions financières sont plus élevés dans le modèle de Taylor que dans celui de Calvo. En outre, les coûts en bien-être avec un processus asymétrique sont élevés par rapport à ceux du processus symétrique dans les deux modèles. La contribution majeure de ce chapitre est qu'il complète la littérature existante sur le trend d'inflation positif variable dans le temps, en proposant des contrats nominaux de Taylor pour examiner les questions liées aux coûts en bien-être.

CHAPTER I

THE CYCLICAL BEHAVIOR OF MARKUPS IN THE NEW KEYNESIAN MODELS

Abstract

Different methods have been used in the literature to measure and analyze price markup cyclical behavior. We use a medium-scale DSGE Model with positive trend inflation, in which neutral technology, marginal efficiency of investment, and monetary policy shocks drive aggregate fluctuations and where both price and wage markups vary. We find that when raising trend inflation from 0% to 4% and 2% to 4%, wage markup is more important than price markup in explaining the dynamics effects of shocks. Therefore, the interaction between positive trend inflation and marginal efficiency of investment shock has more significant cyclical effects on wage markup than on price markup. These results put into question the focus on the price markup cyclicality in the literature, which ignores the implications of trend inflation and wage markup.

JEL classification: E31, E32.

Keywords: Medium-scale dsge model; Markups; Cyclicality

1.1 Introduction

Nominal price and wage rigidities are essential components of medium-scale DSGE models, with price and wage markups playing a vital role in the propagation mechanism. Measuring markups and estimating their cyclicality is one of the more challenging issues in modern dynamic macroeconomics literature.

Different methods [1] have been used to examine price markup cyclicality and its role in explaining the dynamic effects of shocks in the New Keynesian Models, with mixed results. Most of the papers have tended to find procyclical or acyclical price markup (Domowitz, Hubbard and Petersen, 1986; Haskel, Martin and Small, 1995; Morrison, 1994; Chirinko and Fazzari, 1994; Nekarda and Ramey, 2013). However, the others find evidence supporting countercyclical price markup (Bils, 1987; Rotemberg and Woodford, 1999). In support of this evidence, modern theories predict that price markup should move opposite directions to supply and demand shocks. This result is behind the stylized facts at the foundation of modern New Keynesian models (Erceg, Henderson and Levin, 2000; Smets and Wouters, 2003, 2007; Christiano, Eichenbaum and Evans, 2005).

Accordingly, in light of existing mixed results, Blanchard (2008) argues that:

> ' *How markups move, in response to what, and why, is however nearly terra incognita for macro. We have a number of theories. ... Some of these theories imply pro-cyclical markups so that an increase in output leads to a larger increase in the desired price, and thus to more pressure on inflation. Some imply, however, counter-cyclical markups, with the opposite implication. ..... But we are far from having either a clear picture or convincing theories and this is clearly an area where research is urgently needed'.*
> '

The literature on price markup [2] shows that it plays an essential role in explain-

1. Nekarda and Ramey (2013) have surveyed four methods.

2. To our knowledge, the literature on the identification of wage markup cyclicality is not available.

ing shocks' dynamic effects. Most of the work considers the framework where only price markup varies, i.e., a sticky-price model with imperfect competition (Rotemberg, 1982). It is clear that with sticky-prices, the price markup varies in response to shocks and that the wage markup varies with sticky wages. Our main question is, what happens if both price and wage markups vary, assuming non-zero steady-state inflation?

To answer this question, we analyze price and wage markups cyclicality using an extended medium-scale DSGE model. Specifically, we aim to document the determinants of price and wage markups cyclicality, considering positive trend inflation. The proposed theoretical framework is inspired by Ascari, Phaneuf and Sims (2018), which builds upon earlier work by Christiano, Eichenbaum and Evans (2005). They extended this model along four important dimensions. First, they incorporate non-zero steady-state inflation. Second, they added real per capita output growth originating from two distinct growth's sources: trend growth in investment-specific technology (IST) and neutral technology (TFP). Third, consistent with Justiniano, Primiceri and Tambalotti (2011), they assume that marginal efficiency of investment (MEI) shocks are the only investment shocks affecting the business cycle. Fourth, they added a roundabout production structure in the spirit of Basu (1995) and Huang, Liu and Phaneuf (2004).

They use this framework to address two main issues. First, moderate trend inflation's welfare costs. Second, it considers whether moderate trend inflation alters a medium-scale macro model's business-cycle properties in non trivial ways. However, we use the same class of model to assess how positive trend inflation affects the responses of price and wage markups cyclical behavior in explaining the dynamics effects of shocks. Our primary interest is to document sources of price and wage markups cyclicality in the presence of non-zero steady-state inflation.

The benchmark model nests alternative specifications: sticky-price model, sticky-wage model, and sticky-price and sticky-wage model. In each case, various dimensions have been considered. Altogether, twelve stylized models have been analyzed in responses to neutral technology, MEI, and monetary shocks. We then compare contem-

The only exception is the seminal paper by Gali, Gertler and Lopez-Salido (2007).

poraneous correlations of output growth over markups (price and wage) conditional on shocks, as trend inflation increases from 0% to 4% and from 2% to 4%. We find the following main results in our baseline model.

First, the results show that steady-state aggregate price and wage markups exhibit a non-linear trend as trend inflation increases. However, the magnitude of this non-linearity is smaller in the price markup case, while it is much higher in the case of steady-state aggregate wage markup. Put differently, steady-state price markup is weakly related to variations in trend inflation (Nakamura et al., 2018).

Second, we find that when both wage and price markups vary and trend inflation rises from 0% to 4% and from 2% to 4%, conditional correlation of output growth over price markup is procyclical following a neutral technology shock and counter-cyclical in the case of wage markup (Bils, 1987; Gali et al., 2007). Consecutive to a MEI shock, these conditional correlations are either procyclical or counter-cyclical in the case of price markup, and counter-cyclical for the wage markup. Conditional on monetary shock, contemporaneous correlations of output growth over price and wage markups are counter-cyclical in both cases (Rotemberg and Woodford, 1999; Nekarda and Ramey, 2013).

Third, we show that these results have implications on sources of aggregate fluctuations. Indeed, the results indicate that when trend inflation goes from 0% to 4% and 2% to 4%, price markup fluctuations are of a smaller order of magnitude conditional on MEI and neutral technology shocks than those observed in the case of wage markup. However, the interaction between positive trend inflation and MEI shock is more important than the interaction with TFP shock and have more significant cyclical effects on wage markup than on price markup. Furthermore, we observe that this interaction between generates more inefficient wage dispersion which in turn reflects in fluctuations of steady-state and stochastic mean wage markups. Hence, wage markup is more important than price markup in explaining the dynamic effects of shocks in the presence of non-zero steady-state inflation. This result is consistent with what is available in the literature (Ascari et al., 2018).

Finally, returning to the Blanchard's quote, we can summarize the contribution of this chapter as follows. When both price and wage markups vary and trend inflation is positive, fluctuations of the labor wedge mainly reflect fluctuations of the wage markup. Therefore, wage markup cyclical behavior deserves a key place in research on business cycles alongside price markup. In addition, this work has the merit of documenting the determinants of price and wage markups dynamics, using a medium-scale New Keynesian DSGE model with non-zero steady-state inflation.

The remainder of the paper proceeds as follows. In section 2.2, we outline our baseline model specification. In section 2.3, we discuss the calibration of the structural parameters. We present results in section 2.4 and concluding remarks in Section 1.5.

1.2 The Model

We use a medium-scale DSGE model inspired by Ascari et al. (2018). We abstract from zero lower bound on interest rates which would be challenging because of many state variables in the model. We assume no indexation either in prices or in wages since there is no strong evidence as supported by Christiano et al. (2016). We allow for positive trend inflation, trend growth, and roundabout production structure. The economy is inhabited by three types of agents, risk-averse households, production firms and a central bank.

The subsections below outline the decision problems and optimal conditions of different actors in the model, specify stochastic processes for exogenous variables, and give aggregate equilibrium conditions. The full set of detrended equations describing the equilibrium conditions are presented in the appendix.

1.2.1 Households and wage setting

Labor aggregators

The economy features a continuum of households, indexed by $h \in [0,1]$. They are monopoly suppliers of $N_t^d(h)$ units of differentiated labor to a "labor packing firm". This firm assembles heterogeneous labor inputs into a homogeneous labor unit. The bundling technology is given by:

$$N_t^d = \left(\int_0^1 N_t(h)^{\frac{\sigma-1}{\sigma}} dh \right)^{\frac{\sigma}{\sigma-1}}, \sigma > 1 \tag{1.1}$$

where σ denotes the constant elasticity of substitution (CES) between labor types. Labor aggregator is a price-taker in both their output and input markets. He sells composite labor to intermediate producers at the aggregate wage, W_t and unit of differentiated labor costs is $W_t(h)$. The profit maximization problem of the labor aggregating firm gives a downward-sloping demand for each variety of labor:

$$N_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\sigma} N_t^d. \tag{1.2}$$

Inserting this demand function for input h back into the CES aggregator yields the aggregate wage index, i.e

$$W_t^{1-\sigma} = \int_0^1 W_t(h)^{1-\sigma} dh. \tag{1.3}$$

Households

Households maximize expected present discounted value of their lifetime utility function, subject to an inter temporal budget constraint. Preferences are additively separable in consumption and labor, and allows for habit formation in consumption. They own intermediate firms, lend capital services (the product of physical capital and utilization) to firms and make investment and capital utilization decisions. Capital is predetermined at the beginning of a period, but households can adjust its utilization rate subject to some costs. At the end of each period, the household receives nominal dividend payments resulting from the ownership of intermediate-goods-producing firms. They additionally hold their financial wealth in the form of one-period, state-contingent bonds. Financial markets are assumed to be complete. The problem of an individual household can be written [3] :

$$\max_{C_t, N_t(h), K_{t+1}, B_{t+1}, I_t, Z_t} \quad E_0 \sum_{i=0}^{\infty} \beta^i \left(\ln\left(C_{t+i} - bC_{t+i-1}\right) - \eta \frac{N_{t+i}(h)^{1+\chi}}{1+\chi} \right), \tag{1.4}$$

subject to

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

and

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

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

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

where $0 < \beta < 1$ is a discount factor, $0 < \delta < 1$ a depreciation rate, and $0 \leq b < 1$ is a parameter for habit formation. χ is the inverse Frisch elasticity of labor supply. κ is an investment adjustment cost parameter that is strictly positive. P_t is the nominal price of goods. C_t is consumption, I_t investment, $N_t(h)$ labor input, and K_t physical capital. R_t^k is a nominal rental rate on capital services, and i_t the nominal interest rate. B_t is the stock of nominal bonds with which a household enters a period and B_{t+1} is a stock of nominal governmental bonds in period t+1. Π_t^n denotes (nominal) profits

3. Utility is separable and we assume that households are identical with respect to non-labor choices; hence we will drop the h subscripts in subsequent sections. For detail, see Erceg, Henderson and Levin (2000).

remitted by firms, and T_t is a lump sum taxes from the government. Z_t is the level of capital utilization and $a(Z_t)$ is a function mapping utilization of capital into the depreciation rate, with parameters γ_1 and γ_2, providing that $a(1) = 0$, $a'(1) = 0$, and $a''(1) > 0$. $S\left(\frac{I_t}{I_{t-1}}\right)$ 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 growth rate of investment.

The investment-specific term $\varepsilon_t^{I,\tau}$ follows the deterministic trend with no stochastic component [4]:

$$\varepsilon_t^{I,\tau} = g_{\varepsilon^I} \varepsilon_{t-1}^{I,\tau} \tag{1.5}$$

where g_{ε^I} is the gross growth rate and grows at the gross rate $g_{\varepsilon^I} \geq 1$ in each period [5].

The exogenous variable ϑ_t captures the stochastic marginal efficiency of investment shock :

$$\vartheta_t = \left(\vartheta_{t-1}\right)^{\rho_I} \exp\left(s_I u_t^I\right), with\ \ u_t^I \sim iid\left(0,1\right). \tag{1.6}$$

The auto regressive parameter ρ_I governs the persistence of the process and satisfies $0 \leq \rho_I < 1$. The shock is scaled by the known standard deviation equal to s_I and u_t^I is the innovation drawn from a mean zero normal distribution.

The first-order conditions for consumption, capital utilization, investment, capital and bonds are respectively :

$$\lambda_t^r = \frac{1}{C_t - bC_{t-1}} - E_t \frac{\beta b}{C_{t+1} - bC_t}, \tag{1.7}$$

$$r_t^k = \frac{a'\left(Z_t\right)}{\varepsilon_t^{I,\tau}}, \tag{1.8}$$

$$\lambda_t^r = \mu_t \varepsilon_t^{I,\tau} \vartheta_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\right] + \beta E_t \mu_{t+1} \varepsilon_{t+1}^{I,\tau} \vartheta_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right)\left[\frac{I_{t+1}}{I_t}\right]^2, \tag{1.9}$$

4. For more details see Justiniano, Primiceri and Tambalotti (2011) who have documented the distinction between two types of investment shocks and their relative importance.

5. With the implicit normalization that it begins at 1 in period 0 i.e $\varepsilon_0^{I,\tau} = 1$

$$\mu_t = \beta E_t \lambda_{t+1}^r \left(r_{t+1}^k Z_{t+1} - \frac{a(Z_{t+1})}{\varepsilon_{t+1}^{I,\tau}} \right) + \beta(1-\delta) E_t \mu_{t+1}, \tag{1.10}$$

$$\lambda_t^r = \beta E_t \lambda_{t+1}^r (1+i_t) \pi_{t+1}^{-1}, \tag{1.11}$$

where $\lambda_t^r \equiv P_t \lambda_t$, which is the marginal utility of an extra good, $r_t^k \equiv \frac{R_t^k}{P_t}$ the real rental rate on capital services and $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross inflation.

Wage-setting

Let's consider the problem related to Households wage-setting. We assume a Calvo-style staggered wage contracts and no indexation. Each period a randomly selected fraction of Households get to update their nominal wage with the probability $(1-\xi_w)$, where $\xi_w \in [0,1]$. This means that ξ_w of households cannot adjust their nominal wage. The optimal wage $W_t(i)$ is obtained by maximizing :

$$E_t \sum_{h=0}^{\infty} (\beta \xi_w)^h \left(-\frac{\eta}{1+\chi} (N_{t+i}(h))^{-\sigma(1+\chi)} + \lambda_{t+i} W_t(h) N_{t+i}(h) \right), \tag{1.12}$$

subject to

$$N_{t+i}(h) = \left(\frac{W_t(h)}{W_{t+i}} \right)^{-\sigma} N_{t+i}^d,$$

$$W_t(h) = \begin{cases} W_t^*(h) & \text{if } W_t(h) \text{ chosen optimally} \\ W_{t-1}(h) & \text{otherwise.} \end{cases}$$

The first order condition implies that all households will choose the same reset wage, denoted in real terms and given by:

$$w_t^* = \frac{\sigma}{\sigma-1} \frac{h_{1,t}}{h_{2,t}}. \tag{1.13}$$

Recursively the terms $h_{1,t}$ and $h_{2,t}$ evolve as follows

$$h_{1,t} = \eta \left(\frac{w_t}{w_t^*}\right)^{\sigma(1+\chi)} \left(N_t^d\right)^{1+\chi} + \beta \xi_w E_t (\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{w_{t+1}^*}{w_t^*}\right)^{\sigma(1+\chi)} h_{1,t+1}, \quad (1.14)$$

$$h_{2,t} = \lambda_t^r \left(\frac{w_t}{w_t^*}\right)^{\sigma} N_t^d + \beta \xi_w E_t (\pi_{t+1})^{\sigma-1} \left(\frac{w_{t+1}^*}{w_t^*}\right)^{\sigma} h_{2,t+1}. \quad (1.15)$$

1.2.2 Firms and Price setting

Firms production takes place in two stages. First there is a continuum of intermediate goods firms, each producing a differentiated material input under monopolistic competition using a production function with Cobb-Douglas technology and fixed costs. They set nominal prices on a staggered basis *à* la Calvo. Final goods producers then combine these inputs intermediate inputs according to a CES technology into output, which they sell to households under perfect competition.

Final Goods Producers

The final good producer uses $X_t(j)$ units of intermediate goods to produce X_t units of final good. There is a continuum of intermediate goods firms indexed by $j \in (0,1)$, producing differentiated goods. The final good is a constant elasticity of substitution aggregate of intermediate goods, using the production technology given by :

$$X_t = \left(\int_0^1 X_t(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}, \theta > 1. \quad (1.16)$$

The final goods producer maximizes profit, given a final good price, P_t and taking intermediate good prices, $P_t(j)$, as given. The first-order condition gives the conditional demand for intermediate good j :

$$X_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\theta} X_t, \quad \forall j. \tag{1.17}$$

Inserting the demand function for input j back into the CES aggregator gives the aggregate price index:

$$P_t^{1-\theta} = \int_0^1 P_t(j)^{1-\theta} dj. \tag{1.18}$$

Intermediate Producers

Each intermediate-good firm, indexed by j, uses $\widehat{K}_t(j)$ [6] units of capital services, $N_t^d(j)$ units of labor, and intermediate inputs, $\Upsilon_t(j)$, to produce $X_t(j)$ units of the intermediate good j. Its production function is given by :

$$X_t(j) = \max\left\{A_t \Upsilon_t(j)^{\phi}\left(\widehat{K}_t(j)^{\alpha} N_t^d(j)^{1-\alpha}\right)^{1-\phi} - \Psi_t \bar{Z}, 0\right\}, \tag{1.19}$$

where $\phi \in (0,1)$ is the intermediate input share while $\alpha \in (0,1)$ and $(1-\alpha)$ are value-added share with respect to capital services and labor inputs, $\bar{Z}$ is a fixed cost, that is identical across firms. It is chosen so that steady state profits equal to zero, given a growth factor Ψ_t.

The neutral technology A_t follows a process with both a trending and stationary component :

$$A_t = A_t^{\tau} \widetilde{A}_t, \tag{1.20}$$

where the deterministic trend component A_t^{τ} grows at the gross rate $g_A \geq 1$ in each period [7] such that :

$$A_t^{\tau} = g_A A_{t-1}^{\tau}. \tag{1.21}$$

6. It is the product of utilization and physical capital

7. With the implicit normalization that it begins at 1 in period 0 i.e $A_0^{\tau} = 1$

The stochastic process driving the detrended level of technology $\widetilde{A}_t$ is given by

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(s_A u_t^A\right), \tag{1.22}$$

which, taking its natural logarithm, yields

$$\ln \widetilde{A}_t = \rho_A \ln \widetilde{A}_{t-1} + s_A u_t^A, \quad u_t^A \sim iid\,(0,1). \tag{1.23}$$

The auto regressive parameter ρ_A governs the persistence of the process and satisfies $0 \leq \rho_A < 1$. The shock is scaled by the known standard deviation equal to s_A and u_t^A is the innovation, drawn from a mean zero normal distribution.

Cost Minimization

The producer of differentiated goods j is assumed to set its price, $P_t(j)$, according to Calvo pricing (Calvo, 1983) and decides in every period its quantities of intermediates, capital services, and labor input. The cost of intermediate is just the aggregate price level, P_t. The user cost of capital and labor are R_t^k and W_t (in nominal terms), respectively.

The cost-minimization problem of a typical firm choosing its inputs is given by :

$$\min \quad P_t \Upsilon_t(j) + R_t^k \widehat{K}_t + W_t N_t^d(j) \tag{1.24}$$

subject to

$$A_t \Upsilon_t(j)^{\phi} \left(\widehat{K}_t(j)^{\alpha} N_t^d(j)^{1-\alpha}\right)^{1-\phi} - \Psi_t \bar{Z} \geq \left(\frac{P_t(j)}{P_t}\right)^{-\theta} X_t.$$

Profit Maximization and Price Setting

Each intermediate producing firm [8] chooses its price $P_t(j)$ that maximizes the expected present discount value of its future profit. The firm problem is given by :

$$\max_{P_t(j)} \quad E_t \sum_{i=0}^{\infty} (\xi_p)^i D_{t,t+i} \left(P_t(j) X_{t+i}(j) - V\left(X_{t+i}(j)\right)\right) \tag{1.25}$$

subject to

$$X_{t+i}(j) = \left(\frac{P_t(j)}{P_{t+i}}\right)^{-\theta} X_{t+i}$$

$$P_t(j) = \begin{cases} P_t^*(j) & \text{if } P_t(j) \text{ chosen optimally} \\ P_{t-1}(j) & \text{otherwise} \end{cases}$$

where $D_{t,t+i}$ is the discount rate for future profits and $V(X_t(j))$ is the total cost of producing good $X_t(j)$. Note that $D_{t,t+i} = \frac{\beta^i \lambda_{t+i}}{\lambda_t}$. Written in real terms, it is $\frac{P_{t+i} D_{t,t+i}}{P_t}$. Hence, the real discount factor is $\frac{\beta^i P_{t+i} \lambda_{t+i}}{P_t \lambda_t}$, which we can write as: $\frac{\beta^i \lambda_{t+i}^r}{\lambda_t^r}$, where $\lambda_t^r = P_t \lambda_t$. The first-order condition for $p_t^*(j)$ is :

$$p_t^*(j) = \frac{\theta}{\theta - 1} \frac{\sum_{i=0}^{\infty} (\xi_p \beta)^h \lambda_{t+i}^r mc_{t+i}(j) \pi_{t+1,t+i}^{\theta} X_{t+i}}{\sum_{i=0}^{\infty} (\xi_p \beta)^i \lambda_{t+i}^r \pi_{t+1,t+i}^{\theta-1} X_{t+i}}, \tag{1.26}$$

where $p_t^*(j) = \frac{P_t(j)}{P_t}$ is the real optimal price and mc_t the real marginal cost, which is equal to $\frac{V'(X_{t+i}(j))}{P_{t+i}}$.

8. A fraction $(1 - \xi_p)$ of these firms can optimally adjust its price (Calvo, 1983).

1.2.3 Monetary Policy

Monetary policy consists of a talor-type rule. It responds to deviations of inflation from an exogenous steady state target, π, and to deviations of output growth from its trend level, g_Y, and is of the form :

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i} \left[\left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y_{t-1}} g_Y^{-1}\right)^{\alpha_y}\right]^{1-\rho_i} \varepsilon_t^r. \tag{1.27}$$

with i_t and i the nominal and steady state interest rate respectevely, $\frac{\pi_t}{\pi}$ the inflation gap, $\frac{Y_t}{Y}$ the output growth, ρ_i the interest rate smooting, α_π and α_y the control parameters, and ε_t^r an exogenous shock to the policy rule, where $\varepsilon_t^r \sim N\left(0, \sigma_{\varepsilon^r}^2\right)$. To ensure determinacy, we assume that $0 \leq \rho_i < 1$, $\alpha_\pi > 1$ and $\alpha_y \geq 0$.

1.2.4 Aggregation

The aggregate inflation and the real wage evolve according to:

$$1 = \xi_p (\pi_t)^{\theta-1} + (1-\xi_p)\left(p_t^*\right)^{1-\theta}, \tag{1.28}$$

$$w_t^{1-\sigma} = \xi_w \left(\frac{w_{t-1}}{\pi_t}\right)^{1-\sigma} + (1-\xi_w)\left(w_t^*\right)^{1-\sigma}. \tag{1.29}$$

Market-clearing requires that $\int_0^1 \widehat{K}_t(j)dj = \widehat{K}_t$, $\int_0^1 N_{d,t}(j)dj = N_t$ and $\Upsilon_t = \int_0^1 \Upsilon_t(j)dj$ respectively for capital services, labor inputs and intermediate inputs. Hence, aggregate gross output can be written as

$$s_t X_t = A_t \Upsilon_t^{\phi} \left(\widehat{K}_t^{\alpha} N_t^{1-\alpha}\right)^{1-\phi} - \Psi_t \bar{Z} \tag{1.30}$$

and the aggregate input demands as

$$\Upsilon_t = \phi mc_t \left(s_t X_t + \Psi_t \bar{Z}\right), \tag{1.31}$$

$$\widehat{K}_t = \alpha(1-\phi)\frac{mc_t}{r_t^k}\left(s_t X_t + \Psi_t \bar{Z}\right), \tag{1.32}$$

$$N_t = (1-\alpha)(1-\phi)\frac{mc_t}{w_t}\left(s_t X_t + \Psi_t \bar{Z}\right). \tag{1.33}$$

where s_t denotes the price dispersion term and can be written recursively:

$$s_t = (1-\xi_p)p_t^{*-\theta} + \xi_p\left(\pi_t\right)^{-\theta} s_{t-1}. \tag{1.34}$$

With real GDP being the aggregate production of the goods, X_t, minus the aggregate production of intermediate inputs, the aggregate net output, Y_t is given by:

$$Y_t = X_t - \Upsilon_t. \tag{1.35}$$

The aggregate resource constraint is therefore given by:

$$Y_t = C_t + I_t + \frac{a(Z_t)}{\varepsilon_t^{I,\tau}} K_t. \tag{1.36}$$

1.3 Parametrization and Selected Moments

In order to generate quantitative results, a calibration of model parameters needs to be settled. Table 1.1 summarizes our baseline model parameter values into non-shock and shock parameters (Ascari, Phaneuf and Sims, 2018).

1.3.1 Non-shock Parameters

We set our non-shock parameters, which are standard in the literature, as follows: the discount factor (β) is about 0.99. The capital depreciation rate (δ) equals to 0.025, corresponding to an annual capital depreciation of 10 percent. The capital services share amounts to 1/3. η the scaling parameter on disutility from labor is 6 and the inverse Frisch elasticity of labor supply (χ) equals to 1. Consumption habit formation is $b = 0.7$ (Fuhrer, 2000). The investment adjustment cost is set to $\kappa = 3$ (Christiano, Eichenbaum and Evans, 2005). We choose the utilization cost, γ_2 equals to 0.05 to match capital utilization elasticity of 1.5 (Basu and Kimball, 1997; Dotsey and King, 2006).

The elasticity parameters for goods and labor are set to a uniform value $\sigma = \theta = 6$, implying a steady-state price and wage markups of 20 percent (Liu and Phaneuf, 2007). With $\theta = 6$, this implies intermediate inputs share ϕ of 0.61.

The Calvo price and wage parameters are set to $\xi_p = 0.66$ and $\xi_w = 0.75$, respectively. The Calvo price is consistent with the evidence reported in Bils and Bils and Klenow (2004) and the value assigned to the Calvo probability of wage with the evidence reported in Christiano et al. (2005).

For the parameters of the monetary policy rule, we set the smoothing coefficient to $\rho_i = 0.75$, $\alpha_\pi = 1.5$ for the coefficient on inflation, and $\alpha_y = 0.2$ for the coefficient on output growth. These values are standard in the literature.

1.3.2 Trend inflation, Trend Growth, and Shock Parameters

Following Ascari et al. (2018), trend growth and inflation are calibrated to fit the data's observable features. The price index's average growth rate over the period 1960:I-2007:III is 0.008675. It implies a steady-state level of trend inflation of 3.52 percent annualized (i.e., $\pi^* = 1.0352^{0.25}$). The output per capita's average growth rate, over the same period, is 0.005712, which corresponds to an output growth rate of $g_Y = 1.005712$ or 2.28 at an annual frequency. The average growth rate of the relative price of investment over the period is -00472. It suggests the value of $g_I = 1.00472$. Given the values of g_I and ϕ, we set g_A value to 1.0022 $(i.e., g_A^{1-\phi} = 1.0022)$ to generate the appropriate output volatility observed in the data.

For the parameters governing the shock processes, we proceed as follows. Given the growth rates of real GDP and trend inflation , we set shocks to neutral technology (σ_A), (hereafter TFP), to the marginal efficiency of investment (σ_I), (hereafter MEI), and monetary policy (σ_r). to match output growth volatility over the sample period. Following Ascari et al. (2018) and Phaneuf and Victor (2019b), we take a stand on the percentage contribution of each type of shocks to output growth volatility.

The MEI shocks contribution is about 50 percent, based on the evidence produced by Justiniano et al. (2011) and others (Fisher, 2006a; Justiniano and Primiceri, 2008a; Justiniano et al., 2010b; Altig et al., 2011). The neutral technology shock is set to 35 percent, and the monetary policy shock 15 percent. The AR(1) parameters of the neutral and marginal efficiency of investment shocks are set to a constant value of 0.95 ($\rho_A = \rho_I = 0.95$) with the resulting shocks' variances: $s_I = 0.0176$, $s_A = 0.0022$, and $s_r = 0.0019$.

1.3.3 Selected Moments

Table 1.2 reports the selected moments. Some statistics implied by the model match the data: the mean value of real per capita output growth, the variability of inflation and the volatility of output growth at 0.0057, 0.0064, and 0.0078, respectively. The others are either very close (e.g., the volatility of consumption, Inflation persistence) or slightly higher (e.g., the volatility of output) if not somewhat higher (e.g., the volatility of an investment, positive autocorrelation in output growth) in the model relative to the data.

Therefore, the model delivers an exact match of the average growth rate of real per capita output, the volatility of output growth, and the variability of inflation during the postwar era, thus performing very well along standard business-cycle dimensions.

1.4 The Results

In this section, we examine the cyclical behavior of price and wage markups in the benchmark model. First, we show how the steady-state price and wage markups behave when trend inflation increases. We then analyze their role in explaining the dynamic effects of shocks as trend inflation rises from 0% to 4% and from 2% to 4%.

1.4.1 Trend Inflation and Steady-State Markups

In the log-linearized equilibrium conditions (Appendix 1.A), variables are expressed as log deviations from their respective steady-state. In this perspective, we first examine how do changes in trend inflation affect the steady-state price and wage markups when trend inflation augments. The steady-state equations of price (Appendix 1.B) and wage (Appendix 1.C) markups are presented in the Appendix. The equations obtained succinctly summarize their respective determinants. The steady-state price markup depends on three factors: the discount factor, the elasticity of substitution between differentiated goods, and the trend inflation's level. While, the steady-state wage markup is related to the discount factor, the steady-state growth rate of real per capita output, the elasticity of substitution between differentiated labor skills, the inverse Frisch elasticity of labor supply, and the level of trend inflation.

We plot the deterministic steady-state levels of wage and price markups at various trend inflation rates in figure 1.1. In this figure (Right panel), we observe that at 2% of trend inflation, the steady-state wge markup is around 0.22% at the impact. It passes to 0.26% and 0.56% when trend inflation rises to 4% and 8% respectively. For the steady-state price markup (Figure 1.1, left panel), these features are 0.180%, 0.182%, and 0.19%, respectively. From these results, we notice a nonlinear relationship between trend inflation and steady-state aggregate markups. Put differently, a given amount of increase in trend inflation leads to a larger increase in the steady-state levels of both markups in response to higher trend inflation. However, when referring to the Y-axis scale in both graphs, we observe a greater impact on the steady-state wage markup compared to the steady-state price markup case i.e., the latter is weakly related to changes in trend inflation (Nakamura, Steinsson, Sun and Villar, 2018). The relative magnitude of this non-linearity is a key factor in understanding the role of wage and price markups in explaining the dynamic effects of shocks.

1.4.2 Markups' Cyclical Behavior

Tables 1.3 to 1.8 report the conditional correlations between markups and output across alternative models. These correlations are either negative (countercyclical) or positive (procyclical) conditional to individual shock. Figures 1.2 to 1.10 report the impulse-responses of variables of interest.

Figures 1.2, 1.5, and 1.8 report the impulse-responses of our variables of interest. They reveal that, under zero trend inflation, hours (output and real wage) fall on impact in responses to a positive TFP shock causing the marginal product of labor (hereafter MPL) to increase (or the marginal cost to decrease). Because of the sticky-price, the price cannot adjust immediately, and this gives rise to procyclical movements in price markup in the short run to nearly acyclical movements in the medium run.

From tables 1.3, 1.4, 1.7, and 1.8, we see that raising trend inflation from 0 to 4 percent has no significant impact on the magnitude of price markup cyclicality following a positive TFP shock. The primary reason is whether trend inflation is 0 or 4 percent, the price level and inflation responses are approximately the same, i.e., the TFP shock has little effect on inflation. Our results complement and qualify several other contributions in the literature regarding the effects of TFP shock on the price markup cyclicality (Bils, 1987; Rotemberg and Woodford, 1999; Nekarda and Ramey, 2013; Ascari, Phaneuf and Sims, 2018).

However, wage markup comoves negatively with real output in TFP shock responses under zero trend inflation (Tables 1.5 to 1.8). It becomes more countercyclical as trend inflation passes from 0 to 4 percent. With higher labor demand in the medium-term, the marginal disutility of working rises; with higher consumption, the marginal utility of consumption falls. In consequence, the marginal rate of substitution (hereafter MRS) rises further. From the efficiency equilibrium condition, as the MPL and price markup go unresponsive consecutive to positive trend inflation and the MRS rises, the wage markup becomes more negative to adjust. Thus, the interaction between positive trend inflation and TFP shock significantly impacts on MRS and wage markup.

In tables 1.7 and 1.8 and figure 1.9, we summarize the contemporaneous correlations and impulse-responses of the main variables in response to MEI shock. Under zero trend inflation, a positive MEI shock leads to a fall in the MPL consecutive to an increase in hours. As the MPL declines, the marginal cost increases. Due to price rigidity, price markup decreases but comoves negatively with output. Meanwhile, following the hours' increase and consumption response on impact, the MRS also increases. As a result, wage markup falls but comoves negatively with real output.

When raising trend inflation from 0 to 4 percent, price markup remains countercyclical with no significant changes in magnitude, whereas wage markup changes from countercyclical to procyclical (Table 1.7) and with significant changes in magnitude (Table 1.8). The interaction between trend inflation and MEI shock has more substantial distorting effects as wage dispersion is much stronger than the price dispersion. It leads to the threads of wage erosion. In consequence, households set higher wage markup with higher trend inflation. Thus, the interplay between non-zero steady-state inflation and MEI shock has a more significant impact on wage markup than on price markup.

In our benchmark model, monetary policy shock indirectly impacts the MPL and labor demand schedules through intermediate inputs and capital utilization. Figure 1.10 gives the impulse-responses of variables related to a positive monetary policy shock. It leads to lower real output (MPL, intermediate inputs, and capital utilization) and consumption. Meanwhile, the lower demand for goods pushes down the demand for labor input. With lower labor demand, the marginal disutility of working falls; with lower consumption, the marginal utility of consumption rises. Thus, MRS falls so does the real wage. Since the real wage is part of the real marginal cost, the later falls, so the price markup rises but negatively affects the real output. As MPL and MRS fall, price markup rises, from the efficiency equilibrium condition, so the wage markup rises to adjust (Tables 1.7 and 1.8).

When raising trend inflation from 0 to 4 percent, there is a relatively small impact on MPL, MRS, price, and wage markups. Thus, the interaction between positive trend inflation and monetary policy shock has no significant impact on price and wage markups, i.e., trend inflation has little distorting effects on the efficiency equilibrium condition

(Figure 1.10).

1.4.3 Alternative Case

Trend inflation measured as 'average inflation over each of the decades in the US data' is positive. Moreover, the average inflation over the past 30 years has hovered around 2% (Nakamura et al., 2018). From a practical standpoint, we include the case of 2%, in addition to the 0% and 4% case. This 2% will indicate how the conditional cyclicality of markups is affected when positive trend inflation alone changes.

Note that the shift from zero to a positive trend inflation modifies the structure of the DSGE model's price-wage Phillips curves. The modified model structure (relative to the 0% case) is the same between these two cases (i.e., the 2% and 4% cases). Therefore, we compare the case from 0% to 4% to the 2% to 4% case, to isolate the effects of changes in positive trend inflation alone.

Table 1.9 reports conditional correlations of the first-differenced and hp-filtered output growth over markups for the 2% case. This table is compared to tables 1.7 and 1.8. The results indicate that going from 2% to 4%, contemporaneous correlation of the output growth over price-markup is procyclical conditional on neutral technology shock (Bils, 1987). It's countercyclical in the case of wage-markup (Gali et al., 2007). Conditional on MEI shock, these correlations become either procyclical or counter-cyclical in the case of price-markup, and counter-cyclical for the wage-markup. For monetary shock, these features are counter-cyclical for both markups. These findings are similar to the results in the 0% to 4% case.

The implications of these results on sources of aggregate fluctuations are illustrated in Figures 1.8, 1.9, and 1.10. These figures report the impulse-response of variables of interest (in the baseline model) conditional on neutral technology, MEI, and monetary shocks, respectively. Overall, we notice that when trend inflation goes from 0% to 4% and 2% to 4%, wage markup fluctuations are of a higher order of magnitude conditional on MEI shock (Figure 1.9) and neutral technology shock (Figure 1.8) than those observed in the price markup case. Specifically, when trend inflation interacts with MEI shock (or neutral technology), as trend inflation increases, this generates an inefficient wage dispersion which in turn reflects fluctuations of steady-state and stochastic mean wage markups. This results in a nonlinear relationship between wage markup and trend inflation of a higher magnitude than in the case of price markup. Gali et al. (2007) reach a similar conclusion and show that wage markup, accounts for the bulk of the fluctuations of the labor wedge [9]. However, our results concur with the findings in Bils et al. (2018) which ignore the implication of positive trend inflation. They find that price markup movements are at least as important as wage markup movements.

Reflecting back on the Blanchard's quote in the motivation, the contribution of this paper regarding markups, is that when trend inflation is positive, and both wage and price markups vary, fluctuations of the labor wedge predominantly reflect fluctuations of the wage markup. Therefore, we find that wage markup cyclical behavior deserves a key role in business cycle research alongside price markup.

9. See also Karabarbounis (2014b).

1.5 Conclusion

This paper examines the cyclical behavior of price and wage markups in the News Keynesians Models and their role in explaining the dynamics of shocks when positive trend inflation is considered. In the literature, much more attention has been put on price markup cyclicality. We use an extended medium-scale DSGE model, where both price and wage markup vary relative to non-zero trend inflation. In this framework, aggregate fluctuations are driven by TFP, MEI, and monetary shocks.

The results show that when raising trend inflation from 0% to 4% and 2% to 4%, wage markup is more important than price markup in explaining shocks dynamics effects. We also find that the interactions between positive trend inflation and MEI shock are more important than those with TFP shock and have more significant cyclical effects on wage markup than on price markup. Our results show that the focus on price markup cyclicality in the literature ignores positive trend inflation and wage markup implications.

For future research, the baseline model can be estimated using a Bayesian approach. This approach will make it possible to be fixed on markups cyclical behavior conditional on the estimates obtained in this analysis.

Table 1.1: Model calibration

Parameter	Description	Value
Non-Shock :		
β	Time discount factor	0.99
δ	Depreciation rate on physical capital	0.025
α	Capital services share	$1/3$
η	Weight on labor disutility	6
χ	Inverse Frisch elasticity	1
b	Habit formation parameter	0.7
κ	Investment adjustment cost parameter	3
γ_2	Capital utilization elasticity	0.05
θ	Elasticity of substitution between differentiated goods	6
σ	Elasticity of substitution between differentiated labor types	6
ξ_p	Calvo price probability	0.66
ξ_w	Calvo wage probability	0.66
ϕ	Intermediate inputs share	0.61
ρ_i	Taylor rule smoothing coefficient	0.75
α_π	Taylor rule inflation coefficient	1.5
α_y	Taylor rule output growth coefficient	0.2
Shock :		
ρ_r	Monetary policy shock, error term autocorrelation	0
s_r	Standard deviation of the monetary shock	0.0019
g_A	Neutral productivity growth in trend output	$1.0025^{1-\phi}$
ρ_A	Neutral productivity shock, error term autocorrelation	0.95
s_A	Standard deviation of the neutral shock	0.0022
g_I	Investment-specific productivity growth in trend output	1.0025
ρ_I	Investment productivity shock, error term autocorrelation	0.95
s_I	Standard deviation of the MEI shock	0.0176

Note: Table 1.1 describes key parameters used to solve the model (First and second columns) and provides their respective values in the third column.

Table 1.2: Moments

	$E(\Delta Y)$	$\sigma(\Delta Y)$	$\sigma(\Delta I)$	$\sigma(\Delta C)$	$\rho_1(\Delta Y)$
Model	0.0057	0.0078	0.0247	0.0048	0.539
Data	(0.0057)	(0.0078)	(0.0202)	(0.0047)	(0.363)
	$\sigma(Y^{hp})$	$\sigma(C^{hp})$	$\sigma(I^{hp})$	$\sigma(\pi)$	$\rho_1(\pi)$
Model	0.0169	0.0089	0.0555	0.0064	0.892
Data	(0.0162)	(0.0086)	(0.0386)	(0.0064)	(0.907)

Note: Table 1.2 reports the selected moments. $E(\Delta Y)$ is the mean value of real per capita output growth. $\sigma(.)$ denotes the volatility of variables and $\rho_1(.)$ their persistence.

Table 1.3: Conditional Correlation of Output Growth over Changes in Markups

π^*=1.00						
	Neutral Shock		MEI Shock		Monetary Shock	
Model	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$
SP	0.1113	-	0.3709	-	-0.9381	-
SPRP	0.0120	-	0.2751	-	-0.8639	-
SPG	0.1436	-	0.3781	-	-0.9431	-
SPRPG	0.0381	-	0.2952	-	-0.8729	-

π^*=1.04						
	Neutral Shock		MEI Shock		Monetary Shock	
Model	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$
SP	0.1414	-	0.349	-	0.9469	-
SPRP	0.0310	-	0.1983	-	-0.8819	-
SPG	0.1782	-	0.3445	-	-0.9502	-
SPRPG	0.0615	-	0.1946	-	-0.8882	-

Note: Table 1.3 shows conditional correlations ($\rho(.)$) of output over markups. μ_p stands for price markup and μ_w wage markup.Variables are first-differenced ($\Delta(.)$). SP is the sticky-price model, SPRP is the sticky-price model with roundabout production structure, SPG is the sticky-price model with trend growth, and SPRPG is the sticky-price model with both roundabout production structure and trend growth.

Table 1.4: Conditional Correlation of Output over Markups (HP-filtered)

π^*=1.00						
	Neutral Shock		MEI Shock		Monetary Shock	
Model	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$
SP	0.1284	-	-0.3795	-	-0.9055	-
SPRP	0.0691	-	-0.5225	-	-0.8492	-
SPG	0.1401	-	-0.3816	-	-0.9134	-
SPRPG	0.0805	-	-0.5102	-	-0.8594	-

π^*=1.04						
	Neutral Shock		MEI Shock		Monetary Shock	
Model	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$
SP	0.1292	-	-0.4208	-	-0.9299	-
SPRP	0.0649	-	-0.5888	-	-0.8816	-
SPG	0.1460	-	-0.4376	-	-0.9343	-
SPRPG	0.0851	-	-0.5972	-	-0.8881	-

Note: Table 1.4 shows conditional correlations ($\rho(.)$) of output over markups. μ_p stands for price markup and μ_w wage markup.Variables are hp-filtered (hp). SP is the sticky-price model, SPRP is the sticky-price model with roundabout production structure, SPG is the sticky-price model with trend growth, and SPRPG is the sticky-price model with both roundabout production structure and trend growth.

Table 1.5: Conditional Correlation of Output Growth over Changes in Markups

π^*=1.00						
	Neutral Shock		MEI Shock		Monetary Shock	
Model	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$
SW	-	-0.2176	-	-0.9722	-	-0.7715
SWRP	-	-0.6949	-	-0.9547	-	-0.7446
SWG	-	-0.9098	-	-0.9904	-	-0.7766
SWRPG	-	-0.9476	-	-0.9856	-	-0.7499

π^*=1.04						
	Neutral Shock		MEI Shock		Monetary Shock	
Model	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$
SW	-	-0.5553	-	-0.9702	-	-0.7705
SWRP	-	-0.9445	-	-0.9526	-	-0.7442
SWG	-	-0.9694	-	-0.9832	-	-0.7753
SWRPG	-	-0.8956	-	-0.9766	-	-0.7493

Note: Table 1.5 shows conditional correlations ($\rho(.)$) of output over markups. μ_p stands for price markup and μ_w wage markup.Variables are first-differenced ($\Delta(.)$). SW is the sticky-wage model, SWRP is the sticky-wage model with roundabout production structure, SWG is the sticky-wage model with trend growth, and SWRPG is the sticky-wage model with both roundabout production structure and trend growth.

Table 1.6: Conditional Correlation of Output over Markups (HP-filtered)

π^*=1.00						
	Neutral Shock		MEI Shock		Monetary Shock	
Model	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$
SW	-	-0.8098	-	-0.9837	-	-0.8122
SWRP	-	-0.9516	-	-0.9718	-	-0.779
SWG	-	-0.9873	-	-0.9898	-	-0.8186
SWRPG	-	-0.9821	-	-0.982	-	-0.7859

π^*=1.04						
	Neutral Shock		MEI Shock		Monetary Shock	
Model	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$
SW	-	-0.866	-	-0.9692	-	-0.8094
SWRP	-	-0.9509	-	-0.9473	-	-0.7763
SWG	-	-0.9779	-	-0.9687	-	-0.815
SWRPG	-	-0.961	-	-0.955	-	-0.7825

Note: Table 1.6 shows conditional correlations ($\rho(.)$) of output over markups. μ_p stands for price markup and μ_w wage markup.Variables are hp-filtered (hp). SW is the sticky-wage model, SWRP is the sticky-wage model with roundabout production structure, SWG is the sticky-wage model with trend growth, and SWRPG is the sticky-wage model with both roundabout production structure and trend growth.

Table 1.7: Conditional Correlation of Output Growth over Changes in Markups

π^*=1.00									
	Neutral Shock			MEI Shock			Monetary Shock		
Model	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$
SPSW	0.0157	-0.3187	-0.1002	0.5017	-0.9429	-0.5904	-0.982	-0.7609	-0.7821
SPSWRP	0.0505	-0.5519	-0.176	0.4625	-0.9839	-0.8962	-0.996	-0.6973	-0.7131
SPSWG	0.0071	-0.4785	-0.1633	0.5239	-0.9751	-0.6995	-0.9797	-0.7671	-0.7872
SPSWRPG	0.0279	-0.8644	-0.3137	0.4919	-0.9978	-0.9529	-0.9940	-0.7047	-0.7197

π^*=1.04									
	Neutral Shock			MEI Shock			Monetary Shock		
Model	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$
SPSW	0.0051	-0.3007	-0.1103	0.4699	-0.9439	-0.6051	-0.986	-0.7665	-0.7893
SPSWRP	0.0289	-0.5246	-0.1742	0.3884	-0.9933	-0.9316	-0.9967	’ -0.7077	-0.724
SPSWG	0.026	-0.5886	-0.2142	0.4777	-0.981	-0.7935	-0.9804	-0.7724	-0.7935
SPSWRPG	0.0081	-0.9745	-0.4700	0.3929	-0.9965	-0.9863	-0.986	-0.7665	-0.7893

Table 1.8: Conditional Correlation of Output over Markups (HP-filtered)

	π^*=1.00								
	Neutral Shock			MEI Shock			Monetary Shock		
Model	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$
SPSW	0.0346	-0.9569	-0.6859	-0.103	-0.9878	-0.9207	-0.9741	-0.8088	-0.8312
SPSWRP	0.0163	-0.8802	-0.513	-0.1914	-0.9962	-0.9794	-0.9941	-0.7348	-0.7577
SPSWG	0.0649	-0.8383	-0.4145	-0.0589	-0.9936	-0.9379	-0.9703	-0.8182	-0.8383
SPSWRPG	0.0346	-0.9569	-0.6859	-0.1445	-0.9995	-0.9887	-0.9911	-0.7487	-0.7694

	π^*=1.04								
	Neutral Shock			MEI Shock			Monetary Shock		
Model	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$
SPSW	0.06	-0.6332	-0.2932	-0.1888	-0.9813	-0.9088	'-0.9701	-0.8273	-0.8477
SPSWRP	0.0317	-0.837	-0.4336	-0.3274	-0.9972	-0.9791	'-0.9953	-0.7516	-0.7746
SPSWG	0.0873	-0.8565	-0.4604	-0.1721	-0.9852	-0.9383	-0.9701	-0.8273	-0.8477
SPSWRPG	0.0663	-0.9911	-0.7418	-0.3258	-0.9957	-0.9894	-0.9882	-0.7676	-0.7871

Note: Tables 1.7 and 1.8 show conditional correlations ($\rho(.)$) of output over markups. μ_p stands for price markup, μ_w wage markup, and μ is the labor wedge. Variables are first-differenced ($\Delta(.)$) in table 1.7 and hp-filtered (hp) in table 1.8. SPSW is the sticky-price and sticky-wage model, SPSWRP is the sticky-price and sticky-wage model with roundabout production structure, SPSWG is the sticky-price and sticky-wage model with trend growth, and SPSWRPG is the sticky-price and sticky-wage model with both roundabout production structure and trend growth.

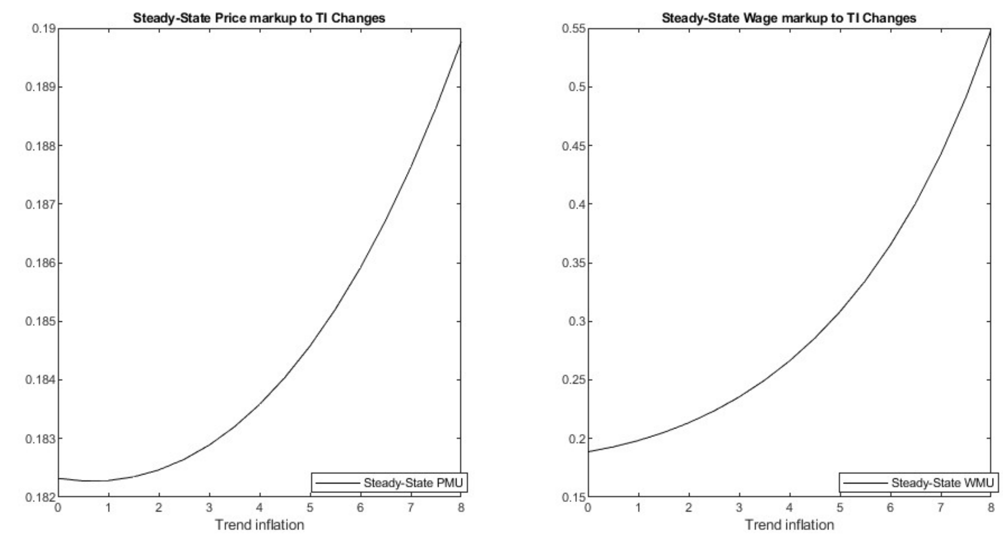
Table 1.9: Conditional Correlation of Output over Markups

	π^*=1.02								
	Neutral Shock			MEI Shock			Monetary Shock		
Model	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$	$\rho(\Delta Y,\Delta\mu_p)$	$\rho(\Delta Y,\Delta\mu_w)$	$\rho(\Delta Y,\Delta\mu)$
SPSW	0.0057	-0.3041	-0.1032	0.49	-0.9421	-0.5877	-0.977	-0.8128	-0.8360
SPSWRP	0.0403	-0.5307	-0.1708	0.4338	-0.9887	-0.9098	-0.995	-0.7422	-0.7652
SPSWG	0.0172	-0.5124	-0.1817	0.5059	-0.978	-0.7349	-0.971	-0.8221	-0.8425
SPSWRPG	0.0174	-0.9496	-0.3666	0.4524	-0.9992	-0.9710	-0.9904	-0.7568	-0.7771

	π^*=1.02								
	Neutral Shock			MEI Shock			Monetary Shock		
Model	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$	$\rho(Y^{hp},\mu_p^{hp})$	$\rho(Y^{hp},\mu_w^{hp})$	$\rho(Y^{hp},\mu^{hp})$
SPSW	0.0537	-0.6701	-0.3024	-0.1378	-0.9854	-0.9138	0.4524	-0.9992	-0.9710
SPSWRP	0.0226	'-0.8783	-0.471	-0.2486	-0.9975	-0.9791	-0.9966	-0.7019	-0.7179
SPSWG	0.0748	-0.8426	-0.4271	-0.1067	-0.9906	-0.9363	-0.9806	-0.7694	-0.7900
SPSWRPG	0.0494	-0.9907	-0.7027	-0.2238	-0.999	-0.9891	-0.9935	-0.7093	-0.7243

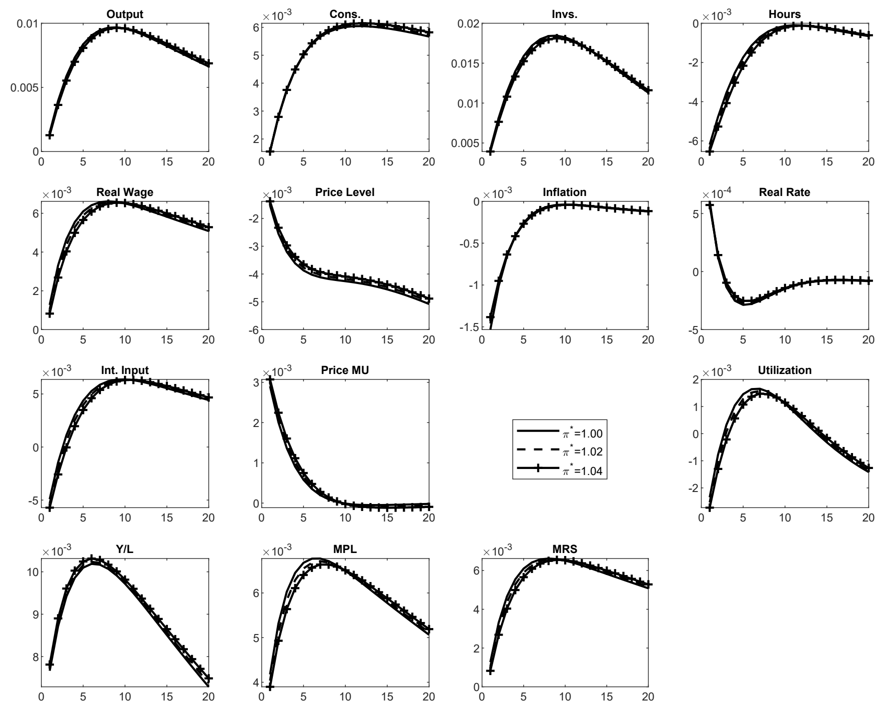
Note: Table 1.9 shows conditional correlations ($\rho(.)$) of output over markups. μ_p stands for price markup, μ_w wage markup, and μ is the labor wedge for alterantive case. Variables are first-differenced ($\Delta(.)$) and hp-filtered. SPSW is the sticky-price and sticky-wage model, SPSWRP is the sticky-price and sticky-wage model with roundabout production structure, SPSWG is the sticky-price and sticky-wage model with trend growth, and SPSWRPG is the sticky-price and sticky-wage model with both roundabout production structure and trend growth.

Figure 1.1: Steady-State Price and Wage Markups to Trend Inflation Changes



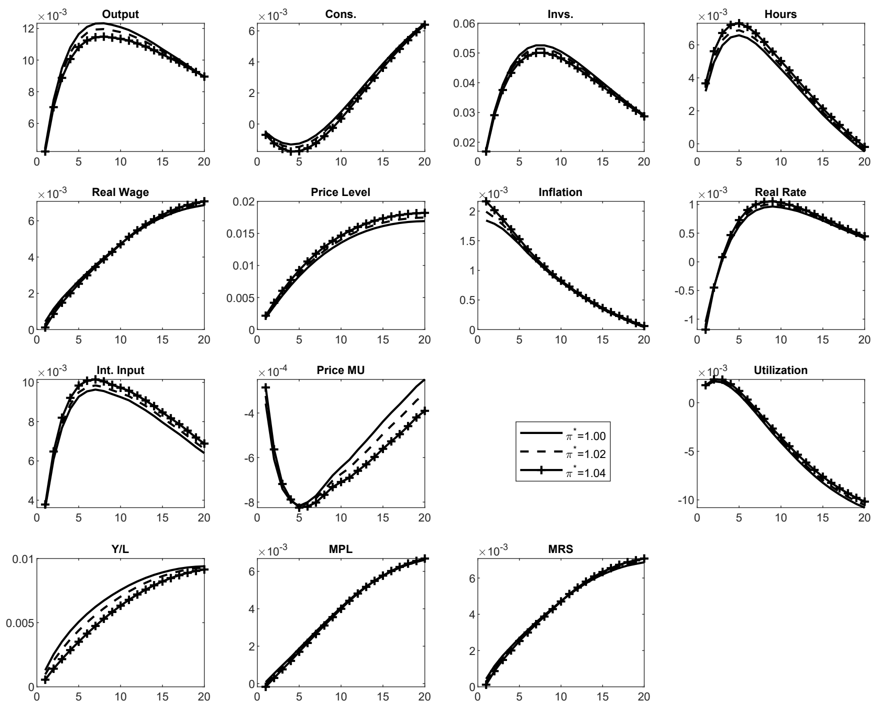
Note: This figure plots the impulse responses of steady-state price (Left Panel) and wage (Right Panel) markups in response to changes in trend inflation.

Figure 1.2: TFP shock, SPRPG Model



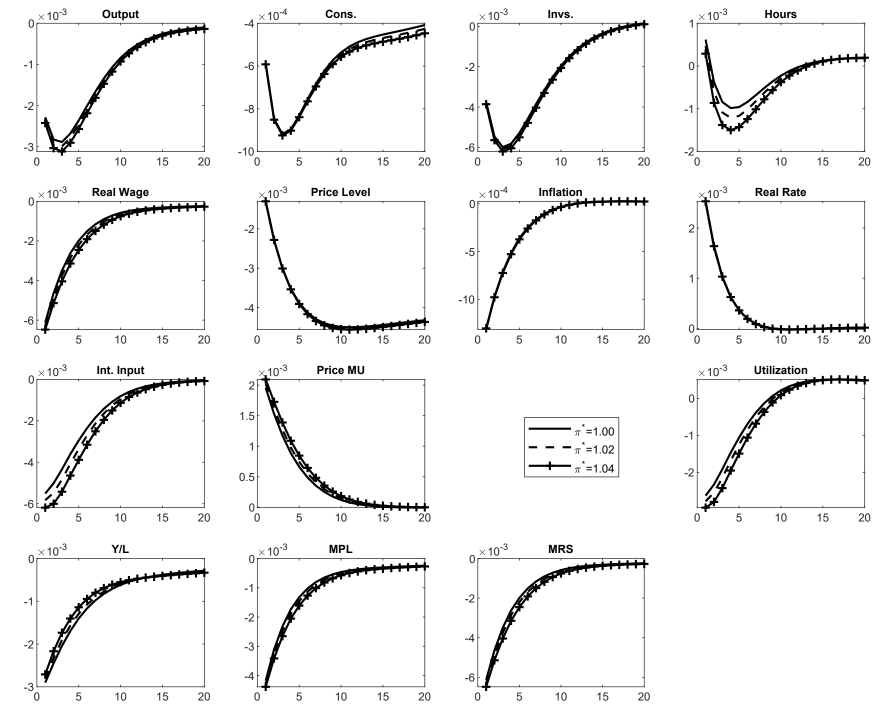
Note: This figure plots the impulse responses of variables of interest to a neutral technology shock in the sticky-price model with roundabout production structure and exogenous growth (SPRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with "+" show responses when trend inflation is 4%.

Figure 1.3: MEI shock, SPRPG Model



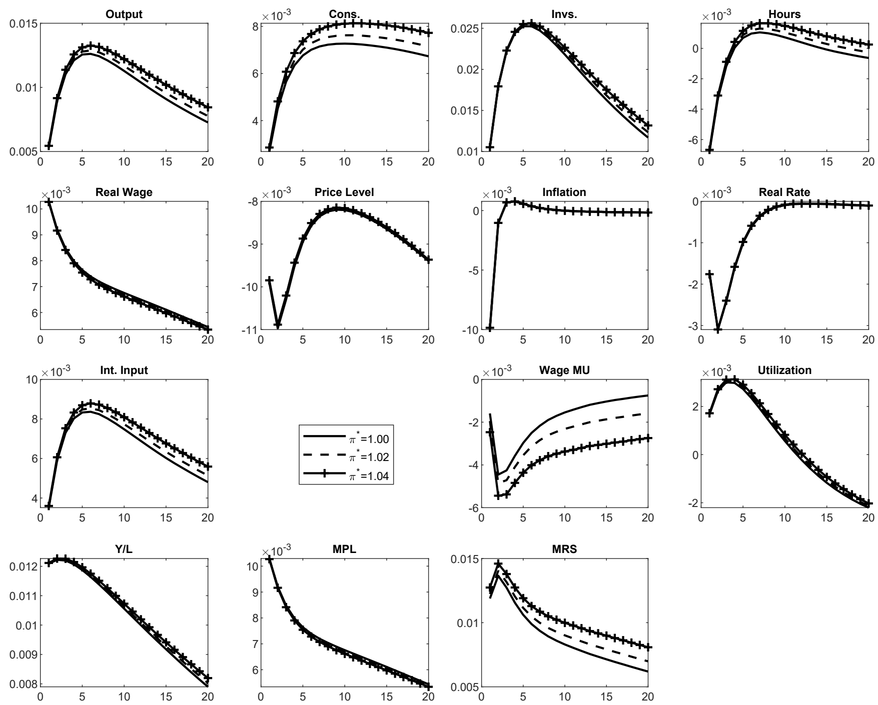
Note: This figure plots the impulse responses of variables of interest to a marginal efficiency of investment shock in the sticky-price model with roundabout production structure and exogenous growth (SPRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with "+" show responses when trend inflation is 4%.

Figure 1.4: Monetary shock, SPRPG Model



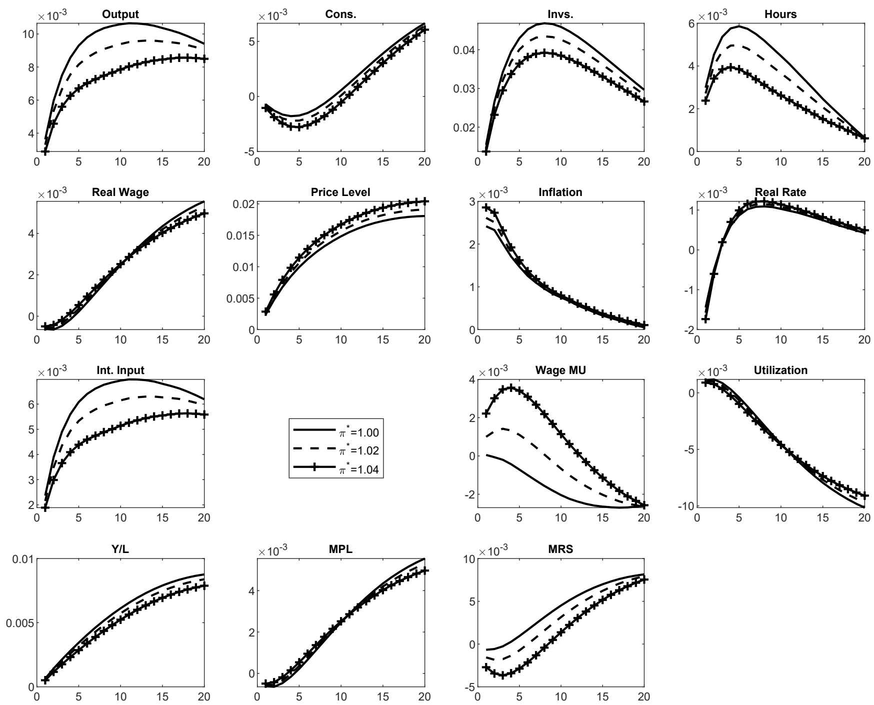
Note: This figure plots the impulse responses of variables of interest to a monetary policy shock in the sticky-price model with roundabout production structure and exogenous growth (SPRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with "+" show responses when trend inflation is 4%.

Figure 1.5: TFP shock, SWRPG Model



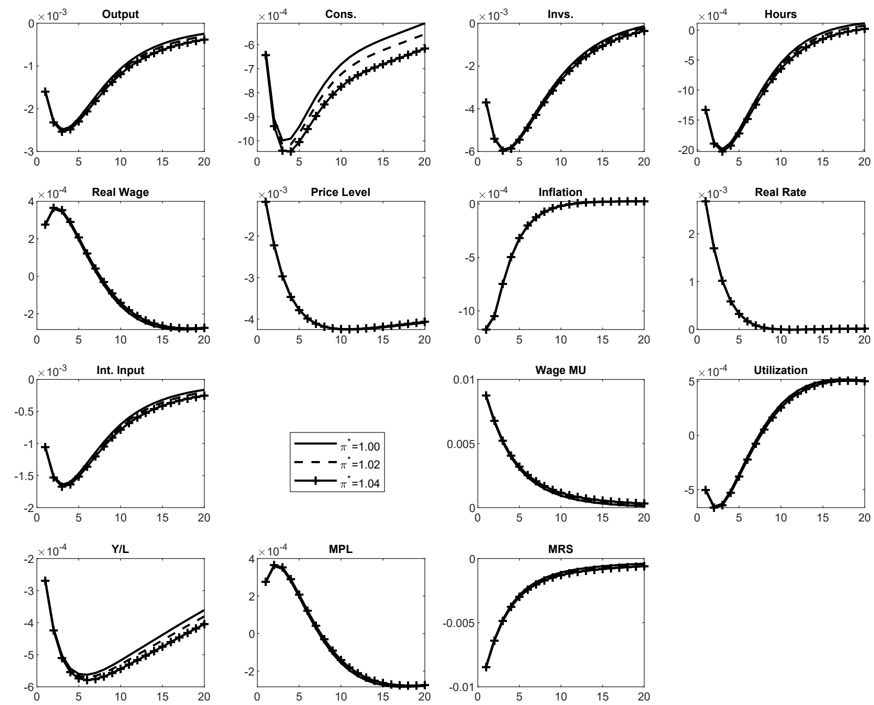
Note: This figure plots the impulse responses of variables of interest to a neutral technology shock in the sticky-wage model with roundabout production structure and exogenous growth (SWRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with "+" show responses when trend inflation is 4%.

Figure 1.6: MEI shock, SWRPG Model



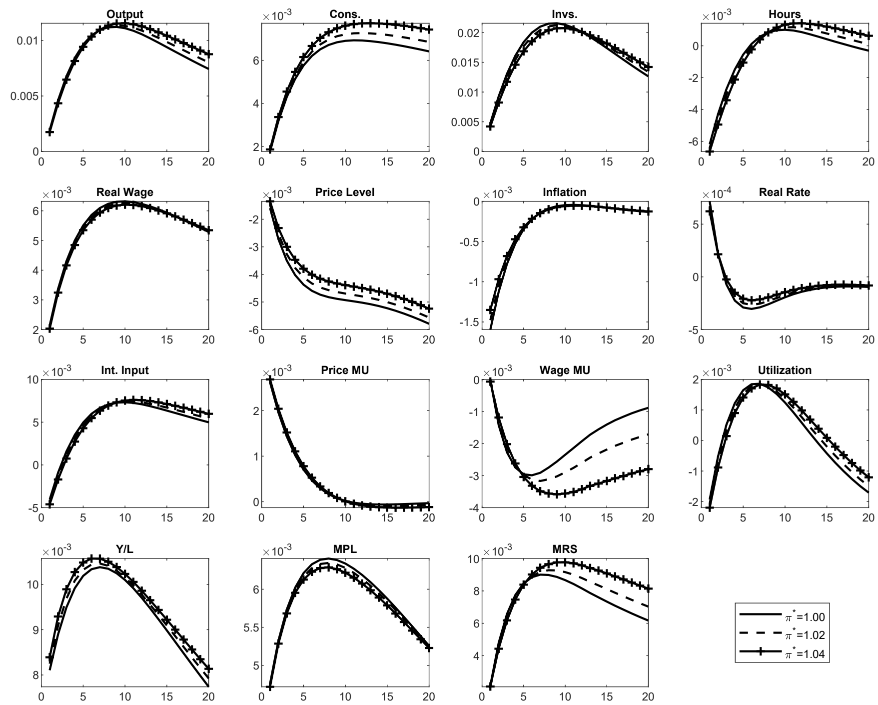
Note: This figure plots the impulse responses of variables of interest to a marginal efficiency of investment shock in the sticky-wage model with roundabout production structure and exogenous growth (SWRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with "+" show responses when trend inflation is 4%.

Figure 1.7: Monetary shock, SWRPG Model



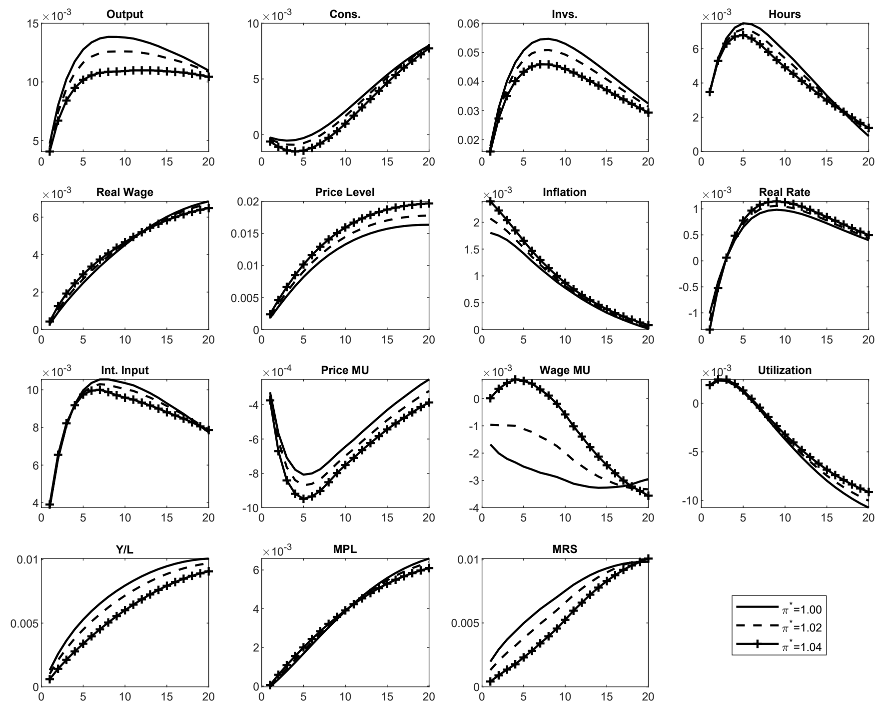
Note: This figure plots the impulse responses of variables of interest to a monetary policy shock in the sticky-wage model with roundabout production structure and exogenous growth (SWRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with "+" show responses when trend inflation is 4%.

Figure 1.8: TFP shock, SPSWRPG Model



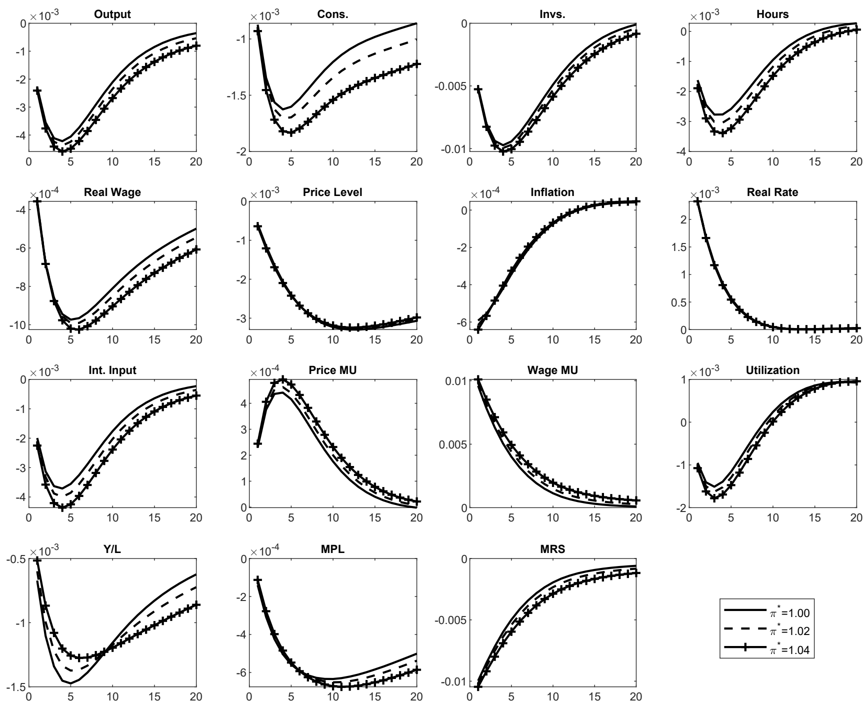
Note: This figure plots the impulse responses of variables of interest to a neutral technology shock in the sticky-price and sticky-wage model with roundabout production structure and exogenous growth (SPSWRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with “+” show responses when trend inflation is 4%.

Figure 1.9: MEI shock, SPSWRPG Model



Note: This figure plots the impulse responses of variables of interest to a marginal efficiency of investment shock in the sticky-price and sticky-wage model with roundabout production structure and exogenous growth (SPSWRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with “+” show responses when trend inflation is 4%.

Figure 1.10: Monetary shock, SPSWRPG Model



Note: This figure plots the impulse responses of variables of interest to a monetary policy shock in the sticky-price and sticky-wage model with roundabout production structure and exogenous growth (SPSWRPG). The solid lines show the responses when trend inflation is zero. The dashed lines show responses when trend inflation is 2%. The dashed lines with "+" show responses when trend inflation is 4%.

APPENDIX

Appendix 1.A Full Set of Equilibrium Conditions

This appendix lists the full set of detrended equations. These equations are expressed in stationary transformations of variables, e.g. $\widetilde{X}_t = \frac{X_t}{\Psi_t}$ for most variables. $g_\Psi = \frac{\Psi_t}{\Psi_{t-1}}$ is the growth rate of the deterministic trend.

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

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

$$\begin{aligned}\widetilde{\lambda}_t^r = \widetilde{\mu}_t \vartheta_t \left(1 - \frac{k}{2}\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi\right)^2 - \kappa\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi\right)\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi\right) + \dots \\ \beta E_t g_\Psi^{-1} \widetilde{\mu}_{t+1} \vartheta_{t+1} \kappa \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Psi - g_\Psi\right)\left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Psi\right)^2\end{aligned} \tag{A3}$$

$$g_I g_\Psi \widetilde{\mu}_t = \beta E_t \widetilde{\lambda}_{t+1}^r \left(\widetilde{r}_{t+1}^k Z_{t+1} - \left(\gamma_1 (Z_{t+1} - 1) + \frac{\gamma_2}{2}(Z_{t+1} - 1)^2\right)\right) + \beta(1-\delta) E_t \widetilde{\mu}_{t+1} \tag{A4}$$

$$\widetilde{\lambda}_t^r = \beta g_\Psi^{-1} E_t (1 + i_t) \pi_{t+1}^{-1} \widetilde{\lambda}_{t+1}^r \tag{A5}$$

$$\widetilde{w}_t^* = \frac{\sigma}{\sigma - 1} \frac{\widetilde{h}_{1,t}}{\widetilde{h}_{2,t}} \tag{A6}$$

$$\widetilde{h}_{1,t} = \eta \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*}\right)^{\sigma(1+\chi)} N_t^{1+\chi} + \beta \xi_w E_t (\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*}\right)^{\sigma(1+\chi)} g_\Psi^{\sigma(1+\chi)} \widetilde{h}_{1,t+1} \tag{A7}$$

$$\widetilde{h}_{2,t} = \widetilde{\lambda}_t^r \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*}\right)^{\sigma} N_t + \beta \xi_w E_t (\pi_{t+1})^{\sigma - 1} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*}\right)^{\sigma} g_\Psi^{\sigma - 1} \widetilde{h}_{2,t+1} \tag{A8}$$

$$\widetilde{\widetilde{K}}_t = g_I g_\Psi \alpha(1-\phi)\frac{mc_t}{\widetilde{r}_t^k}\left(s_t\widetilde{X}_t + \bar{Z}\right) \tag{A9}$$

$$N_t = (1-\alpha)(1-\phi)\frac{mc_t}{\widetilde{w}_t}\left(s_t\widetilde{X}_t + \bar{Z}\right) \tag{A10}$$

$$\widetilde{\Upsilon}_t = \phi mc_t\left(s_t\widetilde{X}_t + \bar{Z}\right) \tag{A11}$$

$$p_t^* = \frac{\theta}{\theta-1}\frac{m_{1,t}}{m_{2,t}} \tag{A12}$$

$$m_{1,t} = \widetilde{\lambda}_t^r mc_t\widetilde{X}_t + \xi_p\beta\left(\frac{1}{\pi_{t+1}}\right)^{-\theta} m_{1,t+1} \tag{A13}$$

$$m_{2,t} = \widetilde{\lambda}_t^r\widetilde{X}_t + \xi_p\beta\left(\frac{1}{\pi_{t+1}}\right)^{1-\theta} m_{2,t+1} \tag{A14}$$

$$1 = \xi_p\left(\frac{1}{\pi_t}\right)^{1-\theta} + (1-\xi_p)p_t^{*1-\theta} \tag{A15}$$

$$\widetilde{w}_t^{1-\sigma} = \xi_w g_\Psi^{\sigma-1} \left(\frac{\widetilde{w}_{t-1}}{\pi_t} \right)^{1-\sigma} + (1-\xi_w) \widetilde{w}_t^{*1-\sigma} \tag{A16}$$

$$\widetilde{Y}_t = \widetilde{X}_t - \widetilde{\Upsilon}_t \tag{A17}$$

$$s_t \widetilde{X}_t = \widetilde{\Upsilon}_t^{\phi} \widetilde{\widehat{K}}_t^{\alpha(1-\phi)} N_t^{(1-\alpha)(1-\phi)} g_\Psi^{\alpha(\phi-1)} - \bar{Z} \tag{A18}$$

$$\widetilde{Y}_t = \widetilde{C}_t + \widetilde{I}_t + g_\Psi^{-1} g_I^{-1} \left(\gamma_1 (Z_t - 1) + \frac{\gamma_2}{2} (Z_t - 1)^2 \right) \widetilde{K}_t \tag{A19}$$

$$\widetilde{K}_{t+1} = \vartheta_t \left(1 - \frac{\kappa}{2} \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi \right)^2 \right) \widetilde{I}_t + (1-\delta) g_\Psi^{-1} g_I^{-1} \widetilde{K}_t \tag{A20}$$

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i} \right)^{\rho_1} \left(\frac{1+i_{t-2}}{1+i} \right)^{\rho_2} \left[\left(\frac{\pi_t}{\bar{\pi}} \right)^{\alpha_\pi} \left(\frac{\widetilde{Y}_t}{\widetilde{Y}_{t-1}} \right)^{\alpha_y} \right]^{1-\rho_1-\rho_2} \exp\left(\varepsilon_t^r\right) \tag{A21}$$

$$\widetilde{\widehat{K}}_t = Z_t \widetilde{K}_t \tag{A22}$$

$$s_t = (1-\xi_p) p_t^{*-\theta} + \xi_p \left(\frac{1}{\pi_t} \right)^{-\theta} s_{t-1} \tag{A23}$$

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

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

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

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

$$\Phi_t = \frac{\beta \ln g_\Psi}{(1-\beta)^2} \tag{A28}$$

$$\vartheta_t = (\vartheta_{t-1})^{\rho_I} \exp\left(s_I u_t^I \right) \tag{A29}$$

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1} \right)^{\rho_A} \exp\left(s_A u_t^A \right) \tag{A30}$$

Equation (A1) defines the real multiplier on the flow budget constraint. (A2) is the optimality condition for capital utilization. (A3) and (A4) 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 (A5). (A6)-(A8) describe optimal wage setting for households given the opportunity to adjust their wages. Optimal factor demands are given by equations (A9)-(A11). Optimal price setting for firms given the opportunity to change their price is described by equations (A12)-(A14). The evolutions of aggregate inflation and the aggregate real wage index are given by (A15) and (A16), respectively. Net output is gross output minus intermediates, as given by (A17). The aggregate production function for gross output is (A18). The aggregate resource constraint is (A19), and the law of motion for physical capital is given by (A20). The Taylor rule for monetary policy is (A21). Capital services are defined as the product of utilization and physical capital, as in (A22). The law of motion for price dispersion is (A23) and for wage dispersion is (A24). (A25) and (A26) are recursive utility from consumption and labor in the levels. The aggregate welfare is (A27) and (A28) a shift term. (A29)-(A30) give the assumed laws of motion for other exogenous variables.

Appendix 1.B The Steady-State Price Markup and Price Dispersion

We use variables without a time subscript to denote a non-stochastic steady state value. From (A12), we can solve for steady-state price markup (μ_p) as follows:

$$\mu_p = p^* \frac{m_2}{m_1}$$

Where $\mu_p = \frac{\theta}{\theta-1}$.

We use this to solve for steady state p^* from (A15):

$$p^* = \left(\frac{1 - \xi_p \pi^{(\theta-1)}}{1 - \xi_p} \right)^{\frac{1}{1-\theta}}$$

Note that if steady state inflation is 1, then $p^* = 1$.

Now solve for steady state m_1 from (A13):

$$m_1 = \frac{\widetilde{\lambda}^r \widetilde{X} mc}{1 - \xi_p \beta \pi^{\theta}}$$

Do likewise for m_2 from (A14):

$$m_2 = \frac{\widetilde{\lambda}^r \widetilde{X}}{1 - \xi_p \beta \pi^{(\theta-1)}}$$

Hence, the ratio is:

$$\frac{m_1}{m_2} = mc \frac{1 - \xi_p \beta \pi^{(\theta-1)}}{1 - \xi_p \beta \pi^{\theta}}$$

Combining these equations, to solve for steady state price markup μ_p, we have:

$$\mu_p = \frac{p^*}{mc \frac{1-\xi_p \beta \pi^{\theta}}{1-\xi_p \beta \pi^{(\theta-1)}}}$$

Now, we can solve for the steady state value of the price dispersion term from (A23):

$$s = \frac{(1-\xi_p)p^{*-\theta}}{(1-\xi_p \pi^{\theta})}$$

Appendix 1.C The Steady-State Wage Markup and Wage Dispersion

From (A6), we derive the steady-state wage markup (μ_w):

$$\mu_w = \widetilde{w}^* \frac{\widetilde{h}_2}{\widetilde{h}_1}$$

Where $\mu_w = \frac{\sigma}{\sigma-1}$.

Let's solve for the steady state reset real wage ($\widetilde{w}^*$) in terms of the actual steady state real wage ($\widetilde{w}$) from (A16):

$$\frac{\widetilde{w}^*}{\widetilde{w}} = \left(\frac{1-\xi_w g_{\Psi}^{\sigma-1} \pi^{(\sigma-1)}}{1-\xi_w} \right)^{\frac{1}{1-\sigma}}$$

We can solve for the steady state real wage ($\widetilde{w}$) as from an earlier condition defining real marginal cost (mc) written in steady state terms:

$$mc = \bar{\phi} \widetilde{A} \left(\widetilde{r}^k \right)^{\alpha(1-\phi)} \widetilde{w}^{(1-\alpha)(1-\phi)}$$

With steady state capital utilization set to 1, from (A2), this implies:

$$r^k = \gamma_1$$

Now, evaluated in steady state, we already know mc and r^k, so we can solve for the wage from this:

$$\widetilde{w} = \left(\frac{mc \left(\widetilde{r}^k\right)^{\alpha(\phi-1)}}{\phi^{-\phi}(1-\phi)^{\phi-1}\left(\alpha^{-\alpha}(1-\alpha)^{\alpha-1}\right)^{1-\phi}} \right)^{\frac{1}{(1-\alpha)(1-\phi)}}$$

Now, find the steady state of the auxiliary variables from (A7) and (A8):

$$\widetilde{h}_1 = \frac{\eta \left(\frac{\widetilde{w}}{\widetilde{w}^*}\right)^{\sigma(1+\chi)} N^{1+\chi}}{1-\beta\xi_w g_\Psi^{\sigma(1+\chi)} \pi^{\sigma(1+\chi)}}$$

$$\widetilde{h}_2 = \frac{\widetilde{\lambda}^r \left(\frac{\widetilde{w}}{\widetilde{w}^*}\right)^{\sigma} N}{1-\beta\xi_w g_\Psi^{\sigma-1} \pi^{(\sigma-1)}}$$

The ratio of these is:

$$\frac{\widetilde{h}_1}{\widetilde{h}_2} = \left(\widetilde{\lambda}^r\right)^{-1} \eta \left(\frac{\widetilde{w}}{\widetilde{w}^*}\right)^{\sigma\chi} N^{\chi} \frac{1-\beta\xi_w g_\Psi^{\sigma-1}\pi^{(\sigma-1)}}{1-\beta\xi_w g_\Psi^{\sigma(1+\chi)}\pi^{\sigma(1+\chi)}}$$

Then, combining these equations, we have the steady state wage markup:

$$\mu_w = \frac{\widetilde{w}^*}{\left(\widetilde{\lambda}^r\right)^{-1} \eta \left(\frac{\widetilde{w}}{\widetilde{w}^*}\right)^{\sigma\chi} N^{\chi} \frac{1-\beta\xi_w g_\Psi^{\sigma-1}\pi^{(\sigma-1)}}{1-\beta\xi_w g_\Psi^{\sigma(1+\chi)}\pi^{\sigma(1+\chi)}}}$$

Now, we can solve for the steady state value of the wage dispersion term from (A24):

$$v^w = \frac{(1-\xi_w)\left(\frac{\widetilde{w}_t^*}{\widetilde{w}_t}\right)^{-\sigma(1+\chi)}}{1-\xi_w g_\Psi^{\sigma(1+\chi)}\pi^{\sigma(1+\chi)}}$$

CHAPTER II

ON THE WELFARE COSTS OF POSTWAR U.S. CONVENTIONAL MONETARY POLICY

Abstract

This paper analyzes the welfare costs related to changes in monetary policy and trend inflation in the Postwar U.S. economy. We use a medium-scale New Keynesian DSGE model and find the following results. First, changes in monetary policy and trend inflation play an essential role in reducing macroeconomic variables volatility in the post-1980s. Second, welfare costs are smaller in the post-1980s period compared to the pre-1980s period. Third, we find that when trend inflation and trend productivity growth are combined with nominal wage rigidity, responding to the output gap results in highly significant consumption-equivalent losses.

JEL classification: E31, E32.

Keywords: Medium-scale dsge model;

2.1 Introduction

The significant decline in macroeconomic volatility after the early 1980s and before the Great Recession received much attention in the literature. In a seminal contribution, Clarida et al. (2000) explored the role of monetary policy in achieving macroeconomic stability during the Great Moderation. They proposed and estimated simple forward-looking equations for the monetary policy's reaction function before and after 1979 and used their estimates in an archetype sticky-price model. They find a significant difference in the conduct of the monetary policy. The Federal funds rate in the Volcker-Greenspan era (post-1979) seems to have been much more sensitive to variations in expected inflation than in the pre-Volcker era (pre-1979). They explain this difference as an essential source of the decline in macroeconomic volatility in the post-1979 period [1].

Using a limited information estimation strategy, Coibion and Gorodnichenko (2011) challenge this view. Based on several estimated Taylor Rules and a calibrated staggered-price model with nonzero trend inflation, they attribute this decline not only to changes in the Fed's response to inflation but also to the fall in trend inflation during the Volcker's disinflation period [2].

However, this literature has been silent about the welfare implications. To fill in the gap, we examine the welfare costs associated with changes in the Taylor rule's calibration and a lower level of trend inflation after the early 1980s. A medium-scale New Keynesian DSGE model inspired by Ascari et al. (2018) is used to carry out this analysis. Nevertheless, our approach differs from theirs along the following lines. We extend their model to include the policy rule, which features a response to inflation, output growth, and the output gap. We split [3] the study into the years before and after

1. Lubik and Schorfheide (2004), Orphanides (2004), and Hirose et al. (2015) corroborate these results.

2. This result is consistent with Arias, Ascari, Branzoli and Castelnuovo (2014).

3. Following Galí and Gambetti (2009), the year 1984 is considered the starting period of enhanced stability in the Postwar U.S. economy.

the early 1980s, and calibrate the Fed's reaction function based on estimates in Smets and Wouters (2007) and Coibion and Gorodnichenko (2011). We use these policy rules estimates in the calibrated medium-scale New Keynesian model. There are three types of shocks: a neutral technology shock, an investment shock, and a monetary policy shock.

From a welfare perspective, we consider two consumption-equivalent measures: one based on non-stochastic steady-states and the other on stochastic means. Following the estimates in Smets and Wouters (2007) policy rule parameters (baseline case), we find that the consumption-equivalent welfare loss of going from 0 to 4.75 percent [4] trend inflation (the pre-1980s period) is about 7.65 percent for the non-stochastic steady states and 9.65 percent for the stochastic means. However, when we remove the output gap from the policy rule [5], we get 7.65 percent for the steady states and 8.25 percent for the stochastic means. On the other hand, going from 0 to 2.29 percent trend inflation (the post-1980s period), we find that the welfare costs are about 2.26 percent for the steady states and 2.36 percent in terms of the stochastic means. These features change when we remove the output gap from the policy rule: the steady-state of consumption equivalent remains unchanged, and the stochastic mean amounts to 2.34 percent.

When we consider the estimates produced by Coibion and Gorodnichenko (2011), we observe that the welfare costs of going from 0 to 4.75 percent of trend inflation (in the pre-1980s period) amount to 7.56 and 9.37 percent of trend inflation respectively for the steady states and the stochastic means. In the case without the output gap, welfare losses are the same for the steady-state 7.56 percent and 8.13 percent in terms of the stochastic mean. However, going from 0 to 2.29 percent of trend inflation (the post-1980s period), we note that the consumption equivalent welfare loss is about 2.26 percent for the steady-state and 2.45 percent for the stochastic mean. When we remove the output gap, we get 2.26 percent for the steady-state and 2.39 percent for the stochastic mean.

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4. Trend inflation rises in the pre-1980s period (from 1960: I to 1983: IV), it gets around 4.75 percent and drops to 2 .29 percent in the post-1980s period (from 1984: I to 2007: III).

5. See subsection 2.2.3 for more details.

The basic insight from our results [6] reveals that [7]: First, in our medium-scale New Keynesian DSGE model with trend inflation and trend productivity growth, and in which the policy rule features a response to inflation, to output growth, and the output gap, we have noticed that the welfare losses are essential in the case with the output gap. We find that reacting strongly to the output gap can result in high welfare costs than responding to output growth. Second, trend productivity growth and trend inflation associated with nominal wage rigidity, make wage dispersion plays a significant role from a welfare perspective.

This work is in line with a set of papers that studies the effects of positive trend inflation on the dynamics of macroeconomic variables in New Keynesian models. Ascari and Ropele (2007) explore the effects of nonzero trend inflation on optimal monetary policy. Whereas Amano, Moran, Murchison and Rennison (2009) study the implications for the optimal rate of inflation. Amano et al. (2007) examine the implications for the time-series properties of macro variables, Amano et al. (2009), and Coibion and Gorodnichenko (2011) study the effect of trend inflation on the indeterminacy of the model. Our paper differs from theirs as it studies the effects of monetary policy and trend inflation changes on welfare costs before and after 1984.

The work closest to ours, in line with the "effects of nonzero trend inflation" literature, is the one by Ascari et al. (2018). It examines the effects of moderate trend inflation on the welfare and business-cycle properties of medium-scale New Keynesian models over the period 1960:I-2007:III. At the same time, we explore the welfare implications of monetary policy changes and trend inflation before and after 1984.

Our paper is also closely related to Clarida et al. (2000). However, we use a sticky price and sticky wage model extended to non-zero trend inflation, trend growth and roundabout production structure whereas they use a sticky price model based on zero trend inflation. They examine how was the role of monetary policy different in the

6. Using both Smets and Wouters (2007) and Coibion and Gorodnichenko (2011) policy rule parameters.

7. These findings endorse the conclusion of Sims (2013).

pre-1979 and post-1979 period while we explore the welfare effects.

The rest of the paper is organized as follows. In point 2.2, we describe the baseline model. Point 2.3 discusses the calibration of structural parameters. We present results in point 2.4 and conclude with final remarks.

2.2 The Model

We use a medium-scale New Keynesian DSGE model inspired by Ascari et al. (2018). We extended it to include a mixed [8] Taylor rule specification for monetary policy (Coibion and Gorodnichenko, 2011). This specification best-fits the post-World War II U.S. data, as shown by Coibion and Gorodnichenko (2012).

We abstract from zero lower bound on interest rates, which would be challenging because of many state variables in the model. We assume no indexation either in prices or wages since there is no reliable evidence as supported by Christiano et al. (2016). We allow for positive trend inflation, trend growth, and firm networking. The economy has three types of agents, risk-averse households, production firms, and a central bank.

The subsections below outline the decision problems and optimal conditions of different actors in the model, specify stochastic processes for exogenous variables and give aggregate equilibrium conditions. In the appendix, the full set of detrended equations describing the equilibrium conditions is presented.

2.2.1 Households and wage-setting

Labor aggregators

The economy features a continuum of households, indexed by $h \in [0,1]$. They are monopoly suppliers of $N_t^d(h)$ units of differentiated labor to a "labor packing firm."

8. See subsection 2.2.3 for a definition.

This firm assembles various labor inputs into a homogeneous labor unit. The bundling technology is given by:

$$N_t^d = \left(\int_0^1 N_t(h)^{\frac{\sigma-1}{\sigma}} dh \right)^{\frac{\sigma}{\sigma-1}}, \sigma > 1 \tag{2.1}$$

where σ stands for the constant elasticity of substitution (CES) between labor types. Labor aggregator is a price-taker in both their output and input markets. He sells composite labor to intermediate producers at the aggregate wage, W_t, and unit of differentiated labor costs is $W_t(h)$. The profit maximization problem of the labor aggregating firm gives demand for each variety of labor:

$$N_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\sigma} N_t^d. \tag{2.2}$$

Inserting this demand function for input h back into the CES aggregator yields the aggregate wage index, i.e

$$W_t^{1-\sigma} = \int_0^1 W_t(h)^{1-\sigma} dh. \tag{2.3}$$

Households

Households maximize expected present discounted value of their lifetime utility function, subject to an intertemporal budget constraint. Preferences are additively separable in consumption and labor and allow for habit formation in consumption. They own intermediate firms, lend capital services (the product of physical capital and utilization) to firms, and make investment and capital utilization decisions. Capital is predetermined at the beginning of a period, but households can adjust its utilization rate subject to some costs. Households receive nominal dividend payments resulting from the ownership of intermediate-goods-producing firms. Additionally, they hold their financial wealth in the form of one-period, state-contingent bonds. Financial markets are assumed to be complete. The problem of an individual household can be written [9]:

$$\max_{C_t, N_t(h), K_{t+1}, B_{t+1}, I_t, Z_t} \quad E_0 \sum_{i=0}^{\infty} \beta^i \left(\ln\left(C_{t+i} - bC_{t+i-1}\right) - \eta \frac{N_{t+i}(h)^{1+\chi}}{1+\chi} \right), \tag{2.4}$$

subject to

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

and

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

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

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

Where $0 < \beta < 1$ is the factor of discount, $0 < \delta < 1$ the rate of depreciation, and $0 \leq b < 1$ denotes habit formation in consumption. χ is the inverse Frisch elasticity of labor supply and κ an investment adjustment cost parameter strictly positive. P_t is the nominal price of goods. C_t is consumption, I_t investment, $N_t(h)$ labor input, and K_t physical capital. R_t^k is a nominal rental rate on capital services, and i_t the nominal interest rate. B_t is the stock of nominal bonds with which a household enters a period, and B_{t+1} is a stock of nominal governmental bonds in period t+1. Π_t^n denotes (nominal) profits remitted by firms, and T_t is a lump sum taxes from the government. Z_t is the level of capital utilization, and $a(Z_t)$ is a function mapping utilization of capital into the depreciation rate, with parameters γ_1 and γ_2, providing that $a(1) = 0$, $a'(1) = 0$, and $a''(1) > 0$. $S\left(\frac{I_t}{I_{t-1}}\right)$ is an investment adjustment cost, satisfying $S(g_I) = 0$, $S'(g_I) = 0$, and $S''(g_I) > 0$, where $g_I \geq 1$ is the steady-state growth rate of investment.

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9. The utility is separable, and we assume that households are identical to non-labor choices. Hence, we will drop the h subscripts in subsequent sections. For detail, see Erceg, Henderson and Levin (2000).

The investment-specific term $\varepsilon_t^{I,\tau}$ follows the deterministic trend with no stochastic component [10]:

$$\varepsilon_t^{I,\tau} = g_{\varepsilon^I}\varepsilon_{t-1}^{I,\tau} \tag{2.5}$$

where g_{ε^I} is the gross growth rate and grows at the gross rate $g_{\varepsilon^I} \geq 1$ in each period [11].

The exogenous variable ϑ_t captures the stochastic marginal efficiency of investment shock :

$$\vartheta_t = (\vartheta_{t-1})^{\rho_I}\exp\left(s_I u_t^I\right), with\ \ u_t^I \sim iid\,(0,1)\,. \tag{2.6}$$

The auto-regressive parameter ρ_I governs the persistence of the process, and satisfies $0 \leq \rho_I < 1$. The shock is scaled by the known standard deviation equal to s_I and u_t^I denotes the innovation drawn from a mean zero normal distribution.

The first-order conditions for consumption, capital utilization, investment, capital, and bonds are respectively:

$$\lambda_t^r = \frac{1}{C_t - bC_{t-1}} - E_t\frac{\beta b}{C_{t+1} - bC_t}, \tag{2.7}$$

$$r_t^k = \frac{a'(Z_t)}{\varepsilon_t^{I,\tau}}, \tag{2.8}$$

$$\lambda_t^r = \mu_t\varepsilon_t^{I,\tau}\vartheta_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\right] + \beta E_t\mu_{t+1}\varepsilon_{t+1}^{I,\tau}\vartheta_{t+1}S'\left(\frac{I_{t+1}}{I_t}\right)\left[\frac{I_{t+1}}{I_t}\right]^2, \tag{2.9}$$

$$\mu_t = \beta E_t\lambda_{t+1}^r\left(r_{t+1}^k Z_{t+1} - \frac{a(Z_{t+1})}{\varepsilon_{t+1}^{I,\tau}}\right) + \beta(1-\delta)E_t\mu_{t+1}, \tag{2.10}$$

$$\lambda_t^r = \beta E_t\lambda_{t+1}^r(1+i_t)\pi_{t+1}^{-1}, \tag{2.11}$$

where $\lambda_t^r \equiv P_t\lambda_t$, which is the marginal utility of an extra good, $r_t^k \equiv \frac{R_t^k}{P_t}$ the real rental rate on capital services and $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross inflation.

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10. For more details, see Justiniano, Primiceri and Tambalotti (2011), who have documented the distinction between two types of investment shocks and their relative importance.

11. With the implicit normalization that it begins at 1 in period 0 i.e $\varepsilon_0^{I,\tau} = 1$

Wage-setting

Let us consider the problem related to households wage-setting. We assume Calvo-style staggered wage contracts and no indexation. Each period a randomly selected fraction of Households gets to update their nominal wage with the probability $(1-\xi_w)$, where $\xi_w \in [0,1]$. It means that ξ_w of households cannot adjust their nominal wage.

The optimal wage $W_t(i)$ is obtained by maximizing:

$$E_t \sum_{h=0}^{\infty} (\beta \xi_w)^h \left(-\frac{\eta}{1+\chi} (N_{t+i}(h))^{-\sigma(1+\chi)} + \lambda_{t+i} W_t(h) N_{t+i}(h) \right), \tag{2.12}$$

subject to

$$N_{t+i}(h) = \left(\frac{W_t(h)}{W_{t+i}} \right)^{-\sigma} N^d_{t+i},$$

$$W_t(h) = \begin{cases} W_t^*(h) & \text{if } W_t(h) \text{ chosen optimally} \\ W_{t-1}(h) & \text{otherwise.} \end{cases}$$

The first-order condition implies that all households will choose the same reset wage, denoted in real terms and given by:

$$w_t^* = \frac{\sigma}{\sigma - 1} \frac{h_{1,t}}{h_{2,t}}. \tag{2.13}$$

Recursively the terms $h_{1,t}$ and $h_{2,t}$ evolve as follows

$$h_{1,t} = \eta \left(\frac{w_t}{w_t^*} \right)^{\sigma(1+\chi)} \left(N_t^d \right)^{1+\chi} + \beta \xi_w E_t (\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\sigma(1+\chi)} h_{1,t+1}, \tag{2.14}$$

$$h_{2,t} = \lambda_t^r \left(\frac{w_t}{w_t^*} \right)^{\sigma} N_t^d + \beta \xi_w E_t (\pi_{t+1})^{\sigma-1} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\sigma} h_{2,t+1}. \tag{2.15}$$

2.2.2 Firms and Price-setting

The Firms' production takes place in two phases. First, there is an infinitude of intermediate goods firms, each producing a differentiated material input under monopolistic competition using a Cobb-Douglas production function type technology with fixed costs. They set Calvo-type nominal prices. Final goods producers then combine these inputs intermediate inputs according to a CES technology in output, which they put up for sale to households under perfect competition.

Final Goods Producers

The final good producer uses $X_t(j)$ units of intermediate goods to produce X_t units of a final good. There is a continuum of intermediate goods firms indexed by $j \in (0,1)$, producing differentiated goods. The final good is a constant elasticity of substitution aggregate of intermediate goods, using the production technology given by:

$$X_t = \left(\int_0^1 X_t(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}, \theta > 1. \tag{2.16}$$

The final goods producer maximizes profit, given a final good price, P_t and taking intermediate good prices, $P_t(j)$, as given. The first-order condition gives the conditional demand for intermediate good j :

$$X_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\theta} X_t, \quad \forall j. \tag{2.17}$$

Inserting the demand function for input j back into the CES aggregator gives the aggregate price index:

$$P_t^{1-\theta} = \int_0^1 P_t(j)^{1-\theta} dj. \tag{2.18}$$

Intermediate Producers

Each intermediate-good firm, indexed by j, uses $\widehat{K}_t(j)$ [12] units of capital services, $N_t^d(j)$ units of labor, and intermediate inputs, $\Upsilon_t(j)$, to produce $X_t(j)$ units of the intermediate good j. Its production function is given by:

$$X_t(j) = \max\left\{A_t \Upsilon_t(j)^{\phi}\left(\widehat{K}_t(j)^{\alpha} N_t^d(j)^{1-\alpha}\right)^{1-\phi} - \Psi_t \bar{Z}, 0\right\}, \tag{2.19}$$

where $\phi \in (0,1)$ is the intermediate input share while $\alpha \in (0,1)$ and $(1-\alpha)$ are value-added share for capital services and labor inputs, $\bar{Z}$ is a fixed cost that is identical across firms. It is chosen so that steady-state profits equal to zero, given a growth factor Ψ_t.

The neutral technology A_t follows a process with both trending and stationary component:

$$A_t = A_t^{\tau} \widetilde{A}_t, \tag{2.20}$$

where the deterministic trend component A_t^{τ} grows at the gross rate $g_A \geq 1$ in each period [13] such that :

$$A_t^{\tau} = g_A A_{t-1}^{\tau}. \tag{2.21}$$

The stochastic process driving the detrended level of technology $\widetilde{A}_t$ is given by

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(s_A u_t^A\right), \tag{2.22}$$

which, taking its natural logarithm, yields

$$\ln \widetilde{A}_t = \rho_A \ln \widetilde{A}_{t-1} + s_A u_t^A, \quad u_t^A \sim iid\,(0,1). \tag{2.23}$$

The auto-regressive parameter ρ_A governs the persistence of the process and satisfies $0 \leq \rho_A < 1$. The shock is scaled by the known standard deviation equal to s_A and u_t^A is

12. It is the product of utilization and physical capital

13. With the implicit normalization that it begins at 1 in period 0 i.e $A_0^{\tau} = 1$

the innovation, drawn from a mean zero normal distribution.

Cost Minimization

The producer of differentiated goods j is assumed to set its price, $P_t(j)$, according to Calvo pricing (Calvo, 1983) and decides in every period its quantities of intermediates, capital services, and labor input. The cost of an intermediate is just the aggregate price level, P_t. The user cost of capital and labor are R_t^k and W_t (in nominal terms), respectively.

The cost-minimization problem of a typical firm choosing its inputs is given by :

$$\min \quad P_t \Upsilon_t(j) + R_t^k \widehat{K}_t + W_t N_t^d(j) \tag{2.24}$$

subject to

$$A_t \Upsilon_t(j)^{\phi} \left(\widehat{K}_t(j)^{\alpha} N_t^d(j)^{1-\alpha} \right)^{1-\phi} - \Psi_t \bar{Z} \geq \left(\frac{P_t(j)}{P_t} \right)^{-\theta} X_t$$

The first-order conditions yield the following marginal cost and conditional demand functions for the inputs used in the production of $X_t(j)$:

$$\Upsilon_t(j) = \phi mc_t \left(X_t(j) + \Psi_t \bar{Z} \right), \tag{2.25}$$

$$\widehat{K}_t(j) = \alpha(1-\phi) \frac{mc_t}{r_t^k} \left(X_t(j) + \Psi_t \bar{Z} \right), \tag{2.26}$$

$$N_t^d(j) = (1-\alpha)(1-\phi) \frac{mc_t}{w_t} \left(X_t(j) + \Psi_t \bar{Z} \right). \tag{2.27}$$

Profit Maximization and Price-setting

Each intermediate producing firm [14] chooses its price $P_t(j)$ that maximizes the expected present discount value of its future profit. The firm problem is given by:

$$\max_{P_t(j)} \quad E_t \sum_{i=0}^{\infty} (\xi_p)^i D_{t,t+i} \left(P_t(j) X_{t+i}(j) - V(X_{t+i}(j)) \right) \tag{2.28}$$

subject to

$$X_{t+i}(j) = \left(\frac{P_t(j)}{P_{t+i}} \right)^{-\theta} X_{t+i}$$

$$P_t(j) = \begin{cases} P_t^*(j) & \text{if } P_t(j) \text{ chosen optimally} \\ P_{t-1}(j) & \text{otherwise} \end{cases}$$

where $D_{t,t+i}$ is the discount rate for future profits, and $V(X_t(j))$ is the total cost of producing good $X_t(j)$. Note that $D_{t,t+i} = \frac{\beta^i \lambda_{t+i}}{\lambda_t}$. Written in real terms, it is $\frac{P_{t+i} D_{t,t+i}}{P_t}$. Hence, the real discount factor is $\frac{\beta^i P_{t+i} \lambda_{t+i}}{P_t \lambda_t}$, which we can write as $\frac{\beta^i \lambda_{t+i}^r}{\lambda_t^r}$, where $\lambda_t^r = P_t \lambda_t$. The first-order condition for $p_t^*(j)$ is :

$$p_t^*(j) = \frac{\theta}{\theta - 1} \frac{\sum_{i=0}^{\infty} (\xi_p \beta)^h \lambda_{t+i}^r mc_{t+i}(j) \pi_{t+1,t+i}^{\theta} X_{t+i}}{\sum_{i=0}^{\infty} (\xi_p \beta)^i \lambda_{t+i}^r \pi_{t+1,t+i}^{\theta-1} X_{t+i}}, \tag{2.29}$$

where $p_t^*(j) = \frac{P_t(j)}{P_t}$ is the real optimal price and mc_t the real marginal cost, which is equal to $\frac{V'(X_{t+i}(j))}{P_{t+i}}$.

Since all updating firms will choose the same reset price, the optimal reset price relative to the aggregate price index becomes $p_t^* \equiv \frac{P_t^*}{P_t}$. Then the optimal pricing condition (30)

14. A fraction $(1 - \xi_p)$ of these firms can optimally adjust their price (Calvo, 1983).

becomes:

$$p_t^* = \frac{\theta}{\theta - 1} \frac{m_{1,t}}{m_{2,t}}, \tag{2.30}$$

where $m_{1,t}$ and $m_{2,t}$ are auxiliary variables and can be written recursively as

$$m_{1,t} = \lambda_t^r mc_t X_t + \beta \xi_p E_t (\pi_{t+1})^{\theta} m_{1,t+1}, \tag{2.31}$$

$$m_{2,t} = \lambda_t^r X_t + \beta \xi_p E_t (\pi_{t+1})^{\theta - 1} m_{2,t+1}. \tag{2.32}$$

The term λ_t^r in these equations is the marginal utility of an additional unit of real income received by households, and X_t is the aggregate gross output.

2.2.3 Monetary Policy

We assume that the central bank sets the nominal interest rate $\frac{1+i_t}{1+i}$ according to the following contemporaneous mixed Taylor rule specification (Coibion and Gorodnichenko, 2011).

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_1} \left(\frac{1+i_{t-2}}{1+i}\right)^{\rho_2} \left[\left(\frac{\pi_t}{\bar{\pi}}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y_{t-1}} g_\Psi^{-1}\right)^{\alpha_y} \left(\frac{Y_t}{Y_t^f} \frac{Y^f}{Y}\right)^{\alpha_{y^f}}\right]^{1-\rho_1-\rho_2} \exp\left(\varepsilon_t^r\right) \tag{2.33}$$

It responds to deviations of inflation from an exogenous steady-state target $\frac{\pi_t}{\bar{\pi}}$, to deviations of current output growth $\frac{Y_t}{Y_{t-1}}$ from its trend level, g_Ψ and the current output gap. The interest rate smoothing parameter of order two is given by $\rho_i (i = 1, 2)$; α_π, α_{y^f} and α_y are the control parameters, and ε_t^r is an exogenous shock to the policy rule, where $\varepsilon_t^r \sim iid\left(0, \sigma_{\varepsilon^r}^2\right)$. To ensure determinacy, we assume that $\alpha_\pi > 1$, $\alpha_y \geq 0$, $0 < \alpha_{y^f} < 1$, $\rho_1 > 1$ and $\rho_2 \leq 0$.

In the spirit of Rudebusch and Swanson (2012), we model the output gap as

$$\left(\frac{Y_t / Y}{Y_t^f / Y^f}\right) = \left(\frac{Y_t}{Y_t^f} \frac{Y^f}{Y}\right),$$

where Y_t / Y denotes deviations of output relative to its steady-state, and Y_t^f / Y^f the deviations of output relative to its steady-state in the flexible price and wage economy.

2.2.4 Aggregation

The aggregate inflation and the real wage evolve according to:

$$1 = \xi_p(\pi_t)^{\theta-1} + (1-\xi_p)\left(p_t^*\right)^{1-\theta}, \tag{2.34}$$

$$w_t^{1-\sigma} = \xi_w\left(\frac{w_{t-1}}{\pi_t}\right)^{1-\sigma} + (1-\xi_w)\left(w_t^*\right)^{1-\sigma}. \tag{2.35}$$

Market-clearing requires that $\int_0^1 \widehat{K}_t(j)dj = \widehat{K}_t$, $\int_0^1 N_{d,t}(j)dj = N_t$ and $\Upsilon_t = \int_0^1 \Upsilon_t(j)dj$, respectively, for capital services, labor inputs, and intermediate inputs. Hence, aggregate gross output can be written as

$$s_t X_t = A_t \Upsilon_t^{\phi}\left(\widehat{K}_t^{\alpha} N_t^{1-\alpha}\right)^{1-\phi} - \Psi_t \bar{Z} \tag{2.36}$$

and the aggregate input demands as

$$\Upsilon_t = \phi mc_t\left(s_t X_t + \Psi_t \bar{Z}\right), \tag{2.37}$$

$$\widehat{K}_t = \alpha(1-\phi)\frac{mc_t}{r_t^k}\left(s_t X_t + \Psi_t \bar{Z}\right), \tag{2.38}$$

$$N_t = (1-\alpha)(1-\phi)\frac{mc_t}{w_t}\left(s_t X_t + \Psi_t \bar{Z}\right). \tag{2.39}$$

where s_t denotes the price dispersion term and can be written recursively:

$$s_t = (1-\xi_p)p_t^{*-\theta} + \xi_p\left(\pi_t\right)^{-\theta} s_{t-1} \tag{2.40}$$

With real GDP being the aggregate production of the goods, X_t, minus the aggregate production of intermediate inputs, the aggregate net output, Y_t is given by:

$$Y_t = X_t - \Upsilon_t \tag{2.41}$$

The aggregate resource constraint is therefore given by:

$$Y_t = C_t + I_t + \frac{a(Z_t)}{\varepsilon_t^{I,\tau}} K_t \tag{2.42}$$

2.2.5 Measuring Welfare Costs

We consider the approach taken by Sims (2013), and Ascari et al. (2018) by using a second-order approximation and directly calculate the value function of the unconditional expected utility of the representative household. The value function of the h^{th} household is given by:

$$V_t(h) = \ln(C_t - bC_{t-1}) - \eta \frac{N_t(h)^{1+\chi}}{1+\chi} + \beta E_t V_{t+1}(h) \tag{2.43}$$

Given household heterogeneity in labor supply, we assume that a central bank's welfare function is equal to the sum of welfare across households, as in Erceg et al. (2000).

$$V_t = \int_0^1 \left(\ln(C_t - bC_{t-1}) - \eta \frac{N_t(h)^{1+\chi}}{1+\chi} + \beta E_t V_{t+1}(h) \right) dh. \tag{2.44}$$

Since households only differ though their labor supply, this can be written as

$$V_t = \ln(C_t - bC_{t-1}) - \eta \int_0^1 \frac{N_t(h)^{1+\chi}}{1+\chi} dh + \beta E_t V_{t+1}. \tag{2.45}$$

Using the demand curve for each variety of labor in equation (3.2), we can write this as:

$$V_t = \ln(C_t - bC_{t-1}) - \eta \frac{N_t^{1+\chi}}{1+\chi} \int_0^1 \left(\frac{W_t(h)}{W_t} \right)^{\sigma(1+\chi)} dh + \beta E_t V_{t+1} \tag{2.46}$$

The value function is therefore

$$V_t = \ln(C_t - bC_{t-1}) - \eta \frac{N_t^{1+\chi}}{1+\chi} v_t^w + \beta E_t V_{t+1}, \tag{2.47}$$

where $v_t^w = \int_0^1 \left(\frac{W_t(h)}{W_t}\right)^{\sigma(1+\chi)} dh$, is wage dispersion and using Calvo properties of wage-setting, can be written recursively as

$$v_t^w = (1-\xi_w)\left(\frac{w_t^*}{w_t}\right)^{\sigma(1+\chi)} + \xi_w \left(\frac{w_t \pi_t}{w_{t-1}}\right)^{\sigma(1+\chi)} v_{t-1}^w. \tag{2.48}$$

Equation (3.37) can be broken down into separate components from consumption and labor and written recursively; the value function is:

$$V_t = V_t^c + V_t^n \tag{2.49}$$

where the value function over consumption and labor in the levels is respectively:

$$V_t^c = \ln(C_t - bC_{t-1}) + \beta E_t V_{t+1}^c \tag{2.50}$$

$$V_t^n = -\eta \frac{N_t^{1+\chi}}{1+\chi} v_t^w + \beta E_t V_{t+1}^n \tag{2.51}$$

The right side term summarizes the different factors that may affect wage dispersion, and therefore the welfare costs of long-term inflation. As in Ascari et al. (2018), we define the consumption equivalent measure, ψ, as the constant fraction of consumption that households have to give up (or have to be given) each period. We consider two different consumption equivalents, one based on steady states ψ_{ss} and the other on stochastic means ψ_m:

$$\psi_{ss} = 1 - \exp\left[(1-\beta)(V_A^{ss} - V_B^{ss})\right] \tag{2.52}$$

$$\psi_m = 1 - \exp\left[(1-\beta)(E(V_A) - E(V_B))\right] \tag{2.53}$$

where B stands for benchmark case, and A denotes the alternative case. A ss subscript stands for the non-stochastic steady-state and $E(.)$ the unconditional expectations operator.

2.3 Parametrization

The model calibration considers two sub-sample periods. We use quarterly data from 1960:I to 1983:IV and from 1984:I to 2007:III. Over the sub-periods, we assume that structural parameters do not change except for shocks parameters, trend inflation, and real per capita output growth. For monetary policy rule, we use two sets of estimates: Smets and Wouters (2007), the baseline case, and Coibion and Gorodnichenko (2011), the alternative. It is important to mention that their approach differs with the different size of the change in the magnitude of volatility over the sub-periods. Tables 2.1 to 2.3 and 2.14 to 2.16 in the appendix summarize non-shock and shock parameters over both sub-sample periods.

2.3.1 Non-shock Parameters

We set our non-shock parameters (tables 2.1, 2.2, 2.14, and 2.15) to standard values found in the business cycle literature. The households discount factor β equals 0.99 and the depreciation rate δ to 0.025, corresponding to an annual capital depreciation of 10 percent. The capital services share α is set at 1/3. η a scaling parameter on disutility from labor sets to 6, and the inverse Frisch elasticity of labor supply χ is 1. We set the consumption habit formation parameter b to 0.7 following Fuhrer (2000). The value of investment adjustment cost κ is 3 (Christiano et al., 2005). The squared term in the cost of utilization γ_2 is set to 0.05 to match capital utilization elasticity of 1.5 (Basu and Kimball, 1997; Dotsey and King, 2006).

The elasticity parameters for goods θ and labor σ are set to a uniform value of 6, implying a steady-state price and wage markups of 20 percent with zero trend inflation (Liu and Phaneuf, 2007). With θ value of 6, this implies a price markup of 1.2 and a weighted average share of intermediate inputs ϕ of 0.61. The Calvo price ξ_p and wage ξ_w parameters are set to a uniform value of 0.66. The Calvo price is consistent with the evidence reported in Bils and Klenow (2004) and the value assigned to the Calvo probability of wage with the evidence reported in Christiano et al. (2005).

Based on the estimates produced by Smets and Wouters (2007), we assign the following values to parameters describing the policy rule in our baseline calibration: $\rho_1 = 0.81$,$\rho_2 = 0$, $\alpha_\pi = 1.65$, $\alpha_y = 0.2$ and $\alpha_{yf} = 0.17$ (pre-1984) and $\rho_1 = 0.84$,$\rho_2 = 0$, $\alpha_\pi = 1.77$, $\alpha_y = 0.16$ and $\alpha_{yf} = 0.08$ (post-1984). From Coibion and Gorodnichenko (2011) we have : $\rho_1 = 1.34$,$\rho_2 = -0.436$, $\alpha_\pi = 1.043$, $\alpha_y = -0.002$ and $\alpha_{yf} = 0.525$ (pre-1984) and $\rho_1 = 1.052$,$\rho_2 = -0.129$, $\alpha_\pi = 2.201$, $\alpha_y = 1.561$ and $\alpha_{yf} = 0.43$ (post-1984).

2.3.2 Trend inflation, Trend Growth, and Shock Parameters

We use series from the Bureau of Economic Analysis (BEA) to compute trend inflation and trend growth observed in data. However, our approach considers on a split sample. As aforementioned, we use quarterly data covering the sub-samples periods: 1960:I - 1983:IV and 1984:I - 2007:III. Following Galí and Gambetti (2009), the split before and after 1984 is a date generally viewed as the starting point of the period of enhanced stability in the U.S. economy.

We compute the individual components' real series by dividing by their deflators from the National Income and Product Account (NIPA) tables. We then compute the growth rates of the real series by using one period lagged nominal share weights. Second, to compute the real growth rate of non-durable and services consumption, we take the share-weighted growth rates of the real component series. We then compute price indices for consumption and Investment as the nominal ratios to the real series. The relative price of the 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 each period is -0.0029 and -0.0065, respectively. It implies a calibration of investment growth $g_I = 1.0029$ and $g_I = 1.0065$ for before and after 1984 respectively. The price deflator is obtained by taking the ratio between the nominal and real series. The average growth rate of the price index over the periods 1960:I-1983:IV is 0.011679 and 0.005671 for 1984:I-2007:III. It implies trend inflation of $\pi^* = 1.011679$ (1.0475 at an annual frequency) and $\pi^* = 1.005671$

(1.0229 at an annual frequency) for each sub-period respectively, and for both case.

To compute real per capita GDP, we subtract the log civilian non-institutionalized population from the real GDP log-level. The average growth rates of this series over the sub-sample periods are 0.00534 and 0.006088, respectively. The standard deviation of output growth over each period is then 0.00932377 for the pre-1984 and 0.00562996 for the post-1984. From the above calculations, we get the output growth rates of $g_\Psi = 1.00534$ and $g_\Psi = 1.006088$ and investment growth rates $g_I = 1.0029$ and $g_I = 1.0065$, respectively for both sub-periods.

For shocks size, we proceed as follows. Given these growth rates and trend inflation, we set shocks of technology (s_A), of the marginal efficiency of investment (s_I) , and of monetary policy (s_r) to match output growth volatility over each sub-samples for both and each case. It requires taking a stand on the percentage contribution of each type of shocks to output growth volatility.

Based on the evidence produced by Justiniano et al. (2011), the marginal efficiency of investment (MEI) shocks are a significant driver of the business cycle and account for 50 percent or more of the volatility in output. These compare to 35 percent for the neutral technology shocks, and 15 percent for the monetary policy shocks. We set the AR(1) coefficients of investment ρ_I to 0.81 and of technology ρ_A to 0.95, and the resulting variances for different shocks shown in tables 2.3 and 2.16 in the appendix.

2.4 The Results

This section lays out the main results. Point 2.4.1 provides second moments [15] as well as impulse response analysis. Point 2.4.2 examines the steady-state and mean welfare implications of changes in monetary policy and trend inflation.

15. Quarterly (log) data are used across the sub-samples, and we report evidence for both the first-differenced and hp-filtered transformations.

2.4.1 Macroeconomic Dynamics

Second Moments Analysis

Table 2.6 reports the baseline results. It describes the magnitude of unconditional volatility of output, output growth, and inflation before and after 1984. We observe a substantial decline in the volatility, and it is less than half in the post-1984 period, i.e., from 0.0825 to 0.0394 and from 0.0036 to 0.0016 respectively for output and inflation. The last row in table 2.6 gives relative standard deviations between the two sub-periods. We find that all the aforecited variables have experienced a substantial decline in their volatility in the post-1984 period. However, the magnitude of that reduction is not proportional: 0.477 for output, 0.58 for output growth, and 0.44 for inflation. Thus, the decline in the volatility of output growth is not as significant as those experienced by inflation and output.

Meanwhile, the observed patterns in table 2.4 for output growth mean, output growth standard deviation, hp-filtered output, and hp-filtered consumption standard deviations remained unchanged and are consistent with the observed volatility in the data for both sub-periods. The standard deviation of output growth declined from 0.0096 to 0.0056, and from 0.019 to 0.012 for hp-filtered output. The volatility of hp-filtered hours has declined from 0.0126 before 1984 to 0.0067 after 1984 and from 0.0077 to 0.0046 when first-differenced (Table 2.5). In terms of relative volatility [16], the decline observed in hours (hp-filtered hours (0.5317) and first-differenced hours (0.5974)) is smaller than the one experienced by output (0.477).

Tables 2.17 through 2.19 summarize the results obtained from the alternative case, i.e., by using Coibion and Gorodnichenko (2011) policy rule estimates. We observe similar patterns with few exceptions in line with the results in the baseline. The decline observed in terms of the relative volatility of inflation (0.269) is more significant than those experienced by output (0,459) and output growth (0.583) (Table 2.19). The mean

16. In terms of relative volatility over both sub-periods, fewer than 0.5 means a more considerable decline. A value of equal or greater than 0.5 indicates a smaller decline.

output growth remains unchanged except for output growth, hp-filtered output, and hp-filtered consumption standard deviations. Overall, the post-1984 period experienced a decline in volatility, with a slight difference in the magnitude of the baseline case.

Conditional on shocks and relative to the ratio between the two periods, tables 2.7 through 2.9 display the following results for the baseline calibration. From table 2.7, we report relative output volatility conditional on the three types of shocks: neutral productivity shocks (0.474), MEI shocks (0.4702), and monetary shocks (0.421). For output growth, we find the following ratios: 0.625, 0.630, and 0.388, respectively, for neutral productivity, MEI, and monetary shocks (Table 2.8). In line with these results, we can conclude that monetary policy shock has an impact on the decline of volatility in output (0.421) and output growth (0.388) (Tables 2.7 and 2.8). Galí and Gambetti (2009) reach a similar conclusion by using a time-varying SVAR approach. They find that non-technology shocks appear to be the primary source of the decline in output volatility. However, our result concurs with the findings in Justiniano et al. (2011), who point to an important contribution of MEI shocks.

Table 2.9 describes the inflation volatility relative to different types of shocks. It shows that fluctuations in the inflation volatility across the two sub-samples are primarily accounted for by both MEI shocks (0.25) and neutral productivity (0.413) with monetary shocks playing a relatively smaller role (0.75). The interaction between trend inflation and MEI shocks accounts for the more considerable contribution of the latter relative to that of the neutral productivity shocks.

In the results so far, we have assumed that the uncertainty associated with our policy rule estimated coefficients is small in line with Smets and Wouters (2007) (Tables 2.1 and 2.2). In what follows, we assume that the variation associated with these estimated coefficients across the sub-periods is large in the spirit of the findings in Coibion and Gorodnichenko (2011). Thus, we conduct an alternative exercise and assign the following values to parameters describing the policy rule (Tables 2.14 and 2.15) : $\rho_1 = 1.34$, $\rho_2 = -0.436$, $\alpha_\pi = 1.043$, $\alpha_y = -0.002$ and $\alpha_{yf} = 0.525$ in the pre-1984 period) and $\rho_1 = 1.052$, $\rho_2 = -0.129$, $\alpha_\pi = 2.201$, $\alpha_y = 1.561$ and $\alpha_{yf} = 0.43$ (in the post-1984 period).

We find the following results relative to both periods (Tables 2.20 through 2.22 in the appendix). First, from table 2.20 we note that monetary shocks (0.428) and MEI shocks (0.427) have relatively a more important contribution to the volatility of output and its subsequent decline. Second, table 2.21 shows that much of the fluctuations in output growth volatility are accounted for by the monetary shocks (0.428) and appears to display a broader downward trend than neutral productivity shocks (0.529). The contribution of the MEI shocks is much smaller (0.687) in relative terms. Third, table 2.22 reports the volatility of inflation relative to the three types of shocks. It shows that the contribution of MEI shocks (0.125) in the drop of the relative volatility of inflation is more significant than neutral productivity shocks (0.258) and monetary shocks (0.833) in relative terms.

The essential insight obtained from unconditional and conditional volatility is that the findings are more plausible and consistent with the literature. First, we note that monetary shocks play an important role as a source of the increase in output and output growth volatility in the pre-1984 and the subsequent decline in the post-1984. Second, the MEI shocks are responsible for the decline in inflation volatility [17] by more than the neutral productivity and monetary shocks. Finally, the interactions between trend inflation and different types of shocks, as trend inflation goes up (1.0475 percent at an annual frequency) in the first sample period and down (1.0229 percent at an annual frequency) in the second, also account for much of the results.

Next, we analyze the cyclical behavior of the variables mentioned above to assess whether policy changes explain the decline in volatility. Tables 2.5 and 2.18 examine the unconditional correlations among output, consumption, Investment and hours, and their changes over the sub-periods. They report statistics for two different detrending methods: the first-differenced and hp-filtered logarithms of the original variables. First, we use the output as the cyclical indicator of reference and hp-filter as a data transformation. Output and hours are strongly procyclical from 0.7253 in the first period to 0.6406 in the second while the observed correlations in data are 0.8610 and

17. More specifically, the interaction between trend inflation and MEI shocks are responsible for inflation volatility (Ascari et al., 2018).

0.7627, respectively (Table 2.5). In the alternative case (Table 2.18), statistics show for observed co-movements in data 0.8610 in the pre-1984 period and 0.7627 in the post-1984 compare to estimated correlations in the model 0.6809 and 0.3641, respectively. Furthermore, when we consider the cyclical behavior of output measured by its correlation with either consumption or investment, we observe that it is higher and significantly procyclical (Tables 2.5 and 2.18).

The result changes more when we use the first-difference filter. The cyclical behavior of output, measured by its co-movement with hours, has experienced a considerable decline. However, it is still procyclical in the first period to be more weakly procyclical in the second. For the Contemporaneous correlation of consumption, Investment with output, we observe that they are all still strongly correlated from 0.7695 (consumption), 0.9509 (Investment) in the first period to 0.6992 and 0.9492 in the second period in the baseline case (Table 2.5). In the alternative case, the co-movements of output with consumption and Investment are both procyclical in the first period to become weakly procyclical in the second period (Table 2.18). Regarding the relative correlation between both periods, the decline in relative cyclical behavior of output with hours independently of the detrending method used is more significant than the one experienced with consumption and Investment either in data or the model (Tables 2.5 and 2.18). Furthermore, it is noteworthy that the correlations mentioned above almost fit the ones observed in data.

In the results obtained so far, the role of policy changes as a source in explaining the drop of volatility is far from clear. We turn to impulse response functions analysis for a complete picture.

Impulse Response Analysis

In what follows, we analyze impulse response functions relative to neutral productivity, MEI, and monetary shocks. Figures display side by side the impulse responses over the pre-1984 (solid lines) and post-1984 (dashed lines) periods. These IRFs reflect, to some degree, parallel changes as those experienced over the sub-periods in the above conditional second moments analysis. We restrict our analysis to the variables mentioned above and produce two sets of figures. In the first set, IRF's based on the baseline calibration (Figures 2.1 through 2.3). In the second, we use alternative calibration from tables 2.14 and 2.15 to generate IRFs in figures 2.4 through 2.6. We use these two sets of calibration to single out the role of monetary policy over both periods and the implications of trend inflation.

Figures 2.1 and 2.4 display the dynamic responses of variables to neutral productivity shocks. In both cases, it is noticeable that the impulse responses of output and inflation over the pre-1984 and post-1984 periods differ substantially, with the decline in amplitude in the post-1984 period being significantly small at the impact than in the case of MEI and monetary shocks. In this perspective, neutral productivity shocks appear to have a small impact on the drop in volatility of output and inflation (Tables 2.7, 2.9, 2.20, and 2.22).

On the other hand, we observe negative correlations between output and hours, and between hours and labor productivity conditional on a positive, neutral productivity shock (Figures 2.1 and 2.4). This situation can be explained by a persistent decline in the response of hours relative to a positive, neutral productivity shock. Overall, we observe a decline in both conditional correlations and unconditional volatility of output and hours. As identified by Galí and Gambetti (2009) and Stiroh (2009), the decline in the volatility of hours, labor productivity, and covariance between labor productivity and hours can explain a substantial fraction of the decline in output volatility.

Tables 2.9 and 2.22 show that MEI shocks largely explain fluctuations of inflation volatility than the neutral productivity and monetary shocks. This feature of the conditional second moments is reflected by parallel changes in the inflation impulse response functions in figures 2.2 and 2.5. Over the sub-periods, we observe a hump-shaped and very persistent output response to a monetary shock (Figures 2.3 and 2.6). Meanwhile, the magnitude of output volatility changes between the pre and post-1984 periods is larger relative to monetary shocks than to MEI and neutral productivity shocks, as reported in tables 2.7 and 2.20. Also, from tables 2.8 and 2.21, we note that the monetary shocks play an important role as the primary explanation for the volatility of output growth and its subsequent decline. Accordingly, the changes experienced over both periods in output growth second moments reflect parallel changes in its impulse responses. Thus, changes in monetary policy contribute to a larger share in the decline of output and output growth volatility (tables 2.3 and 2.16). This result is in line with the original conclusion of Galí and Gambetti (2009). They find that a sharp fall in non-technology shocks' contribution to the variance of output in absolute and relative terms explains the Great Moderation.

From our results, we observe variations of macroeconomic variables standard deviation, correlation, and impulse response functions over the sub-periods. These variations reflect changes. First, in the composition of shocks (Tables 2.3 and 2.16). The frequency of shocks plays an essential role in variations of output, output growth, hours, and inflation's standard deviations (Tables 2.5-2.9 and 2.18-2.22). Second, in the transmission mechanisms. Indeed in our calibration, Smets and Wouters (2007) and Coibion and Gorodnichenko (2011) Taylor rule estimates reveal a substantial difference in the values of coefficients in the pre-1984 period compared to the post-1984 suggesting a change in the way the economy accommodates shocks. It is captured by the magnitude of changes in the impulse response functions (Figures 2.3 and 2.6).

Overall, we note that the combination of both changes in policy rule parameters and the frequency of exogenous shocks contribute to the reduction of volatility in the post-1984 period. These results are consistent with the conclusion reached by Canova (2009) and Galí and Gambetti (2009). The results so far give us a clear picture of changes experienced by the U.S. economy over the examined period. Next, we analyze the implication of those changes on welfare.

2.4.2 Monetary Policy and Welfare Costs

This section examines the welfare costs related to monetary policy changes and trend inflation before and after 1984. To measure these costs, we consider two different sets of consumption equivalent metrics: one based on stochastic mean and the other on non-stochastic steady-state. For each set, we compute welfare costs for going from 0 to 4.75 percent of trend inflation (all annualized) and from 0 to 2.29 percent of trend inflation (all annualized).

Based on Smets and Wouters (2007) policy rule estimates, table 2.10 reports the consumption-equivalent mean. It shows that the welfare losses of going from 0 to 4.75 percent of trend inflation amount to around 9.65 percent in the pre-1984 period compared to 2.36 percent when trend inflation passes from 0 to 2.29 percent in the post-1984. Table 2.11 describes the steady-state consumption-equivalent welfare losses. We observe that as trend inflation goes from 0 to 4.75 percent in the post-1984 period, the consumption-equivalent welfare loss is about 7.65 percent and around 2.26 percent in the post-1984 sub-period.

To understand the implications of trend inflation and trend growth on welfare losses, we run our model without the output gap, i.e., we set it to 1 in our benchmark calibration. Table 2.12 reports the results. From this table, welfare costs mean going from 0 to 4.75 percent of trend inflation are 8.25 percent in the pre-1984, and around 2.34 percent in the post-1984 when trend inflation goes from 0 to 2.29 percent. In terms of steady-state, table 2.13 reveals that going from 0 to 4.75 percent of trend inflation in the pre-1984 period causes the welfare losses amount to 7.65 percent, and about 2.26 percent at 2.29 percent of trend inflation in the post-1984 sub-sample period.

Overall, welfare costs rise in the pre-1984 period and decline in the post-1984 period as trend inflation, and policy rule parameters change over both sub-periods. In other words, welfare losses are more significant in the high volatility era, i.e., in the years before 1984 and are smaller or modest in the low volatility era, i.e., the years after 1984. The main reason is that from the late 1960s to the early 1980s, the U.S. economy experienced high and volatile inflation and several severe recessions. The Federal Reserve was highly accommodative to expected increases in inflation. The real short-term interest rates declined [18]as anticipated inflation rose macroeconomic instability. However, since the early 1980s, the Fed responded to higher expected inflation by raising real short-term interest rates along with nominal short-term interest rates. Thus, inflation

18. Fed raised nominal interest rates by less than the increase expected inflation.

volatility and output decreases [19], so do the welfare costs compared to the period from the 1960s to the early 1980s.

Furthermore, we also notice that targeting the output gap can result in significant welfare losses. This finding is relative to trend productivity growth and trend inflation in our model, combined with nominal wage rigidity. As shown in Amano et al. (2009) and reported by Sims (2013), when wages are Calvo-style staggered contracts, and trend growth is positive, wage dispersion plays an important role. It is because wage dispersion drives a wedge between labor supply and labor employed, and can be very costly from a welfare perspective, much more so than price dispersion. A positive steady-state wage dispersion significantly increases the welfare costs of inflation variability relative to the output gap, even without trend inflation. Therefore, it is welfare-reducing to react to the output gap. Sims (2013) also reaches a similar conclusion.

In the results so far, we have assumed that the uncertainty associated with the policy rule estimates over both periods is small (Smets and Wouters, 2007). In what follows, we examine a case where this uncertainty is considerable. Thus, we conduct an alternative exercise and assign Coibion and Gorodnichenko (2011) estimates the policy rule. We find the following results. Table 2.23 describes the welfare cost in terms of the stochastic mean. Going from 0 to 4.75 percent of trend inflation causes the mean welfare losses to increase to around 9.37 percent in the pre-1984 period. However, a decline in trend inflation at 2.29 percent in the post-1984 causes these costs to decrease to about 2.45 percent. In terms of steady-state, welfare costs in the pre-1984 are about 7.56 percent and around 2.26 percent in the post-1984 sub-period (Table 2.24).

When we remove the output gap from the policy rule, table 2.25 reports that based on mean, the welfare costs of going from 0 to 4.75 percent of trend inflation are about 8.13 percent and around 2.39 percent as trend inflation rate passes from 0 to 2.29 percent. In terms of steady-state, table 2.26 reveals that going from 0 to 4.75 percent of trend inflation in the pre-1984 period, causes the welfare losses to increase to 7.56 percent and about 2.26 percent at 2.29 percent of trend inflation in the post-1984 period. Al-

19. Inflation has remained steadily low and output growth relatively stable

though alternative specification results are slightly lower than in the benchmark case, we observed that the two sets of findings reach a similar conclusion.

The above results concur with the evidence produced by Nakamura et al. (2018). Measuring the sensitivity of inefficient price dispersion to changes in inflation, they found found minimal variation over the last 30 years. They concluded that the main cost of inflation in New Keynesian models are completely elusive and that the optimality of low inflation based on these models needs to be reassessed [20]. To fix this problem Nakata (2014) advocates a class of state-dependent pricing models with the endogenous frequency of price adjustment than in the Calvo model and in which welfare costs of inflation are most likely lower (Nakamura et al., 2018).

However, they remain silent about the evidence and sensitivity of wage dispersion to changes in inflation. In our model, we have considered nominal rigidities both in labor and goods markets and found that the latter, rather than the former, played an important role from a welfare perspective.

20. Matos et al. (2009) and Gagnon (2009) have shown based on micro-data from other countries that price adjustment is more frequent during the period of high inflation

2.5 Conclusion

This paper has examined the welfare costs related to changes in policy rule parameters and trend inflation in the U.S. economy before and after the early 1980s. This analysis was conducted in a medium-scale New Keynesian DSGE model in which the central bank sets the nominal interest rate according to Taylor's monetary policy rule. The interest rate responds to inflation, output growth, and the output gap. To measure these costs, we have considered two different sets of consumption equivalent metrics: one based on stochastic mean and the other on non-stochastic steady-state.

The results have shown that the welfare costs were higher in the pre-1980s period compared to the post-1980s period. More importantly, when trend inflation and trend productivity growth are combined with nominal wage rigidity, targeting the output gap is very costly, much more so than nominal price rigidity. Therefore, we conclude that wage dispersion rather than price dispersion matters from a welfare perspective.

For future research, the model can be estimated in sub-periods using a Bayesian approach. In this way, it would make it possible to have precise estimates of the average inflation rate and monetary policy rule parameters in sub-periods. In addition, this analysis can be extended to alternative model specifications, namely sticky-price and sticky-wage models to better understand the role of price and wage dispersions on welfare costs.

Baseline calibration

Table 2.1: Non-Shock Parameters, Pre-1984 (Baseline)

β	δ	α	η	χ	b	κ	γ_2	θ
0.99	0.025	1/3	6	1	0.7	3	0.05	6
σ	ξ_p	ξ_w	ϕ	ρ_1	ρ_2	α_π	α_y	α_{yf}
6	0.66	0.66	0.61	0.81	0	1.65	0.2	0.17

Note: Table 2.1 reports baseline non-shock parameters for the pre-1984 sub-period. By construction, structural parameters are the same in both sub-periods except for the monetary policy rule.

Table 2.2: Non-Shock Parameters, Post-1984 (Baseline)

β	δ	α	η	χ	b	κ	γ_2	θ
0.99	0.025	1/3	6	1	0.7	3	0.05	6
σ	ξ_p	ξ_w	ϕ	ρ_1	ρ_2	α_π	α_y	α_{yf}
6	0.66	0.66	0.61	0.84	0	1.77	0.16	0.08

Note: Table 2.2 reports baseline non-shock parameters for the post-1984 sub-period. By construction, structural parameters are the same in both sub-periods except for the monetary policy rule.

Table 2.3: Shock Parameters (Baseline)

	g_A	g_I	ρ_r	s_r	ρ_I	s_I	ρ_A	s_A
Pre-84	$1.00258^{1-\phi}$	1.0029	0	0.0023	0.8	0.0154	0.95	0.0026
Post-84	$1.0019^{1-\phi}$	1.0065	0	0.0006	0.8	0.0096	0.95	0.0018

Notes: Table 2.3 gives the baseline shock parameters for both sub-periods. g_A denotes the trend growth of the neutral productivity process. g_I is the trend growth rate of the IST process. ρ_A, ρ_r, and ρ_I are autoregressive parameters governing the stochastic processes. The shock standard deviations are chosen to match the observed volatility of per capita output growth in each sub-period, with s_A the neutral shock, s_I the marginal efficiency of investment shock, and s_r the monetary shock.

Table 2.4: Moments (Baseline)

	$E(\Delta Y)$	$\sigma(\Delta Y)$	$\sigma(\Delta I)$	$\sigma(\Delta C)$	$\rho_1(\Delta Y)$	$\rho_1(\pi)$	$\sigma(\pi)$	$\sigma(Y^{hp})$	$\sigma(C^{hp})$	$\sigma(I^{hp})$
Data										
Full	0.0057	0.0078	0.020	0.0045	0.36	0.90	0.0065	0.016	0.0083	0.037
Pre-84	0.0053	0.0096	0.024	0.0054	0.32	0.92	0.0076	0.019	0.010	0.045
Model	(0.0053)	(0.0096)	(0.018)	(0.0052)	(0.56)	(0.89)	(0.0037)	(0.019)	(0.010)	(0.041)
Post-84	0.0061	0.0056	0.016	0.0034	0.39	0.59	0.0029	0.012	0.0061	0.028
Model	(0.0061)	(0.0056)	(0.011)	(0.0027)	(0.55)	(0.79)	(0.0016)	(0.012)	(0.0056)	(0.026)

Table 2.5: Moments bis (Baseline)

	$\sigma(\Delta L)$	$\rho(\Delta Y,\Delta I)$	$\rho(\Delta Y,\Delta C)$	$\rho(\Delta Y,\Delta L)$	$\sigma(L^{hp})$	$\rho(Y^{hp},I^{hp})$	$\rho(Y^{hp},C^{hp})$	$\rho(Y^{hp},L^{hp})$
Data								
Full	0.0079	0.9172	0.7542	0.6313	0.0171	0.9701	0.9053	0.875
Pre-84	0.0092	0.9277	0.7882	0.6772	0.0183	0.9645	0.9168	0.8610
Model	(0.0077)	(0.9509)	(0.7695)	(0.4789)	(0.0126)	(0.9583)	(0.8118)	(0.7253)
Post-84	0.0058	0.8634	0.6854	0.4640	0.0134	0.9689	0.8779	0.7627
Model	(0.0046)	(0.9492)	(0.6992)	(0.3436)	(0.0067)	(0.9621)	(0.7623)	(0.6406)

Notes: Tables 2.4 and 2.5 report selected moments from the baseline calibration for each sub-period. $\sigma(.)$ stands for the standard deviation, $\rho(.)$ denotes the contemporaneous correlation coefficient, $\rho_1(.)$ is a first order autocorrelation coefficient, Δ denotes the first diffrence operator, and hp superscript refers to the HP-filtered series. Y, C, I, and L are the log natural of these series. π is quarter-over-quarter inflation.

Table 2.6: Unconditional volatilities (Baseline)

	$\sigma(Y)$	$\sigma(\Delta Y)$	$\sigma(\pi)$
Pre-1984	0.0825	0.0096	0.0036
Post-1984	0.0394	0.0056	0.0016
$\frac{Post-1984}{Pre-1984}$	0.477	0.583	0.444

Notes: Table 2.6 gives the baseline unconditional volatilities of output, output growth, and inflation for each sub-sample and their relative change over the sub-periods.

Table 2.7: Output volatility (Baseline)

	s_A	s_I	s_r
Pre-1984	0.0623	0.0168	0.0038
Post-1984	0.0295	0.0079	0.0016
$\frac{Post-1984}{Pre-1984}$	0.474	0.470	0.421

Notes: Table 2.7 gives the baseline output volatility conditional on neutral (s_A), MEI (s_I), and monetary (s_r) shocks for each sub-sample and their relative change over the sub-periods.

Table 2.8: Output growth volatility

	s_A	s_I	s_r
Pre-1984	0.0032	0.0046	0.0018
Post-1984	0.0020	0.0029	0.0007
$\frac{Post-1984}{Pre-1984}$	0.625	0.630	0.388

Notes: Table 2.8 shows baseline output growth volatility conditional on neutral (s_A), MEI (s_I), and monetary (s_r) shocks for each sub-sample and their relative change over the sub-periods.

Table 2.9: Inflation volatility (Baseline)

	s_A	s_I	s_r
Pre-1984	0.0029	0.0004	0.0004
Post-1984	0.0012	0.0001	0.0003
$\frac{Post-1984}{Pre-1984}$	0.413	0.250	0.750

Notes: Table 2.9 reports baseline inflation volatility conditional on neutral (s_A), MEI (s_I), and monetary (s_r) shocks for each sub-sample and their relative change over the sub-periods.

Table 2.10: Consumption Equivalents, Mean (Baseline)

π^*	1.00→
Pre-1984	
1.0000	0
1.0475	0.0965
Post-1984	
1.0000	0
1.0229	0.0236

Table 2.11: Consumption Equivalents, Steady-State (Baseline)

π^*	1.00→
Pre-1984	
1.0000	0
1.0475	0.0765
Post-1984	
1.0000	0
1.0229	0.0226

Notes: Table 2.10 reports welfare costs from increasing the trend inflation: 0 to 4.75% in the pre-1984 sub-period, and from 0 to 2.29% in the post-1984 sub-period. These costs are based on stochastic means. Likewise, table 2.11 shows consumption equivalent welfare losses based on non-stochastic steady-state.

Table 2.12: Consumption Equivalents,
Mean (Baseline)

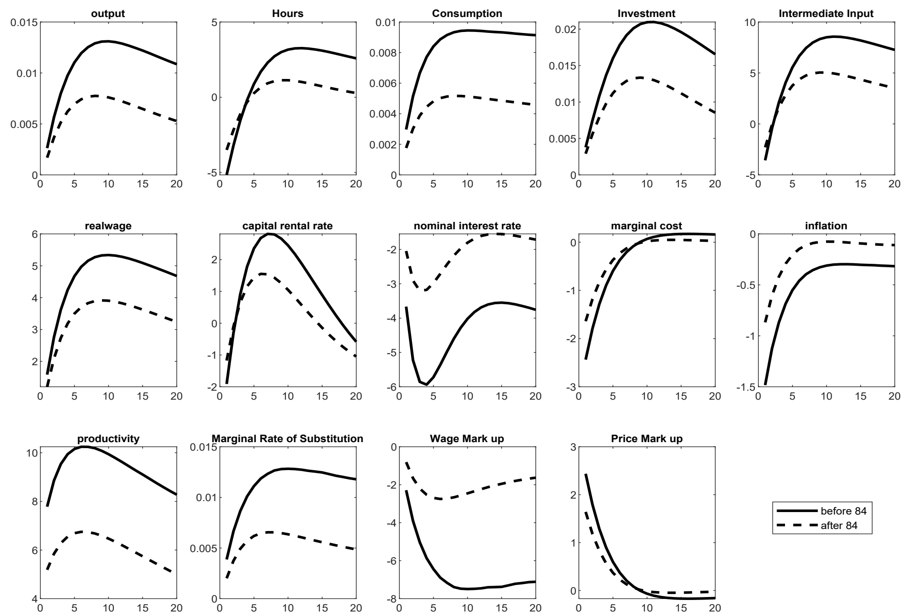
π^*	1.00→
Pre-1984	
1.0000	0
1.0475	0.0825
Post-1984	
1.0000	0
1.0229	0.0234

Table 2.13: Consumption Equivalents,
Steady-State (Baseline)

π^*	1.00→
Pre-1984	
1.0000	0
1.0475	0.0765
Post-1984	
1.0000	0
1.0229	0.0226

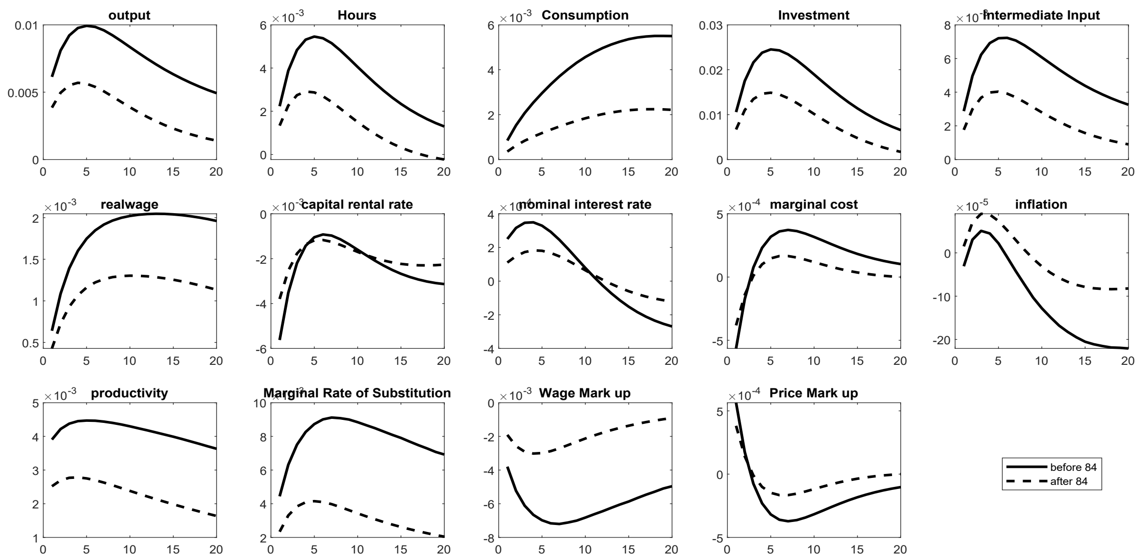
Notes: Table 2.12 reports welfare costs from increasing the trend inflation: 0 to 4.75% in the pre-1984 sub-period, and from 0 to 2.29% in the post-1984 sub-period. These costs are based on stochastic means. Likewise, table 2.13 shows consumption equivalent welfare losses based on non-stochastic steady-state. In tables 2.12 and 2.13, we run our model without (remove) the output gap.

Figure 2.1: Neutral Shock (Baseline)



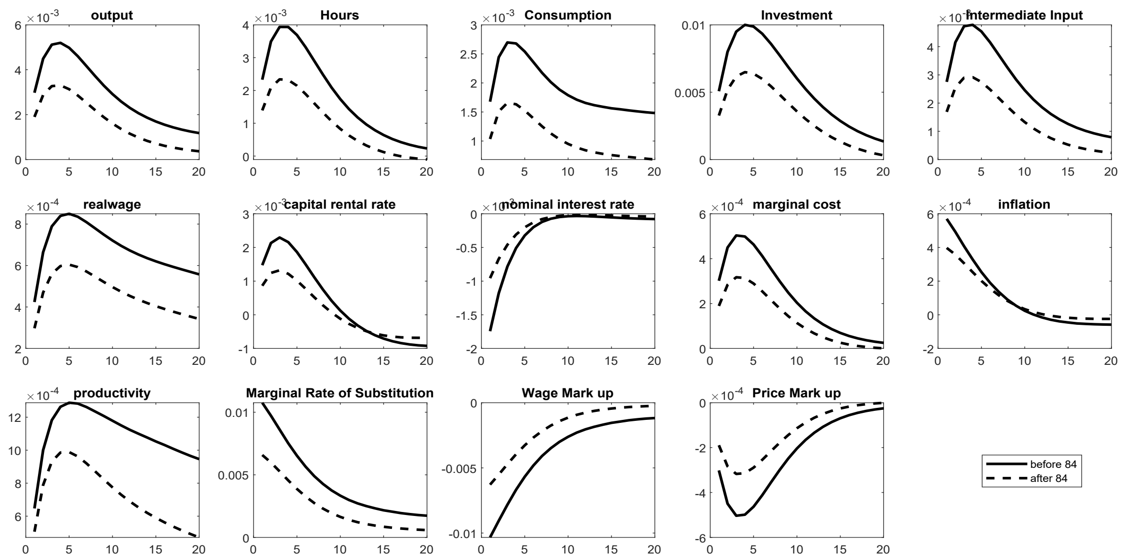
Notes: Figure 2.1 plots the average impulse responses to a neutral productivity shock using the baseline calibration for the two sub-periods indicated in the legend: the solid lines denote the pre-1984 sub-period and the dashed lines describe the post-1984 sub-period.

Figure 2.2: MEI Shock (Baseline)



Notes: Figure 2.2 plots the average impulse responses to a MEI shock using the baseline calibration for the two sub-periods indicated in the legend: the solid lines denote the pre-1984 sub-period and the dashed lines describe the post-1984 sub-period.

Figure 2.3: Monetary Shock (Baseline)



Notes: Figure 2.3 plots the average impulse responses to a monetary shock using the baseline calibration for the two sub-periods indicated in the legend: the solid lines denote the pre-1984 sub-period and the dashed lines describe the post-1984 sub-period.

Alternative calibration

Table 2.14: Non-Shock Parameters, Pre-1984 (Alternative)

β	δ	α	η	χ	b	κ	γ_2	θ
0.99	0.025	$1/3$	6	1	0.7	3	0.05	6
σ	ξ_p	ξ_w	ϕ	ρ_1	ρ_2	α_π	α_y	α_{yf}
6	0.66	0.66	0.61	1.34	-0.436	1.043	-0.002	0.525

Note: Table 2.14 reports alternative non-shock parameters for the pre-1984 sub-period. By construction, structural parameters are the same in both sub-periods except for the monetary policy rule.

Table 2.15: Non-Shock Parameters, Post-1984 (Alternative)

β	δ	α	η	χ	b	κ	γ_2	θ
0.99	0.025	$1/3$	6	1	0.7	3	0.05	6
σ	ξ_p	ξ_w	ϕ	ρ_1	ρ_2	α_π	α_y	α_{yf}
6	0.66	0.66	0.61	1.052	-0.129	2.201	1.561	0.43

Note: Table 2.15 reports alternative non-shock parameters for the post-1984 sub-period. By construction, structural parameters are the same in both sub-periods except for the monetary policy rule.

Table 2.16: Shock Parameters (Alternative)

	g_A	g_I	ρ_r	s_r	ρ_I	s_I	ρ_A	s_A
Pre-84	$1.00258^{1-\phi}$	1.0029	0	0.00087	0.8	0.0162	0.95	0.00260
Post-84	$1.0019^{1-\phi}$	1.0065	0	0.000080	0.8	0.01366	0.95	0.00256

Notes: Table 2.3 gives alternative shock parameters for both sub-periods. g_A denotes the trend growth of the neutral productivity process. g_I is the trend growth rate of the IST process. ρ_A, ρ_r, and ρ_I are autoregressive parameters governing the stochastic processes. The shock standard deviations are chosen to match the observed volatility of per capita output growth in each sub-period, with s_A the neutral shock, s_I the marginal efficiency of investment shock, and s_r the monetary shock.

Table 2.17: Moments (Alternative)

	$E(\Delta Y)$	$\sigma(\Delta Y)$	$\sigma(\Delta I)$	$\sigma(\Delta C)$	$\rho_1(\Delta Y)$	$\rho_1(\pi)$	$\sigma(\pi)$	$\sigma(Y^{hp})$	$\sigma(C^{hp})$	$\sigma(I^{hp})$
Data										
Full	0.0057	0.0078	0.020	0.0045	0.36	0.90	0.0065	0.016	0.0083	0.037
Pre-84	0.0053	0.0096	0.024	0.0054	0.32	0.92	0.0076	0.019	0.010	0.045
Model	(0.0053)	(0.0096)	(0.019)	(0.0049)	(0.59)	(0.95)	(0.013)	(0.020)	(0.010)	(0.043)
Post-84	0.0061	0.0056	0.016	0.0034	0.39	0.59	0.0029	0.012	0.0061	0.028
Model	(0.0061)	(0.0056)	(0.0114)	(0.0025)	(0.46)	(0.73)	(0.0034)	(0.011)	(0.0055)	(0.026)

Table 2.18: Moments bis (Alternative)

	$\sigma(\Delta L)$	$\rho(\Delta Y,\Delta I)$	$\rho(\Delta Y,\Delta C)$	$\rho(\Delta Y,\Delta L)$	$\sigma(L^{hp})$	$\rho(Y^{hp},I^{hp})$	$\rho(Y^{hp},C^{hp})$	$\rho(Y^{hp},L^{hp})$
Data								
Full	0.0079	0.9172	0.7542	0.6313	0.0171	0.9701	0.9053	0.875
Pre-84	0.0092	0.9277	0.7882	0.6772	0.0183	0.9645	0.9168	0.8610
Model	(0.0084)	(0.9448)	(0.7239)	(0.4594)	(0.0130)	(0.9530)	(0.7862)	(0.6809)
Post-84	0.0058	0.8634	0.6854	0.4640	0.0134	0.9689	0.8779	0.7627
Model	(0.0010)	(0.9116)	(0.3862)	(0.2446)	(0.0090)	(0.9344)	(0.5052)	(0.3641)

Notes: Tables 2.17 and 2.18 report selected moments from alternative calibration for each sub-period. $\sigma(.)$ stands for the standard deviation, $\rho(.)$ denotes the contemporaneous correlation coefficient, $\rho_1(.)$ is a first order autocorrelation coefficient, Δ denotes the first diffrence operator, and hp superscript refers to the HP-filtered series. Y, C, I, and L are the log natural of these series. π is quarter-over-quarter inflation.

Table 2.19: Unconditional volatilities (Alternative)

	$\sigma(Y)$	$\sigma(\Delta Y)$	$\sigma(\pi)$
Pre-1984	0.0821	0.0096	0.0126
Post-1984	0.0377	0.0056	0.0034
$\frac{Post-1984}{Pre-1984}$	0.459	0.583	0.269

Notes: Table 2.19 gives alternative unconditional volatilities of output, output growth, and inflation for each sub-sample and their relative change over the sub-periods.

Table 2.20: Output volatility (Alternative)

	s_A	s_I	s_r
Pre-1984	0.0655	0.0145	0.0021
Post-1984	0.0306	0.0062	0.0009
$\frac{Post-1984}{Pre-1984}$	0.467	0.427	0.428

Notes: Table 2.20 gives alternative output volatility conditional on neutral (s_A), MEI (s_I), and monetary (s_r) shocks for each sub-sample and their relative change over the sub-periods.

Table 2.21: Output-growth volatility (Alternative)

	s_A	s_I	s_r
Pre-1984	0.0034	0.0048	0.0014
Post-1984	0.0018	0.0033	0.0006
$\frac{Post-1984}{Pre-1984}$	0.529	0.687	0.428

Notes: Table 2.21 shows alt. output growth volatility conditional on neutral (s_A), MEI (s_I), and monetary (s_r) shocks for each sub-sample and their relative change over the sub-periods.

Table 2.22: Inflation volatility (Alternative)

	s_A	s_I	s_r
Pre-1984	0.0112	0.0008	0.0006
Post-1984	0.0029	0.0001	0.0005
$\frac{Post-1984}{Pre-1984}$	0.258	0.125	0.833

Notes: Table 2.22 reports alternative inflation volatility conditional on neutral (s_A), MEI (s_I), and monetary (s_r) shocks for each sub-sample and their relative change over the sub-periods.

Table 2.23: Consumption Equivalents,
Mean (Alternative)

π^*	1.00$\rightarrow$
Pre-1984	
1.0000	0
1.0475	0.0937
Post-1984	
1.0000	0
1.0229	0.0245

Table 2.24: Consumption Equivalents,
Steady-State (Alternative)

π^*	1.00$\rightarrow$
Pre-1984	
1.0000	0
1.0475	0.0756
Post-1984	
1.0000	0
1.0229	0.0226

Notes: Table 2.23 reports welfare costs from increasing the trend inflation: 0 to 4.75% in the pre-1984 sub-period, and from 0 to 2.29% in the post-1984 sub-period. These costs are based on stochastic means. Likewise, table 2.24 shows consumption equivalent welfare losses based on non-stochastic steady-state.

Table 2.25: Consumption Equivalents,
Mean (Alternative)

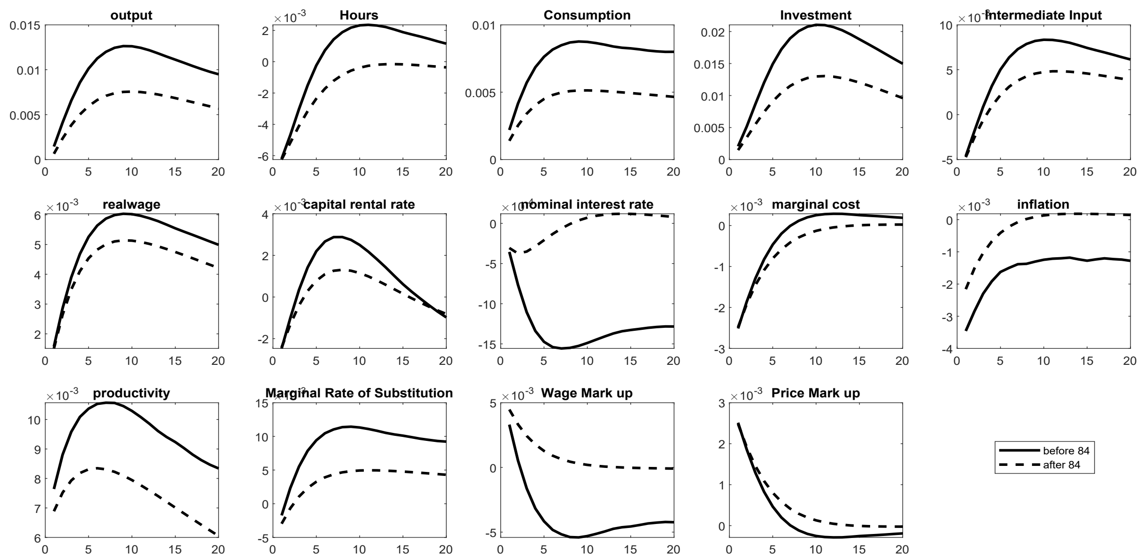
π^*	1.00→
Pre-1984	
1.0000	0
1.0475	0.0813
Post-1984	
1.0000	0
1.0229	0.0239

Table 2.26: Consumption Equivalents,
Steady-State (Alternative)

π^*	1.00→
Pre-1984	
1.0000	0
1.0475	0.0756
Post-1984	
1.0000	0
1.0229	0.0226

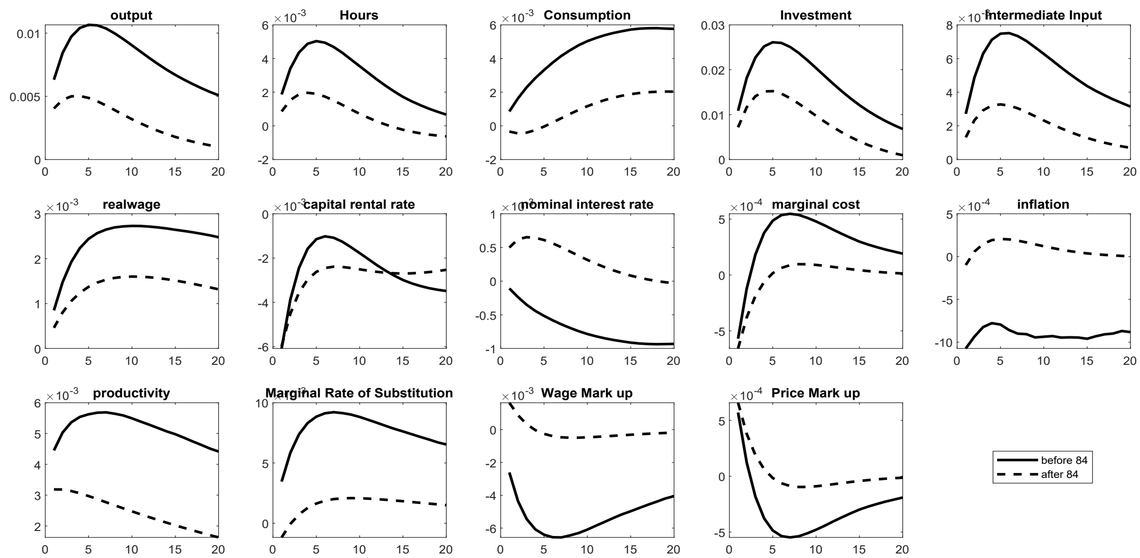
Notes: Table 2.25 reports welfare costs from increasing the trend inflation: 0 to 4.75% in the pre-1984 sub-period, and from 0 to 2.29% in the post-1984 sub-period. These costs are based on stochastic means. Likewise, table 2.26 shows consumption equivalent welfare losses based on non-stochastic steady-state. In tables 2.25 and 2.26, we run our model without (remove) the output gap.

Figure 2.4: Neutral Shock (Alternative)



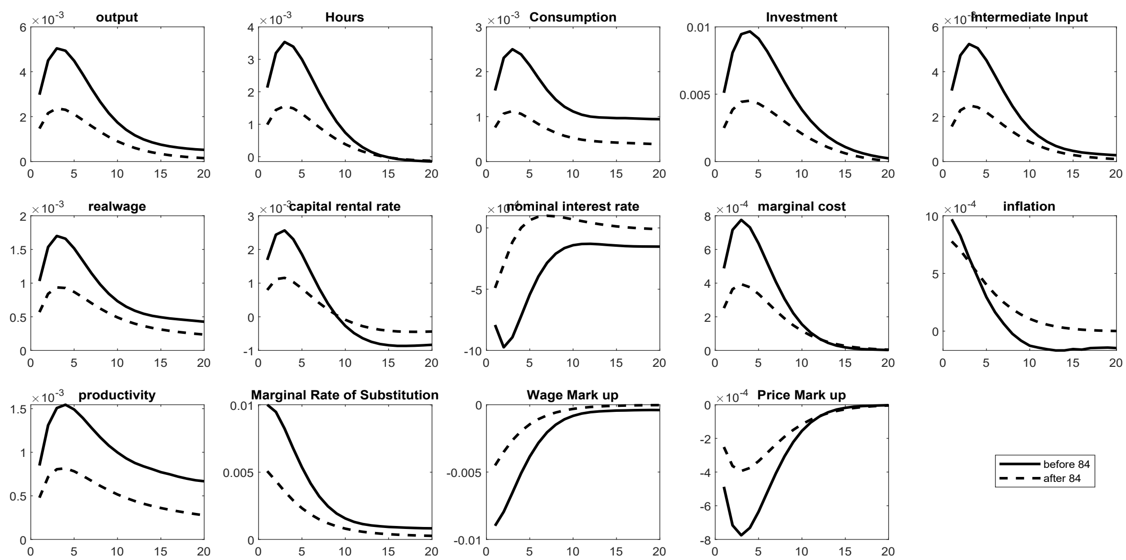
Notes: Figure 2.4 plots the average impulse responses to a neutral productivity shock using alternative calibration for the two sub-periods indicated in the legend: the solid lines denote the pre-1984 sub-period and the dashed lines describe the post-1984 sub-period.

Figure 2.5: MEI Shock (Alternative)



Notes: Figure 2.5 plots the average impulse responses to a MEI shock using alternative calibration for the two sub-periods indicated in the legend: the solid lines denote the pre-1984 sub-period and the dashed lines describe the post-1984 sub-period.

Figure 2.6: Monetary Shock (Alternative)



Notes: Figure 2.6 plots the average impulse responses to a monetary shock using alternative calibration for the two sub-periods indicated in the legend: the solid lines denote the pre-1984 sub-period and the dashed lines describe the post-1984 sub-period.

APPENDIX

Appendix 2.A Output and trend growth rates

Taking g_A and g_I to denote the deterministic trend growth rates of TFP and MEI, the growth factor Ψ_t is then given by:

$$g_\Psi = g_A^{\frac{1}{(1-\phi)(1-\alpha)}} g_I^{\frac{\alpha}{1-\alpha}}$$

The benchmark deterministic growth over pre-1984 sub-sample period is given by $g_A = 1.0026^{(1-\phi)}$ and $g_I = 1.0029$ with output grows at quarterly rate: 1.00533. The contribution of technology progress is 1.003869 and that of MEI progress is 1.001461.

Appendix 2.B Full Set of Equilibrium Conditions

This appendix lists the full set of detrended equations. These equations are expressed in stationary transformations of variables, e.g. $\widetilde{X}_t = \frac{X_t}{\Psi_t}$ for most variables. $g_\Psi = \frac{\Psi_t}{\Psi_{t-1}}$ is the growth rate of the deterministic trend.

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

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

$$\begin{aligned}\widetilde{\lambda}_t^r = \widetilde{\mu}_t \vartheta_t \left(1 - \frac{k}{2}\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi\right)^2 - \kappa \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi\right) \frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi\right) + \ldots \\ \beta E_t g_\Psi^{-1} \widetilde{\mu}_{t+1} \vartheta_{t+1} \kappa \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Psi - g_\Psi\right) \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Psi\right)^2\end{aligned} \tag{A3}$$

$$g_I g_\Psi \widetilde{\mu}_t = \beta E_t \widetilde{\lambda}_{t+1}^r \left(\widetilde{r}_{t+1}^k Z_{t+1} - \left(\gamma_1 (Z_{t+1} - 1) + \frac{\gamma_2}{2} (Z_{t+1} - 1)^2\right)\right) + \beta (1 - \delta) E_t \widetilde{\mu}_{t+1} \tag{A4}$$

$$\widetilde{\lambda}_t^r = \beta g_\Psi^{-1} E_t (1 + i_t) \pi_{t+1}^{-1} \widetilde{\lambda}_{t+1}^r \tag{A5}$$

$$\widetilde{w}_t^* = \frac{\sigma}{\sigma - 1} \frac{\widetilde{h}_{1,t}}{\widetilde{h}_{2,t}} \tag{A6}$$

$$\widetilde{h}_{1,t} = \eta \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*}\right)^{\sigma(1+\chi)} N_t^{1+\chi} + \beta \xi_w E_t (\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*}\right)^{\sigma(1+\chi)} g_\Psi^{\sigma(1+\chi)} \widetilde{h}_{1,t+1} \tag{A7}$$

$$\widetilde{h}_{2,t} = \widetilde{\lambda}_t^r \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*}\right)^{\sigma} N_t + \beta \xi_w E_t (\pi_{t+1})^{\sigma - 1} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*}\right)^{\sigma} g_\Psi^{\sigma - 1} \widetilde{h}_{2,t+1} \tag{A8}$$

$$\widetilde{\widetilde{K}}_t = g_I g_\Psi \alpha (1 - \phi) \frac{mc_t}{\widetilde{r}_t^k} \left(s_t \widetilde{X}_t + \bar{Z}\right) \tag{A9}$$

$$N_t = (1 - \alpha)(1 - \phi) \frac{mc_t}{\widetilde{w}_t} \left(s_t \widetilde{X}_t + \bar{Z}\right) \tag{A10}$$

$$\widetilde{\Upsilon}_t = \phi mc_t \left(s_t \widetilde{X}_t + \bar{Z} \right) \tag{A11}$$

$$p_t^* = \frac{\theta}{\theta - 1} \frac{m_{1,t}}{m_{2,t}} \tag{A12}$$

$$m_{1,t} = \widetilde{\lambda}_t^r mc_t \widetilde{X}_t + \xi_p \beta \left(\frac{1}{\pi_{t+1}} \right)^{-\theta} m_{1,t+1} \tag{A13}$$

$$m_{2,t} = \widetilde{\lambda}_t^r \widetilde{X}_t + \xi_p \beta \left(\frac{1}{\pi_{t+1}} \right)^{1-\theta} m_{2,t+1} \tag{A14}$$

$$1 = \xi_p \left(\frac{1}{\pi_t} \right)^{1-\theta} + (1 - \xi_p) p_t^{*1-\theta} \tag{A15}$$

$$\widetilde{w}_t^{1-\sigma} = \xi_w g_\Psi^{\sigma-1} \left(\frac{\widetilde{w}_{t-1}}{\pi_t} \right)^{1-\sigma} + (1 - \xi_w) \widetilde{w}_t^{*1-\sigma} \tag{A16}$$

$$\widetilde{Y}_t = \widetilde{X}_t - \widetilde{\Upsilon}_t \tag{A17}$$

$$s_t \widetilde{X}_t = \widetilde{\Upsilon}_t^{\phi} \widetilde{\widehat{K}}_t^{\alpha(1-\phi)} N_t^{(1-\alpha)(1-\phi)} g_\Psi^{\alpha(\phi-1)} - \bar{Z} \tag{A18}$$

$$\widetilde{Y}_t = \widetilde{C}_t + \widetilde{I}_t + g_\Psi^{-1} g_I^{-1} \left(\gamma_1 (Z_t - 1) + \frac{\gamma_2}{2} (Z_t - 1)^2 \right) \widetilde{K}_t \tag{A19}$$

$$\widetilde{K}_{t+1} = \vartheta_t \left(1 - \frac{\kappa}{2} \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi \right)^2 \right) \widetilde{I}_t + (1 - \delta) g_\Psi^{-1} g_I^{-1} \widetilde{K}_t \tag{A20}$$

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i} \right)^{\rho_1} \left(\frac{1+i_{t-2}}{1+i} \right)^{\rho_2} \left[\left(\frac{\pi_t}{\bar{\pi}} \right)^{\alpha_\pi} \left(\frac{\widetilde{Y}_t}{\widetilde{Y}_{t-1}} \right)^{\alpha_y} \left(\frac{Y_t}{Y_t^f} \frac{Y^f}{Y} \right)^{\alpha_{y^f}} \right]^{1-\rho_1-\rho_2} \exp\left(\varepsilon_t^r \right) \tag{A21}$$

$$\widetilde{\widehat{K}}_t = Z_t \widetilde{K}_t \tag{A22}$$

$$s_t = (1 - \xi_p) p_t^{*-\theta} + \xi_p \left(\frac{1}{\pi_t} \right)^{-\theta} s_{t-1} \tag{A23}$$

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

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

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

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

$$\Phi_t = \frac{\beta \ln g_\Psi}{(1-\beta)^2} \tag{A28}$$

$$\vartheta_t = (\vartheta_{t-1})^{\rho_I} \exp\left(s_I u_t^I\right) \tag{A29}$$

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(s_A u_t^A\right) \tag{A30}$$

Equation (A1) defines the real multiplier on the flow budget constraint. (A2) is the optimality condition for capital utilization. (A3) and (A4) 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 (A5). (A6)-(A8) describe optimal wage setting for households given the opportunity to adjust their wages. Optimal factor demands are given by equations (A9)-(A11). Optimal price setting for firms given the opportunity to change their price is described by equations (A12)-(A14). The evolution of aggregate inflation and the aggregate real wage index are given by (A15) and (A16), respectively. Net output is gross output minus intermediates, as given by (A17). The aggregate production function for gross output is (A18). The aggregate resource constraint is (A19), and the law of motion for physical capital is given by (A20). The Taylor rule for monetary policy is (A21). Capital services are defined as the product of utilization and physical capital, as in (A22). The law of motion for price dispersion is (A23) and for wage dispersion is (A24). (A25) and (A26) are recursive utility from consumption and labor in the levels. The aggregate welfare is (A27) and (A28) a shift term. (A29)-(A30) give the assumed laws of motion for other exogenous variables.

CHAPTER III

SHIFTING TREND INFLATION AND WELFARE COSTS

Abstract

Recent studies on shifting trend inflation use Standard New Keynesian model with Calvo price setting to address welfare issues. Within this framework, the transmission mechanism gets mainly through price dispersion as an inefficient source of distortion in the output. As a result, firms have high relative prices, labor productivity, and, ultimately, welfare fall. In this study, we provide a new perspective in a medium-scale New Keynesian DSGE model that accounts for nominal rigidities in goods and labor markets, trend growth, time-varying trend inflation, and production networking. We then investigate how shifting trend inflation does affect macroeconomic dynamics to bring about welfare effects. The results show that (i) the interaction between staggered wage contracts and both trend growth and production networking, when trend inflation increases, generates inefficient wage dispersion, which affects aggregate macroeconomic variables and has much larger effects on welfare costs than does price dispersion. (ii) Wages stickiness and inefficient wage dispersion are key drivers of the inflation costs. We also perform sensitivity analysis and conclude with final remarks.

JEL classification: E31, E32.

Keywords: Medium-scale dsge model;

3.1 Introduction

Inflation displays a low-frequency variation pattern or a trend component. As Stock and Watson (2007) and Cogley and Sbordone (2008) point out, trend inflation drives a large part of the dynamics of inflation and, in particular, its persistence. In this perspective, it is important since it can affect the Phillips curve slope and optimal monetary policy. There is virtually no theory about it, and most models ignore it or explain it with exogenous changes in the inflation target (Ascari and Sbordone, 2014; Monti et al., 2017).

A large literature has advocated modeling trend inflation as a very persistent shock [1], a way to explain the high inflation of the 1970s and its subsequent decline [2]. It has examined its implications for different aspects of macroeconomic dynamics (Kozicki and Tinsley, 2001; Ireland, 2007; Cogley and Sbordone, 2008; Cogley et al., 2009).

In an early contribution, Nakata (2014) studies its welfare implications using a Standard New Keynesian (NK) model with Calvo price setting. He points to price dispersion as the inefficient source of distortion in the output and a key factor driving inflation costs. However, evidence produced by Nakamura et al. (2018) challenges the relevance of price dispersion as the key mechanism to bring about inflation costs. Based on micro-data on U.S. price adjustment for the period 1978-2014, they measure the sensitivity of inefficient price dispersion to inflation changes and find very limited variation over the last 30 years. They conclude that the main cost of inflation in New Keynesian models is completely elusive, and the optimality of low inflation based on these models needs to be reassessed [3].

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1. Del Negro and Eusepi (2011) and Del Negro et al. (2015) have modeled a very persistent shock to target inflation as a means to match the inflation dynamics.

2. or even the possibility of a sustained rise in future inflation (Nakata, 2014).

3. Phaneuf and Victor (2019a) cast doubt about the conclusion on the main cost of inflation in New Keynesian models. They show that the Calvo price-setting model is not necessarily inconsistent with the evidence of a weak relation between positive trend inflation and price dispersion.

In this paper, we revisit Nakata's approach and reexamine his conclusions. In particular, we address the following questions: (i) how can time-varying trend inflation affect macroeconomic dynamics to bring about inflation costs? (ii) Does the mechanism channel mainly through price or wage dispersion? To settle these issues, we use a medium-scale DSGE New Keynesian model inspired by Ascari et al. (2018) that features nominal rigidities both in goods and labor markets, trend growth, production networking, and a welfare approach based on households' utility (Erceg et al., 2000). We extend their model to account for exogenous variations in trend inflation. As such, our benchmark framework nests alternative model specifications. In each case, we compute a consumption-equivalent welfare loss metric conditioned on stochastic means. We then compare the welfare costs and a few other properties of an economy with shifting trend inflation and an economy with constant trend inflation.

The results can be summarized as follows. First, with trend inflation set to 3.52 percent annualized, the welfare cost conditioned on means of shifting trend inflation (7.43 percent) is larger than in the constant trend inflation case (5.58 percent). The main reason is that higher trend inflation affects the welfare losses in the order of magnitude higher than in the constant trend inflation case. Nakata (2014) and Lê et al. (2019) have reached a similar conclusion.

Second, we examine the role of nominal rigidities either in goods or labor markets on the welfare. We find that with 3.52 annualized percent of trend inflation, welfare costs are modest and lower as trend inflation augments in a price stickiness environment (0.53 percent in the constant against 1.13 percent in the shifting trend economy). This result is consecutive to the fact that rigidity duration is exogenous compared to the trend. So the price dispersion does not vary with the level of trend inflation. Whereas in a stickiness wage environment, welfare costs are much larger when trend inflation is higher (5.26 percent in the constant economy versus 6.37 percent in the shifting trend economy with 3.52 annualized percent of trend inflation). The main reason is that as trend inflation increases, wages dispersion is affected more than the labor productivity, thereby raising the cost of production and relative prices. The latter in turn, affect the real wage and the demand for consumption and give rise to inefficiencies in the allocation of labor input. As a result, output falls and, ultimately, the observed upward surge in welfare costs. Therefore, wage stickiness and inefficient wage dispersion are key factors driving inflation costs.

Third, we also find that economic growth and networking are key elements of the model. When we remove both trend growth and production networking, welfare cost reduces (down to 2.22 percent for the constant trend inflation economy against 2.79 percent for the shifting trend inflation economy.) and more importantly in the wage stickiness environment (2.01 against 2.48 percent respectively) compared to the price stickiness environment (0.21 versus 0.33 percent respectively). The main explanation is that interaction between nominal rigidities in the wage-setting process and trend growth, when trend inflation increases, generates inefficient wage dispersion (makes wages more dispersed) higher than average wage markups. This last implication, in turn, affects aggregate macroeconomic variables and has much larger effects on welfare costs than does price dispersion.

Some other substantive findings in our paper pertain to sensitivity analysis and model good fitness. We find that varying trend inflation, price adjustment frequency, and wage adjustment frequency lead to an increase in welfare costs, the more these parameters augment. Specifically, when trend inflation rises, wages become more dispersed, affect consumption, labor, output, and have much larger effects on welfare costs than does price dispersion. These findings reinforce our previous results that the transmission mechanism passes mainly through wage dispersion, which, in turn, affects macroeconomic dynamics to bring about welfare effects. However, we notice that with Calvo nominal contracting framework, wage dispersion and welfare costs are very sensitive to trend inflation levels and variations in key model parameters. We also find that the model accounts for some key properties of the aggregate data, particularly the observed inflation volatility and its persistence.

The results of our paper should be of interest to both researchers and policymakers. Indeed, within this model, we highlight several important features that are omitted in most studies on welfare issues using the Calvo nominal contracting framework, the lack of which results in modest or lower inflation costs as observed in Nakata (2014),Nakamura et al. (2018), and Lê et al. (2019).

Our paper is closely related to Ascari et al. (2018). However, we explore the welfare implications of shifting trend inflation and compare a few other properties of different economies. In contrast, they study the welfare costs and cyclical implications of a constant trend inflation economy.

The remaining of the paper is organized as follows. In section 4.2, we describe the medium-scale New Keynesian DSGE model. We discuss issues related to parametrization in section 4.3. The goodness of fit of the model is examined in section 4.4. Section 4.5 presents the results and sensitivity analysis. The last section contains concluding remarks.

3.2 A Medium-Scale DSGE Model with Shifting Trend Inflation

This section describes our medium-scale New Keynesian DSGE model inspired by Ascari et al. (2018)[4]. The key difference is that we incorporate time-varying trend inflation and model it as a highly persistent AR(1) process as in Kozicki and Tinsley (2001), Ireland (2007), Cogley and Sbordone (2008); Cogley et al. (2009), and Nakata (2014).

The model features physical capital accumulation, sticky prices and sticky wages à la Calvo (1983), habit formation in consumption, variable capital utilization, a fixed cost of production, investment adjustment costs, trend growth in investment-specific technology and neutral technology, roundabout production structure (production networking), and shifting trend inflation. Monetary policy is governed by a Taylor rule and there are stochastic shocks to the policy rule, neutral productivity, the marginal efficiency of investment, and trend inflation. The full set of detrended equations characterizing the equilibrium conditions are shown in Appendix 4.A.

4. They assume that the inflation target is fixed and equal to trend inflation.

3.2.1 Households and wage setting

Labor aggregators

The economy features a continuum of households indexed by $h \in [0,1]$. They are monopoly suppliers of $N_t^d(h)$ units of differentiated labor to a "labor packing firm". This firm assembles heterogeneous labor inputs into a homogeneous labor unit. The bundling technology is given by:

$$N_t^d = \left(\int_0^1 N_t(h)^{\frac{\sigma-1}{\sigma}} dh \right)^{\frac{\sigma}{\sigma-1}}, \sigma > 1 \tag{3.1}$$

where σ denotes the constant elasticity of substitution (CES) between labor types. Labor aggregator is a price-taker in both their output and input markets. He sells composite labor to intermediate producers at the aggregate wage, W_t, and unit of differentiated labor costs is $W_t(h)$.

The profit maximization problem of the labor aggregating firm gives a downward-sloping demand for each variety of labor:

$$N_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\sigma} N_t^d. \tag{3.2}$$

Inserting this demand function for input h back into the CES aggregator yields the aggregate wage index, i.e

$$W_t^{1-\sigma} = \int_0^1 W_t(h)^{1-\sigma} dh. \tag{3.3}$$

Households

Households maximize expected present discounted value of their lifetime utility function, subject to an intertemporal budget constraint. Preferences are additively separable in consumption and labor and allow for habit formation in consumption. They own intermediate firms, lend capital services (the product of physical capital and utilization) to firms, and make investment and capital utilization decisions. Capital is predetermined at the beginning of a period, but households can adjust its utilization rate subject to adjustment costs. Households receive nominal dividend payments resulting from their ownership of intermediate-goods-producing firms at the end of each period. They additionally hold their financial wealth in the form of one-period, state-contingent bonds. Financial markets are assumed to be complete. The problem of an individual household can be written [5] :

$$\max_{C_t, N_t(h), K_{t+1}, B_{t+1}, I_t, Z_t} \quad E_0 \sum_{i=0}^{\infty} \beta^i \left(\ln\left(C_{t+i} - bC_{t+i-1}\right) - \eta \frac{N_{t+i}(h)^{1+\chi}}{1+\chi} \right), \tag{3.4}$$

subject to

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

and

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

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

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

where $0 < \beta < 1$ is a discount factor, $0 < \delta < 1$ a depreciation rate, and $0 \leq b < 1$ is a parameter for habit formation. χ is the inverse Frisch elasticity of labor supply. κ is an investment adjustment cost parameter that is strictly positive. P_t is the nominal price of goods. C_t is consumption, I_t investment, $N_t(h)$ labor input, and K_t physical capital. R_t^k is a nominal rental rate on capital services, and i_t the nominal interest rate. B_t is the stock of nominal bonds with which a household enters a period, and B_{t+1} is

5. The utility is separable, and we assume that households are identical concerning non-labor choices. Hence, we will drop the h subscripts in subsequent sections. For detail, see Erceg, Henderson and Levin (2000).

a stock of nominal governmental bonds in period t+1. Π_t^n denotes (nominal) profits remitted by firms, and T_t is a lump sum taxes from the government. Z_t is the level of capital utilization, and $a(Z_t)$ is a function mapping utilization of capital into the depreciation rate, with parameters γ_1 and γ_2, providing that $a(1)=0$, $a'(1)=0$, and $a''(1)>0$. $S\left(\frac{I_t}{I_{t-1}}\right)$ 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 growth rate of investment.

The investment-specific term $\varepsilon_t^{I,\tau}$ follows the deterministic trend with no stochastic component[6]:

$$\varepsilon_t^{I,\tau} = g_{\varepsilon^I}\varepsilon_{t-1}^{I,\tau} \tag{3.5}$$

where g_{ε^I} is the gross growth rate and grows at the gross rate $g_{\varepsilon^I} \geq 1$ in each period[7].

The exogenous variable ϑ_t captures the stochastic marginal efficiency of investment shock:

$$\vartheta_t = \left(\vartheta_{t-1}\right)^{\rho_I}\exp\left(\sigma_I u_t^I\right), with\ u_t^I \sim iid\left(0,1\right). \tag{3.6}$$

The autoregressive parameter ρ_I governs the persistence of the process and satisfies $0 \leq \rho_I < 1$. The shock is scaled by the known standard deviation equal to s_I, and u_t^I is the innovation drawn from a mean zero normal distribution.

The first-order conditions for consumption, capital utilization, investment, capital, and bonds are respectively:

$$\lambda_t^r = \frac{1}{C_t - bC_{t-1}} - E_t\frac{\beta b}{C_{t+1} - bC_t}, \tag{3.7}$$

$$r_t^k = \frac{a'(Z_t)}{\varepsilon_t^{I,\tau}}, \tag{3.8}$$

6. For more details, see Justiniano, Primiceri and Tambalotti (2011), who have documented the distinction between the two types of investment shocks and their relative importance.

7. With the implicit normalization that it begins at 1 in period 0 i.e., $\varepsilon_0^{I,\tau} = 1$

$$\lambda_t^r = \mu_t \varepsilon_t^{I,\tau} \vartheta_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\right] + \beta E_t \mu_{t+1} \varepsilon_{t+1}^{I,\tau} \vartheta_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right)\left[\frac{I_{t+1}}{I_t}\right]^2, \tag{3.9}$$

$$\mu_t = \beta E_t \lambda_{t+1}^r \left(r_{t+1}^k Z_{t+1} - \frac{a(Z_{t+1})}{\varepsilon_{t+1}^{I,\tau}}\right) + \beta(1-\delta) E_t \mu_{t+1}, \tag{3.10}$$

$$\lambda_t^r = \beta E_t \lambda_{t+1}^r (1+i_t) \pi_{t+1}^{-1}, \tag{3.11}$$

where $\lambda_t^r \equiv P_t \lambda_t$, which is the marginal utility of an extra good, $r_t^k \equiv \frac{R_t^k}{P_t}$ the real rental rate on capital services, and $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross inflation.

Wage-setting

Let us consider the problem related to households wage-setting. We assume Calvo-style staggered wage contracts and no indexation. Each period a randomly selected fraction of Households gets to update their nominal wage with the probability $(1-\xi_w)$, where $\xi_w \in [0,1]$. It means that ξ_w of households cannot adjust their nominal wage.

The optimal wage $W_t(h)$ is obtained by maximizing:

$$E_t \sum_{i=0}^{\infty} (\beta \xi_w)^i \left(-\frac{\eta}{1+\chi} (N_{t+i}(h))^{-\sigma(1+\chi)} + \lambda_{t+i} W_t(h) N_{t+i}(h)\right), \tag{3.12}$$

subject to

$$N_{t+i}(h) = \left(\frac{W_t(h)}{W_{t+i}}\right)^{-\sigma} N_{t+i}^d,$$

$$W_t(h) = \begin{cases} W_t^*(h) & \text{if } W_t(h) \text{ chosen optimally} \\ W_{t-1}(h) & \text{otherwise.} \end{cases}$$

The first-order condition implies that all households will choose the same reset wage, denoted in real terms and given by:

$$w_t^* = \frac{\sigma}{\sigma - 1} \frac{h_{1,t}}{h_{2,t}}. \tag{3.13}$$

Recursively the terms $h_{1,t}$ and $h_{2,t}$ evolve as follows

$$h_{1,t} = \eta \left(\frac{w_t}{w_t^*}\right)^{\sigma(1+\chi)} \left(N_t^d\right)^{1+\chi} + \beta \xi_w E_t(\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{w_{t+1}^*}{w_t^*}\right)^{\sigma(1+\chi)} h_{1,t+1}, \quad (3.14)$$

$$h_{2,t} = \lambda_t^r \left(\frac{w_t}{w_t^*}\right)^{\sigma} N_t^d + \beta \xi_w E_t(\pi_{t+1})^{\sigma-1} \left(\frac{w_{t+1}^*}{w_t^*}\right)^{\sigma} h_{2,t+1}. \quad (3.15)$$

3.2.2 Firms and Price-setting

Firms' production takes place in two phases. First, there is an infinitude of intermediate goods firms, each producing a differentiated material input under monopolistic competition using a production function with Cobb-Douglas technology and fixed costs. They set Calvo-type nominal prices. Final goods producers then combine these inputs intermediate inputs according to a CES technology into output, which they put up for sale to households under perfect competition.

Final Goods Producers

The final good producer uses $X_t(j)$ units of intermediate goods to produce X_t units of the final good. There is a continuum of intermediate goods firms indexed by $j \in (0,1)$, producing differentiated goods. The final good is a constant elasticity of substitution aggregate of intermediate goods, using the production technology given by:

$$X_t = \left(\int_0^1 X_t(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}, \theta > 1. \quad (3.16)$$

The final goods producer maximizes profit, given a final good price, P_t and taking intermediate good prices, $P_t(j)$, as given. The first-order condition gives the conditional demand for intermediate good j:

$$X_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\theta} X_t, \quad \forall j. \tag{3.17}$$

Inserting the demand function for input j back into the CES aggregator gives the aggregate price index:

$$P_t^{1-\theta} = \int_0^1 P_t(j)^{1-\theta} dj. \tag{3.18}$$

Intermediate Producers

Each intermediate-good firm, indexed by j, uses $\widehat{K}_t(j)$ [8] units of capital services, $N_t^d(j)$ units of labor, and intermediate inputs, $\Upsilon_t(j)$, to produce $X_t(j)$ units of the intermediate good j. Its production function is given by:

$$X_t(j) = \max\left\{A_t \Upsilon_t(j)^{\phi}\left(\widehat{K}_t(j)^{\alpha} N_t^d(j)^{1-\alpha}\right)^{1-\phi} - \Psi_t \bar{Z}, 0\right\}, \tag{3.19}$$

where $\phi \in (0,1)$ is the intermediate input share while $\alpha \in (0,1)$ and $(1-\alpha)$ are value-added share for capital services and labor inputs, $\bar{Z}$ is a fixed cost that is identical across firms. It is chosen so that steady-state profits equal to zero, given a growth factor Ψ_t.

The neutral technology A_t follows a process with both trending and stationary component:

$$A_t = A_t^{\tau} \widetilde{A}_t, \tag{3.20}$$

where the deterministic trend component A_t^{τ} grows at the gross rate $g_A \geq 1$ in each period [9] such that:

$$A_t^{\tau} = g_A A_{t-1}^{\tau}. \tag{3.21}$$

8. It is the product of utilization and physical capital

9. With the implicit normalization that it begins at 1 in period 0 i.e., $A_0^{\tau} = 1$

The stochastic process driving the detrended level of technology $\widetilde{A}_t$ is given by

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(\sigma_A u_t^A\right), \tag{3.22}$$

which, taking its natural logarithm, yields

$$\ln \widetilde{A}_t = \rho_A \ln \widetilde{A}_{t-1} + \sigma_A u_t^A, \quad u_t^A \sim iid\,(0,1)\,. \tag{3.23}$$

The auto-regressive parameter ρ_A governs the persistence of the process and satisfies $0 \leq \rho_A < 1$. The shock is scaled by the known standard deviation equal to σ_A and u_t^A is the innovation, drawn from a mean zero normal distribution.

Cost Minimization

The producer of differentiated goods j is assumed to set its price, $P_t(j)$, according to Calvo pricing (Calvo, 1983) and decides in every period its quantities of intermediates, capital services, and labor input. The cost of the intermediates is just the aggregate price level, P_t. The user cost of capital and labor are R_t^k and W_t (in nominal terms), respectively.

The cost-minimization problem of a typical firm choosing its inputs is given by :

$$\min \quad P_t \Upsilon_t(j) + R_t^k \widehat{K}_t + W_t N_t^d(j) \tag{3.24}$$

subject to

$$A_t \Upsilon_t(j)^{\phi} \left(\widehat{K}_t(j)^{\alpha} N_t^d(j)^{1-\alpha}\right)^{1-\phi} - \Psi_t \bar{Z} \geq \left(\frac{P_t(j)}{P_t}\right)^{-\theta} X_t$$

The first order conditions yield the following marginal cost and conditional demand functions for the inputs used in the production of $X_t(j)$:

$$\Upsilon_t(j) = \phi m c_t \left(X_t(j) + \Psi_t \bar{Z}\right), \tag{3.25}$$

$$\widehat{K}_t(j) = \alpha(1-\phi)\frac{mc_t}{r_t^k}(X_t(j)+\Psi_t\bar{Z}), \tag{3.26}$$

$$N_t^d(j) = (1-\alpha)(1-\phi)\frac{mc_t}{w_t}(X_t(j)+\Psi_t\bar{Z}). \tag{3.27}$$

Profit Maximization and Price-setting

Each intermediate producing firm [10] chooses its price $P_t(j)$ that maximizes the expected present discount value of its future profit. The firm problem is given by :

$$\max_{P_t(j)} \quad E_t\sum_{i=0}^{\infty}(\xi_p)^i D_{t,t+i}\left(P_t(j)X_{t+i}(j)-V(X_{t+i}(j))\right) \tag{3.28}$$

subject to

$$X_{t+i}(j) = \left(\frac{P_t(j)}{P_{t+i}}\right)^{-\theta} X_{t+i}$$

$$P_t(j) = \begin{cases} P_t^*(j) & \text{if } P_t(j) \text{ chosen optimally} \\ P_{t-1}(j) & \text{otherwise} \end{cases}$$

where $D_{t,t+i}$ is the discount rate for future profits and $V(X_t(j))$ is the total cost of producing good $X_t(j)$. Note that $D_{t,t+i} = \frac{\beta^i\lambda_{t+i}}{\lambda_t}$. Written in real terms, it is $\frac{P_{t+i}D_{t,t+i}}{P_t}$. Hence, the real discount factor is $\frac{\beta^i P_{t+i}\lambda_{t+i}}{P_t\lambda_t}$, which we can write as: $\frac{\beta^i\lambda_{t+i}^r}{\lambda_t^r}$, where $\lambda_t^r = P_t\lambda_t$. The first-order condition for $p_t^*(j)$ is :

$$p_t^*(j) = \frac{\theta}{\theta-1}\frac{\sum_{i=0}^{\infty}(\xi_p\beta)^h\lambda_{t+i}^r mc_{t+i}(j)\pi_{t+1,t+i}^{\theta}X_{t+i}}{\sum_{i=0}^{\infty}(\xi_p\beta)^i\lambda_{t+i}^r\pi_{t+1,t+i}^{\theta-1}X_{t+i}}, \tag{3.29}$$

where $p_t^*(j) = \frac{P_t(j)}{P_t}$ is the real optimal price and mc_t the real marginal cost, which is equal to $\frac{V'(X_{t+i}(j))}{P_{t+i}}$.

10. A fraction $(1-\xi_p)$ of these firms can optimally adjust their price (Calvo, 1983).

Since all updating firms will choose the same reset price, the optimal reset price relative to the aggregate price index becomes $p_t^* \equiv \frac{P_t^*}{P_t}$. Then the optimal pricing condition (30) becomes :

$$p_t^* = \frac{\theta}{\theta - 1} \frac{m_{1,t}}{m_{2,t}}, \tag{3.30}$$

where $m_{1,t}$ and $m_{2,t}$ are auxiliary variables and can be written recursively as

$$m_{1,t} = \lambda_t^r mc_t X_t + \beta \xi_p E_t (\pi_{t+1})^{\theta} m_{1,t+1}, \tag{3.31}$$

$$m_{2,t} = \lambda_t^r X_t + \beta \xi_p E_t (\pi_{t+1})^{\theta - 1} m_{2,t+1}. \tag{3.32}$$

The term λ_t^r in these equations is the marginal utility of an additional unit of real income received by household and X_t is the aggregate gross output.

3.2.3 Monetary Policy

Monetary policy consists of a Taylor rule that includes time-varying target inflation. It responds to the inflation gap, $\frac{\pi_t}{\bar{\pi}_t}$, and deviations of output growth, $\frac{Y_t}{Y_{t-1}}$, from its trend level, g_Ψ.

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i} \right)^{\rho_i} \left[\left(\frac{\pi_t}{\bar{\pi}_t} \right)^{\alpha_\pi} \left(\frac{Y_t}{Y_{t-1}} g_\Psi^{-1} \right)^{\alpha_y} \right]^{1-\rho_i} \varepsilon_t^r, \tag{3.33}$$

where $\bar{\pi}_t^*$ is time-varying target inflation, i the steady-state level of i_t. $\varepsilon_t^r \sim iid\left(0, \sigma_{\varepsilon^r}^2\right)$ is a shock to the policy rule. The interest rate smoothing parameter is given by ρ_i, and α_π, and α_y are the control parameters. To ensure determinacy, we assume that $0 \leq \rho_i < 1$, $\alpha_\pi > 1$, and $\alpha_y \geq 0$.

Following Kozicki and Tinsley (2001), Ireland (2007), Cogley et al. (2009), and Nakata (2014), we model time-varying trend inflation as a stationary and highly persistent AR(1) process.

$$\ln(\bar{\pi}_t) = (1 - \rho_{\bar{\pi}}) \ln(\bar{\pi}^*) + \rho_{\bar{\pi}} \ln(\bar{\pi}_{t-1}) + \sigma_{\bar{\pi}} u_t^{\bar{\pi}} \tag{3.34}$$

where $0 < \rho_{\bar{\pi}} < 1$, $\bar{\pi}$ steady-state trend inflation, and $u_t^{\bar{\pi}}$ a shock to trend inflation, $\sim iid\left(0, \sigma_{\bar{\pi}}^2\right)$.

In the baseline specification in equation (4.20), trend inflation evolves symmetrically around 3.52 percent steady-state level, the average rate over the period 1960:I-2007:III. As trend inflation increases over time, this symmetric assumption may not be realistic, implying a negative inflation value with some probability, as suggested by Nakata (2014). Therefore, we consider an asymmetric trend inflation process given by

$$\ln\left[\bar{\pi}_t - 1\right] = \left(1 - \rho_{\bar{\pi}}\right)\ln\left[\bar{\pi}^* - 1\right] + \rho_{\bar{\pi}}\ln\left[\bar{\pi}_{t-1} - 1\right] + \sigma_{\bar{\pi}} u_t^{\bar{\pi}}, \tag{3.35}$$

where $u_t^{\bar{\pi}} \sim iid\left(0, \varpi\sigma_{\bar{\pi}}^2\right)$ with ϖ a constant chosen so that the variance of trend inflation is the same as in equation (4.20).

3.2.4 Measuring Welfare Costs

We consider the approach taken by Sims (2013), and Ascari et al. (2018) by using a second-order approximation and directly calculate the value function of the unconditional expected utility of the representative household. The value function of the h^{th} household is given by:

$$V_t(h) = \ln(C_t - bC_{t-1}) - \eta\frac{N_t(h)^{1+\chi}}{1+\chi} + \beta E_t V_{t+1}(h), \tag{3.36}$$

Given household heterogeneity in labor supply, we assume that a central bank's welfare function is equal to the sum of welfare across households, as in Erceg et al. (2000).

Fiddling with the equation 4.21 and simplifying some more, the value function can be written:

$$V_t = \ln(C_t - bC_{t-1}) - \eta\frac{N_t^{1+\chi}}{1+\chi}v_t^w + \beta E_t V_{t+1}, \tag{3.37}$$

where $v_t^w = \int_0^1 \left(\frac{W_t(h)}{W_t}\right)^{\sigma(1+\chi)} dh$, is wage dispersion and using Calvo properties of wage-setting, can be written recursively as

$$v_t^w = (1-\xi_w)\left(\frac{w_t^*}{w_t}\right)^{\sigma(1+\chi)} + \xi_w\left(\frac{w_t\pi_t}{w_{t-1}}\right)^{\sigma(1+\chi)} v_{t-1}^w. \tag{3.38}$$

Equation (3.37) can be broken down into separate components from consumption and labor and written recursively; the value function is:

$$V_t = V_t^c + V_t^n \tag{3.39}$$

where the value function over consumption and labor in the levels is respectively:

$$V_t^c = \ln\left(C_t - bC_{t-1}\right) + \beta E_t V_{t+1}^c, \tag{3.40}$$

$$V_t^n = -\eta\frac{N_t^{1+\chi}}{1+\chi}v_t^w + \beta E_t V_{t+1}^n. \tag{3.41}$$

The consumption-equivalent welfare loss measures the welfare cost of shifting trend inflation, ψ, as the constant fraction of consumption that makes households in an economy with no variation in trend inflation as well-off as the one in another economy with variation in trend inflation (Nakata, 2014). Specifically, we define a measure of consumption-equivalent welfare loss [11] based on stochastic means ψ_m. It can be written:

$$\psi_m = 1 - \exp\left[(1-\beta)\left(E\left(V_A^m\right) - E\left(V_B^m\right)\right)\right], \tag{3.42}$$

where B stands for a constant trend inflation economy [12] ($\sigma_{\bar{\pi}} = 0$) and A is the alternative case i.e., an economy with time-varying trend inflation ($\sigma_{\bar{\pi}} > 0$). $E(.)$ is the unconditional expectations operator.

11. For more details, see Ascari et al. (2018).

12. The baseline case, i.e., with no variation in trend inflation.

3.3 Parametrization

We use the calibration procedure by choosing values for the key parameters to solve the model [13]. Table 4.1 lists these parameters. The household's preference parameters, the parameters governing the production sector, and coefficients in the Taylor rule are from Ascari et al. (2018) and are in line with the standard estimates found in the literature.

The factor of discount, β, is set to 0.99 and the depreciation rate on physical capital δ to 0.025, corresponding to an annual capital depreciation of 10 percent. The capital services share α is set at 1/3, η a scaling parameter on disutility from labor is set to 6, and the inverse Frisch elasticity of labor supply χ is set at 1. Consumption habit formation b is set to 0.8 (Fuhrer, 2000). The value of investment adjustment cost κ is 3 (Christiano, Eichenbaum and Evans, 2005). The squared term in the cost of utilization γ_2 is set to 0.05 to match capital utilization elasticity of 1.5 (Basu and Kimball, 1997; Dotsey and King, 2006). The value of the parameter on the linear term γ_1 is set so that steady-state utilization is 1 ($\gamma_1 = 0.0457$).

The elasticity parameters for goods θ and labor σ are set to the same value of 6, implying a steady-state price and wage markups of 20 percent with zero trend inflation (Liu and Phaneuf, 2007). Following Nakamura and Steinsson (2010), as reported in Ascari et al. (2018), the share of weighted average revenue of intermediate inputs in the U.S. private sector using Consumer Price Index (CPI) expenditure weights is roughly 51% in 2002. So the cost share of intermediate inputs is equal to this revenue share times the markup. Thus, with a theta-value of 6, this implies a price markup of 1.2 and a weighted average cost share of intermediate inputs $\phi = 0.61$. The Calvo price ξ_p and wage ξ_w parameters are set to a uniform value of 0.66. The fixed cost of production, $\bar{Z}$, is chosen so that profits equal to zero in the steady-state. Given other parameters, this implies a value of $\bar{Z} = 0.0183$.

For monetary policy rule, we set ρ_i the smoothing coefficient to 0.8, the coefficient

13. The full set of aggregated and stationarized equations characterizing the equilibrium conditions are shown in Appendix 4.A

on inflation (α_π) to 1.92 [14], and the coefficient on output growth (α_y) to 0.2.

Following Ascari et al. (2018), trend growth and inflation are calibrated to fit the data's observable features. The average growth rate of the price index over the period 1960:I-2007:III is 0.008675. It implies a steady-state level of trend inflation of 3.52 percent annualized (i.e., $\pi^* = 1.0352^{0.25}$). The output per capita's average growth rate, over the same period, is 0.005712, which corresponds to an output growth rate of $g_Y = 1.005712$ or 2.28 at an annual frequency. The average growth rate of the relative price of investment over the period is -00472. It suggests the value of $g_I = 1.00472$. Given the values of g_I and ϕ, we set g_A value to 1.0022 $(i.e., g_A^{1-\phi} = 1.0022)$ to generate the appropriate output volatility observed in the data.

For the parameters governing the shock processes, we proceed as follows. Given the growth rates of real GDP and trend inflation , we set shocks to technology (σ_A), to the marginal efficiency of investment (σ_I), monetary policy (σ_r) and to the trend inflation $(\sigma_{\bar{\pi}})$ to match output growth volatility over the sample period. Following Ascari et al. (2018) and Phaneuf and Victor (2019b), we take a stand on the percentage contribution of each type of shocks to output growth volatility.

Based on the evidence produced by Justiniano et al. (2011) and others (Fisher, 2006a; Justiniano and Primiceri, 2008a; Justiniano et al., 2010b; Altig et al., 2011), we fix the marginal efficiency of investment shock contribution to 50 percent of output volatility, 35% for the neutral technology, 10 % for the monetary policy shock, and 5 % for the shock to trend inflation [15]. We set the AR(1) coefficients of investment ρ_I to 0.81 and of technology ρ_A to 0.95. For the persistence of the trend inflation process, we set the AR(1) coefficient to 0.95 [16]. The resulting volatility for different shocks is shown in Table 3.1.

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14. Following Nakata (2014).

15. For trend inflation shock parameter, we target 5% such as the baseline model approximates its volatility in the literature (Nakata, 2014; Ha, 2018).

16. Cogley et al. (2009) and Nakata (2014) set it to 0.995, and we find it to be highly persistent.

3.4 Second Moments Analysis

This section measures the goodness of fit of the model. All series are expressed in per capita term [17], transformed in real terms, and then in the logs to approximate their percentage changes. The consumption and investment series [18] are from the U.S. Bureau of Economic Analysis (BEA) accounts. The growth rate of the price index is referred to as inflation. Total hours are total hours in the non-farm business sector from the U.S. Bureau of Labor Statistics (BLS). The data are from 1960:Q1 up through 2007:Q3.

Table 3.2 reports selected model-generated unconditional moments (Second row). These moments are both hp-filtered and first-order differenced to facilitate comparison with unconditional data moments shown in parentheses (First row). In particular, we are interested in the standard deviation (volatility), contemporaneous correlations, and the first-order auto-correlation (persistence).

As in Ascari et al. (2018), the model matches the mean value of 0.0057 for real GDP growth rate $\left(E(\Delta Y)\right)$ and 0.0078 for its volatility $\left(\sigma(\Delta Y)\right)$ in the data by construction. The other statistical properties of the estimated cyclical components implied by the model are either very close or slightly higher if not somewhat higher relative to the data. The empirical standard deviation of consumption $\left(\sigma(\Delta C)\right)$ deviates about 0.43 percent from its mean value in the model against 0.47 percent in the data. For investment, the magnitude of its variability $\left(\sigma(\Delta I)\right)$ is about 2 percent versus 2.02 percent in the data, whereas it is 0.86 percent against 0.79 for hours $\left(\sigma(\Delta N)\right)$. On the other hand, using the hp filter, we denote that the estimated average percentage deviation of 1.74 for real GDP $(\sigma(Y^{hp}))$, 0.90 for consumption $(\sigma(C^{hp}))$ and 4.48 for investment $(\sigma(I^{hp}))$ are slightly higher, whereas hours $(\sigma(N^{hp}))$ with 1.32 percent are considerably less volatile than in the data.

17. By dividing by the civilian non-institutionalized population aged 16 and over.

18. We compute real GDP and its growth rate following the steps in Ascari et al. (2018). See their appendix for more details.

For contemporaneous correlation, the results show that the degree to which consumption growth and output growth ($\rho(\Delta Y, \Delta C)$), and hours and output growth ($\rho(\Delta Y, \Delta N)$) moves together is substantially closer relative to the data. However, the co-movement between investment growth and output growth ($\rho(\Delta Y, \Delta I)$) is displaying a clear positive correlation (0.9282) but slightly greater than in the data. Taking the hp-filter, the correlation coefficients tend to be much lesser ($\rho(Y^{hp}, C^{hp})$, $\rho(Y^{hp}, N^{hp})$) or closer ($\rho(Y^{hp}, I^{hp})$) than in the data (Table 3.2). The degree of persistence of output growth ($\rho_1(\Delta Y)$) is somewhat higher in the model (0.749) relative to the data (0.363).

We further focus on inflation match in the data (i.e., inflation persistence $\rho_1(\pi)$ and volatility $\sigma(\pi)$) to establish whether modeling time-varying trend inflation as a stationary and highly AR(1) process constitutes an improvement in such a framework. We observe that the empirical coefficient of the first-order autocorrelation in inflation ($\rho_1(\pi)$) is slightly higher 0.9855 in the model vs. 0.9071 in the data. Its standard deviation ($\sigma(\pi)$) is more volatile in the model (0.0150) than in the data (0.0065).

However, when we adjust for the AR(1) coefficient in equation 4.20 from 0.995 [19] down to 0.95 [20], we get the output growth mean ($E(\Delta Y)$ value of 0.0057, and 0.9071 for inflation persistence ($\rho_1(\pi)$) both match in the data. The volatility of Inflation $\sigma(\pi)$ is 0.0052 in the model against 0.0065 in the data, and output growth ($\sigma(\Delta Y)$ is 0.0076 in the model vs. 0.0078 in the data.

Compared to the constant trend inflation framework unconditional moments match, we observe that the latter ignores some salient properties of the aggregate data such as inflation volatility and its persistence. Therefore, modeling time-varying trend inflation as a stationary and AR(1) process can help to better match inflation dynamics [21] during the postwar era (Del Negro and Eusepi, 2011; Del Negro et al., 2015). Over-

19. Following Cogley et al. (2009).

20. Sensitive analysis

21. The dynamics of inflation and particularly its persistence are driven in large part by a low-frequency, or trend component (trend inflation), as documented, for instance, in Stock and Watson (2007) and Cogley and Sbordone (2008).

all, the model does fit well the aggregate data and explains the usual business-cycle dimensions.

3.5 Quantitative Analysis

This section focuses on issues related to quantitative results. The baseline model features nominal frictions in goods and labor markets, shifting trend inflation, production networking [22], and real per capita output growth [23], which originates from neutral and investment-specific technology. As such, it nests alternative model specifications. We first examine the cyclical implications of shifting trend inflation and then analyze its normative aspects or the welfare properties.

3.5.1 Macroeconomic Dynamics

Transmission Mechanism

In our baseline specification, we assess whether the transmission channel is through price dispersion or wage dispersion and how it affects welfare costs. To settle this issue, we focus on how the labor wedge [24] behaves. The analysis is conducted in a constant trend inflation economy as an important step toward understanding the shifting trend inflation case, which will be discussed later.

Figure 3.1 reports steady-state levels of macroeconomic variables at various annualized trend inflation rates in a constant trend inflation economy. Panel 3, second row, illustrates how labor wedge varies to changes in trend inflation. We observe a nonlinear relationship: it varies significantly as trend inflation gets higher, indicating

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22. Firms are interconnected through input-output linkages.

23. i.e., Trend productivity growth.

24. The labor wedge is defined as the wedge between the household's marginal rate of substitution of consumption and leisure (MRS) and the firm's marginal product of labor (MPN) (Chari et al., 2007; Shimer, 2009; Karabarbounis, 2014b).

inefficiencies in the allocation of labor input (Sala et al., 2010).

Furthermore, we are interested in understanding whether these inefficiencies reflect fluctuations of the gap between the household's marginal rate of substitution (MRS) and the real wage or fluctuations of the gap between the firm's marginal product of labor (MPN) and the real wage. In this perspective, Karabarbounis (2014b) emphasizes that: 'If the household component of the labor wedge is important over the business cycle, we would observe a volatile and countercyclical labor wedge..If the firm component of the labor wedge is important over the business cycle, then we would observe a relatively smooth and pro-cyclical labor wedge'.

In our case, we find that these inefficiencies reflect fluctuations of the gap between the marginal rate of substitution (MRS) and the real wage as the contemporaneous correlation between output and labor wedge is countercyclical with a value of -0.434 in the model against -0.68 in the data (Karabarbounis, 2014a,b).

Going back to figure 3.1 i.e., in a long-term perspective, we observe a negative relation between labor wedge (panel 3, second row) and the steady-state level of output (panel 2, first row) as trend inflation increases. Likewise, the relation between the labor wedge and the steady-state level of labor demand (panel 3, third row) is also negative. However, the steady-state labor wedge and consumption equivalent welfare loss (panel 1, first row) display a positive relation. In other words, as trend inflation gets higher, inefficiencies in labor wedge grow larger and are welfare-reducing.

Some key features of these results are worth noting. First, inefficiencies in output are due to the inefficiencies in the allocation of labor input. Second, changes in labor wedge predominantly reflect variations of the gap between the real wage and the MRS. Third, following the the result mentioned above in point 2, wage dispersion plays a substantial role in the transmission mechanism and has a strong implication about the welfare as trend inflation augments. Sims (2013) and Ascari et al. (2018) reach a similar conclusion. They sustain that wage dispersion can be very costly from a welfare perspective, much more so than price dispersion.

Overall, the steady-state relations in figure 3.1 can be summarized as follows: An upswing in the steady-state trend inflation causes inefficiencies in the steady-state of the labor wedge (panel 3, second row). As a result, the steady-state level of labor demand falls (panel 3 in the third row), leading to a decrease in the steady-state output (panel 2, first row). The main reason is that an increase in the steady-state trend inflation leads to a larger increase in the steady-state levels of wage dispersion (panel 1, second row) than in steady-state price dispersion (panel 3, first row) when the steady-state trend inflation is higher. It impacts steady-state wages more than the steady-state productivity of labor (panel 2, second row) and thereby raises the steady-state cost of production of commodities (steady-state marginal cost). In turn, firms have high relative prices for their products. It affects not only households but also sectors that used them as inputs for the production of commodities. Therefore, the steady-state costs of production of other sectors will rise and push up the relative prices of products for optimally price-adjusting firms. The combined effect of steady-state prices rise and decrease in the steady-state real wage affect the steady-state demand for consumption (panel 2, third row), reduce the incentive to save, and give rise to inefficiencies in the allocation of labor input. Hence, the steady-state level of labor demand (panel 3, third row) decreases as firms adjust to maintain their profit margins. Consequently, the steady-state output falls, and ultimately the observed upward surge in steady-state welfare costs (panel 1, first row).

We now consider the shifting trend inflation economy and how it affects the transmission mechanism. As trend inflation is a highly persistent AR(1) process, any changes in its level would affect the point around which the model is log-linearly approximated, the steady-state. As a result, the log-linear dynamics of the model adjusts, and therefore, the economy is taken to a new steady-state with different trend inflation level. Hence, higher trend inflation would amplify the persistence and volatility of macroeconomic variables (Nakata, 2014; Ha, 2018). The next subsection provides a more detailed analysis of this issue.

Shock to Trend Inflation and Impulse-Response Analysis

In what follows, we simulate a positive shock to trend inflation and examine how it leads to changes in aggregate economic variables. The basic intuition behind the trend inflation shock is as follows. Central bank decides to increase the inflation target, which results in more inflation dynamics and reinforce expected inflation (Dou, Lo, Muley and Uhlig, 2017). The inflation dynamics, in turn, determines economic choices in the present.

Figure 3.2 highlights the short-run co-movement between the nominal rates and inflation conditional on the positive shock to trend inflation, i.e., conditional on a positive change in the inflation target. It shows that a positive trend inflation shock drives up expected inflation and, hence inflation around 0.09 percent, in the baseline ('SPSW'), which in turn lowers the real interest rate at -0.07 percent, given the level of the nominal interest rate of 0.014 percent. The same mechanism can be observed for alternative model specifications, namely the sticky price ('SP') and sticky wage ('SW') models.

Furthermore, important changes in aggregate economic variables are reported in Figure 3.3. Indeed, the decline in the real interest rate (panel 2, first row) induces, through inter-temporal substitution by households, an increase in consumption (panel 1, second row) and investment goods (panel 2, second row) demand which in turn, leads to a rise in labor income (real wage). That increase reinforces the contemporaneous rise in consumption (panel 1, second row) and employment (panel 3, second row). The expansion in employment drives wages and marginal costs of production up (Christiano et al., 2018). Confronted with an increase in production costs, some firms decide to reduce their profit margins, whereas others gradually transfer these costs onto the final price. The latter effect eventually ends up raising inflation (panel 1, first row) (Dou, Lo, Muley and Uhlig, 2017).

Overall, the decline in the real interest rate leads to persistent and hump-shaped responses of consumption, investment, employment, and output, which are higher in the SPSW model than in the SP framework and relatively small in the SW case. We also find that the SW framework yields a more persistent response to inflation (or more sensitive to changes in inflation) than the SP and SPSW models. The results so far yield analytical specificity to understand better the substantial role of nominal rigidities in labor and goods markets on macroeconomic dynamics and welfare costs. In section 3.5.2, we will focus on quantifying the welfare implications.

3.5.2 Welfare Effects

This section examines the welfare costs of shifting trend inflation. To measure these costs, we consider the consumption-equivalent welfare loss [25] metric based on stochastic means denoted ψ_m. We first analyze the welfare effects of constant trend inflation and then those of shifting trend inflation. Finally, we will conduct a sensitivity analysis.

Constant Trend Inflation

Baseline Model

The baseline model (SPSW) features nominal frictions both in goods and labor markets, shifting trend inflation, production networking, and trend growth, among others. It nests alternative model specifications, namely the sticky price and sticky wage frameworks. Table 3.3 in panel 'baseline' compares the welfare costs of an economy in which trend inflation is constant at 0 percent to the one in which trend inflation is constant at 4 percent (annualized) in the benchmark model.

The results show that increasing trend inflation from 0 to 4 percent generates the consumption-equivalent welfare loss of 5.85 percent. In terms of the discrepancy between the two economies, we observe that the total welfare (V) is higher (-569.013) in the low trend inflation economy than in the high trend inflation economy (-575.037). The main difference comes from the consumption (V^c) and labor (V^n) components of the total welfare with the former playing a leading role (-519.157/-523.835 in low/high

25. How much one would have to give up in the baseline to have the same welfare in the alternative.

trend inflation) versus (-106.245/-107.590) for the latter (Table 3.3, panel 'baseline'). It is because as trend inflation increases, wages are affected more than labor productivity and raising the cost of production and relative prices. The latter, in turn, affect the real wage (labor income) and the demand for consumption and induce inefficiencies in the allocation of labor input. Consequently, output falls and, ultimately, the observed upward surge in welfare costs (figure 3.1, panel 1-second row, panel 2-third row, and panel 3-third row).

Table 3.4 in the panel 'baseline' assumes that there are no production networking and no trend growth in our benchmark model. The welfare loss of going from 0 percent trend inflation to 4 percent of trend inflation (annualized) is 2.22 percent, substantially smaller than in the case with the features mentioned earlier. To understand this result, we refer to Ascari et al. (2018) on the role of trend growth and production networking. They argue that trend growth interacts with nominal rigidity in labor to increase wage dispersion resulting in welfare losses. For the role of roundabout production structure, they argue that the latter serves as an amplification source for a real shock, resulting in more overall volatility, which tends to make an increase in trend inflation more costly. These remarks provide an excellent point in understanding the mechanism behind the observed lower welfare cost as trend inflation increases.

Alternative Model Specifications

We are now interested in apprehending the role of nominal rigidities in goods or labor markets on welfare. Table 3.3 in panel 'sticky-price' illustrates welfare costs in the case where nominal wages are flexible, i.e., sticky-price model. The consumption-equivalent welfare loss of going from 0 percent to 4 percent of trend inflation is only 0.53 percent. Furthermore, when we abstract from trend growth and production networking the welfare loss lowers down to 0.21 percent (Table 3.4, panel 'sticky-price'). This result is consistent with Nakata (2014), who also finds modest welfare costs when wages are flexible.

However, these features change in the sticky wage model. We observe substantial variations in the order of magnitude of the welfare losses conditioned on means (Tables 3.3 and 3.4, 'sticky wage' panel). The results show that the effects of trend productivity growth on welfare costs come in through wage dispersion (v_t^w). As trend growth is positive (g_Ψ), this introduces first-order wage dispersion effects (equation A24 in the appendix). This interaction makes inflation so much more costly (see welfare equation A27 and its components equations A25 and A26). Likewise, Phaneuf and Victor (2019a) show that the interaction between sticky wages and technical change generates inefficient wage dispersion which fuels inflation costs.

Some Key features of these results are worth mentioning. First, in the baseline specification, welfare costs are important. Second, when considering alternative model specifications, we observe that consumption-equivalent welfare losses based on stochastic means are larger in the model with wage rigidity than in price rigidity. Hence, wage rigidity is a lot more important than price rigidity, and it is what matters. This result is consistent with Ascari et al. (2018).

Shifting Trend Inflation

In this subsection, trend inflation is modeled as an exogenous shock process. Following Nakata (2014), we set the steady-state level of trend inflation fixed at 3.52 percent annualized and compute welfare cost conditioned on means of shifting trend inflation by comparing an economy in which the standard deviation of shocks to trend inflation is zero (i.e., $\sigma_\pi = 0$) to an economy in which it is positive (i.e., $\sigma_\pi > 0$). We first consider the baseline model and then its alternative specifications.

Baseline Model

Table 3.5 in the panel 'baseline' describes welfare costs conditioned on means of shifting trend inflation in the baseline model. The consumption-equivalent welfare loss conditioned on means of shifting trend inflation is about 7.43 percent. We observe that welfare is lower in the shifting trend inflation economy (-581.383) than in the constant inflation trend case (-573.668). The difference comes mainly from the volatility component, which is higher in the former (6.6421) than in the latter (2.5758). However, when we remove trend productivity growth and roundabout production structure from the baseline specification, the welfare cost of shifting trend inflation falls from 7.43 percent down to 2.71 percent. The volatility of welfare also changes. It passes from 2.5758 down to 0.8752 for the constant trend inflation economy and from 6.6421 down to 2.2481 for the shifting trend inflation economy (Table 3.6, panel 'baseline'). Overall, we observe that welfare costs are lower without trend growth and roundabout production structure as trend inflation increases.

Alternative Model Specifications

Panel 'sticky-price' of table 3.5 considers the case where wages are flexible. The consumption-equivalent welfare loss with price rigidity is smaller and about 1.13 percent. Whereas when we abstract from trend growth and roundabout production structure, the welfare cost decreases to 0.33 percent (Table 3.6, panel 'sticky-price'). We observe that when wages are flexible, the welfare costs of shifting trend inflation are modest in either case with or without trend growth and roundabout production structure.

We now investigate the role of wage rigidity. Panel 'sticky-wage' of table 3.5 illustrates the welfare cost of shifting trend inflation, which is about 6.37 percent. However, when we assume that there is no trend growth and no roundabout production structure, this cost lowers down to 2.48 percent (Table 3.5, panel (sticky-wage)) but still important compared to the case where wages are flexible.

In summary, it is clear from our results that transmission mechanism channels mainly through wage dispersion to affect welfare. This move is accentuated by the interaction between trend productivity growth and nominal rigidity in the labor market as trend inflation increases. Hence, wage rigidity matters in both the constant and shifting trend inflation economies. We also find that welfare costs are larger in the former than in the latter.

Alternative Welfare Costs of Shifting Trend inflation

This subsection features alternative welfare costs of shifting trend inflation. Particularly, we compute the consumption-equivalent welfare loss conditioned on means and steady-states of raising trend inflation from 0 to 4 percent annualized. We assume trend inflation is modeled as a persistent AR(1) process, and its standard deviation is positive (i.e., $\sigma_\pi > 0$) in both economies. We then assess how costly it would be to increase trend inflation from 0 to 4 percent compared to the costs of shifting trend inflation examined in the benchmark case.

Tables 3.7 and 3.8 display the characteristics and welfare costs of shifting trend inflation. The results show that the mean cost of going from 0 to 4 percent is around 6.35 percent (Table 3.7), while it is 7.43 percent in the benchmark case (Table 3.5), with trend inflation fixed at 3.52 percent annualized. Under the alternative case, the consumption-equivalent welfare loss results in a steady-state of 0.48 percent and a mean cost of 0.6 percent in the sticky-price model. In contrast, these features are 4.88 percent and 5.71 percent, respectively, in the sticky-wage environment (Table 3.7).

Conversely, when we remove trend growth from the baseline specification (Table 3.8), we observe that the costs of inflation are still important in the sticky-wage model resulting in a steady-state value of 1.87 percent and a mean value of 2.16 percent. Furthermore, these costs are 0.19 percent and 0.23 percent, respectively, in the sticky-price model. Compared to the benchmark scenario (Tables 3.5 and 3.6), we observe in the later that these costs are higher.

Two features are worth mentioning. First, the cost of increasing trend inflation from 0 to 4 percent is lower when trend inflation is modeled as an exogenous shock process, and the two economies experience a positive shock to the trend inflation. While in the case where only one economy experiences a positive shock to the trend inflation and for the other economy, the standard deviation is fixed at zero, the steady-state trend inflation set to 3.52 percent in the two cases, the results show that the costs of inflation are higher than in the former. Second, we find that wage-stickiness and trend growth are key factors in assessing the cost of inflation. This last result is consistent with the conclusions in Ascari et al. (2018), (Phaneuf and Victor, 2019a), and Phaneuf and Victor (2019b). On the other hand, Galí (2011) also shows the key role of nominal wage rigidities. He produces evidence that the staggered wage setting provides some theoretical foundations to a Phillips-like relation between wage inflation and unemployment.

Sensitivity Analysis

In what follows, we perform a number of robustness exercises on how different values of parameters affect the mean welfare costs of shifting trend inflation under a given set of assumptions. Particularly, we examine a range of different values for the volatility of trend inflation process, $\sigma_{\bar{\pi}} = [0.025, 0.05, 0.075, 0.10]$, its persistence, $\rho_{\bar{\pi}} = [0.9, 0.99, 0.995]$, trend inflation, $\bar{\pi}^* = \left[1.02^{0.25}, 1.04^{0.25}, 1.06^{0.25}\right]$, the frequency of price adjustment, $\xi_p = [0.5, 0.55, 0.6, 0.65, 0.7, 0.75]$, and the frequency of wage adjustment, $\xi_w = [0.5, 0.55, 0.6, 0.65, 0.7, 0.75]$.

Table 3.9 shows the degree to which the welfare cost of shifting trend inflation depends on the volatility of the trend inflation process ($\sigma_{\bar{\pi}}$), its persistence ($\rho_{\bar{\pi}}$), and to the level of trend inflation ($\bar{\pi}^*$). We observe that as the volatility gets to 0.075, the welfare cost of shifting trend inflation increases to 4.77 percent and gets even larger to 8.34 percent with a high volatility estimate of 0.10. Likewise, in the third column, the effect of varying persistence of shocks to the trend inflation on the welfare costs are quantitatively higher [26]. Finally, the fifth column describes the effect of the trend inflation level on the welfare cost. With 2 percent annualized trend inflation, the welfare cost is about 0.69 percent and goes up to 13.07 percent when the level of trend inflation augments to 6 percent annualized. This fact is illustrated in the left panel of figure 3.4, where we observe the welfare cost of shifting trend inflation varies non-linearly (i.e., in large proportion) when trend inflation augments.

Figure 3.4 in the right panel reports the sensitivity of price dispersion (s) and wage

26. However, we observe that when we adjust the persistence of trend inflation shocks to match the inflation dynamics in the data, for the sample period 1960:I-2007: III, the welfare cost is modest and lowers to around 2.1 percent.

dispersion (v^w) to changes in trend inflation ($\bar{\pi}^*$). Indeed, we notice a weak interaction between price dispersion and trend inflation (dotted line). When trend inflation passes from 2 to 6 percent, the price is less dispersed (from 0 to 0.01). Consequently, consumption, labor, and output are less affected by the level of trend inflation, and welfare costs of shifting trend inflation are therefore modest and smaller. However, we observe a strong interaction between trend inflation and wage dispersion (dashed line); the more trend inflation increases. Hence, as trend inflation passes from 2 to 6 percent annualized, wages become more dispersed (from 0.03 to 0.4) and affect consumption, labor, output, and ultimately welfare costs increase in a large proportion (i.e., non-linearly) more than does price dispersion.

Furthermore, figures 3.5 and 3.6 show how the welfare costs of shifting trend inflation vary with the frequency of price adjustment (ξ_p), and the frequency of wage adjustment (ξ_w). The effect of price adjustment frequency on the welfare costs of shifting trend inflation is reported in figure 3.5. With less price stickiness of around 0.55, the welfare cost of shifting trend inflation is less than 0.2 percent. With 0.75 price adjustment frequency, the welfare cost exceeds one percent. Conversely, figure 3.6 describes the effect of wage adjustment frequency on the welfare costs of shifting trend inflation. We observe that a rise in ξ_w from 0.55 to 0.75 leads to an increase in welfare costs of shifting trend inflation from less than 2 percent to almost 14 percent.

Overall, we observe that varying trend inflation, price adjustment frequency, and wage adjustment frequency lead to a nonlinear increase in welfare costs of shifting trend inflation, the more these parameters augment. Specifically, when trend inflation rises in a wage stickiness environment, wages become more dispersed, affect aggregate macroeconomic variables and have much larger effects on the welfare cost of shifting trend inflation than does price dispersion in a price stickiness environment. This fact suggests that the transmission mechanism passes mainly through wage dispersion which affects macroeconomic dynamics to bring about welfare effects.

However, like in Phaneuf and Victor (2019a), we also notice that with Calvo nominal contracts wage dispersion and welfare costs are very sensitive to trend inflation levels and variations in key model parameters (Table 3.9 and figures 3.5 and 3.6). In this perspective, Nakata (2014) and Nakamura et al. (2018) advocate a class of state-dependent pricing models with an endogenous frequency of price adjustment than in the Calvo model in which welfare costs of inflation are most likely lower. It would be practical to extend this analysis to other classes of models such as Taylor's nominal contracting framework. This preoccupation is beyond the scope of the present study and will be discussed in a separate paper.

3.6 Conclusion

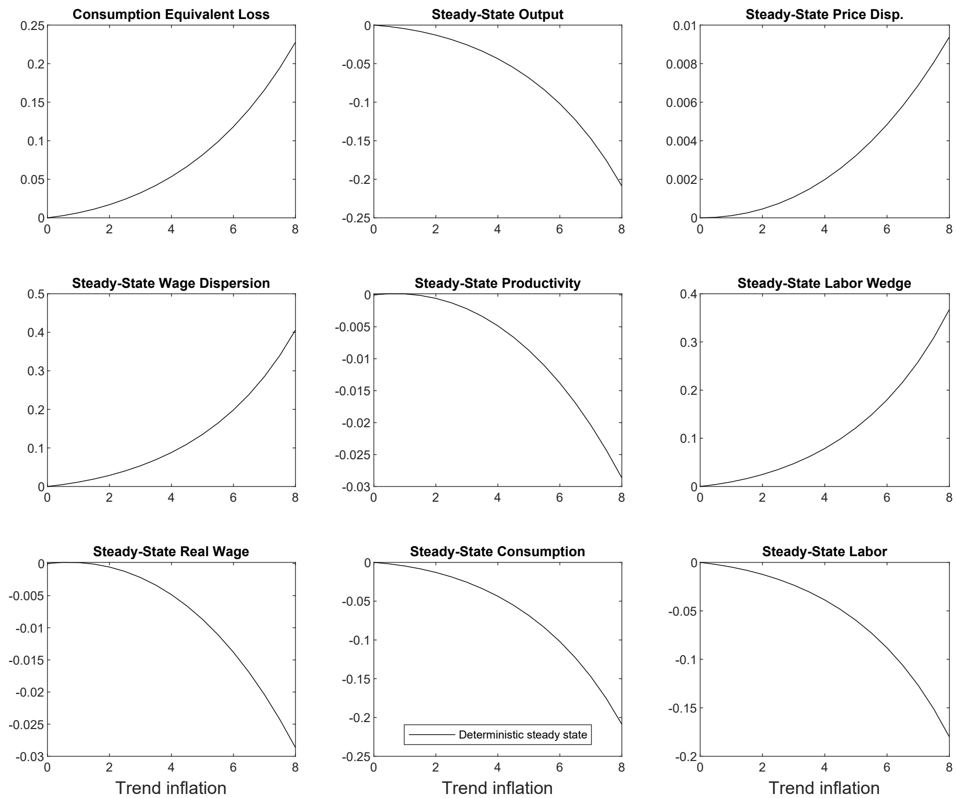
This study focused on the welfare costs of shifting trend inflation. The existing literature used Standard New Keynesian models with price stickiness to discuss this issue. Within this framework, price dispersion plays a crucial role in the transmission mechanism to engender welfare costs. In this paper, we offered a new perspective in a medium-scale New Keynesian DSGE model that featured nominal frictions in goods and labor markets, trend growth, and roundabout production structure, among others. We then examined the implication of time-varying trend inflation on macroeconomic dynamics and welfare, both in the baseline and alternative model specifications To measure the welfare, we used a consumption-equivalent welfare loss metric conditioned on stochastic means.

We offered new insights into the effects of shifting trend inflation on welfare costs. First, we compare both constant and shifting trend inflation economies. We show that welfare costs conditioned on means of shifting trend inflation are larger than in the constant trend inflation case. We notice that when we remove trend growth and roundabout production structure from the baseline specification, welfare costs are reduced in both cases, but still greater in the case of shifting trend inflation. Second, we examined the role of nominal frictions either in goods or labor markets on the welfare. We found that the frequency of price adjustment does not vary with the level of trend inflation. Therefore, welfare costs are modest and smaller as trend inflation augments in a price stickiness environment. Whereas in a stickiness wage environment, welfare costs are much larger when trend inflation is higher. Indeed, the interaction between trend growth and wage stickiness, as trend inflation increases, makes wages more dispersed, which has much larger effects on welfare costs than does price dispersion.

We also perform several robustness exercises for a large range of parameter values. We found that varying trend inflation, Calvo price adjustment frequency, and wage adjustment frequency lead to an increase in welfare costs, the more these parameters augment. Specifically, when trend inflation rises, wages become more dispersed, affecting consumption, labor, output, and having much larger effects on welfare costs than price dispersion. The results suggest that the transmission mechanism passes mainly through wage dispersion, which, in turn, affects macroeconomic dynamics to bring about welfare effects.

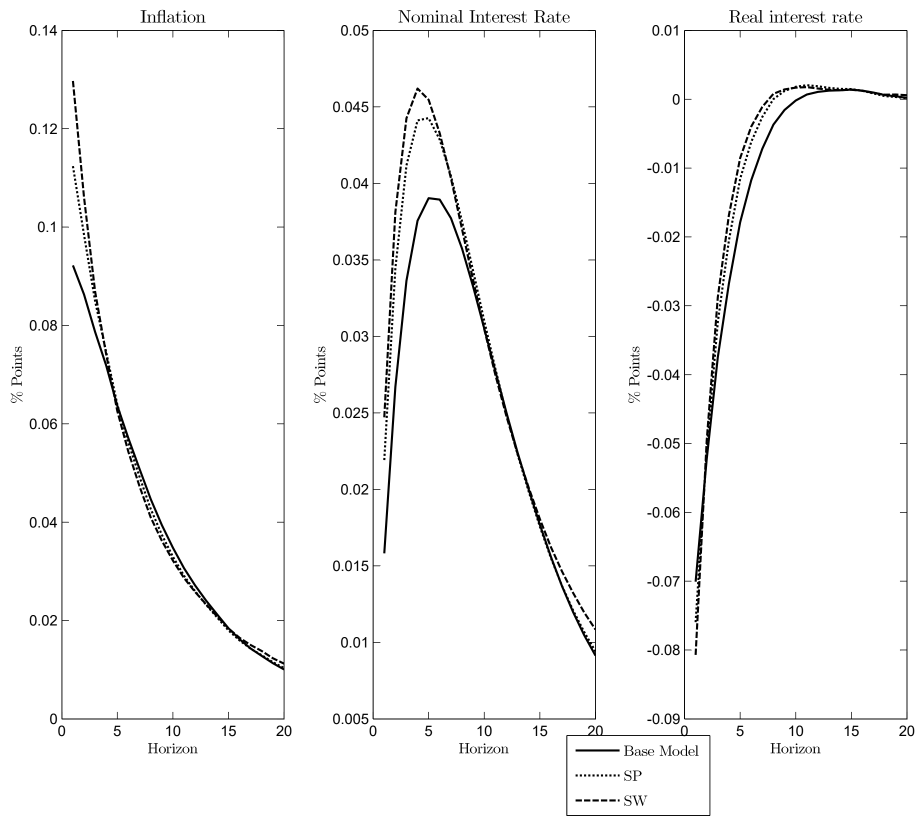
For future research, it would be useful to extend our analysis to other classes of models than Calvo staggered nominal contracts and assess whether this affects the results obtained so far. In addition, a Bayesian approach can be used to estimate the persistence of trend inflation shock and its standard deviation.

Figure 3.1: Steady-State of Variables and Trend Inflation



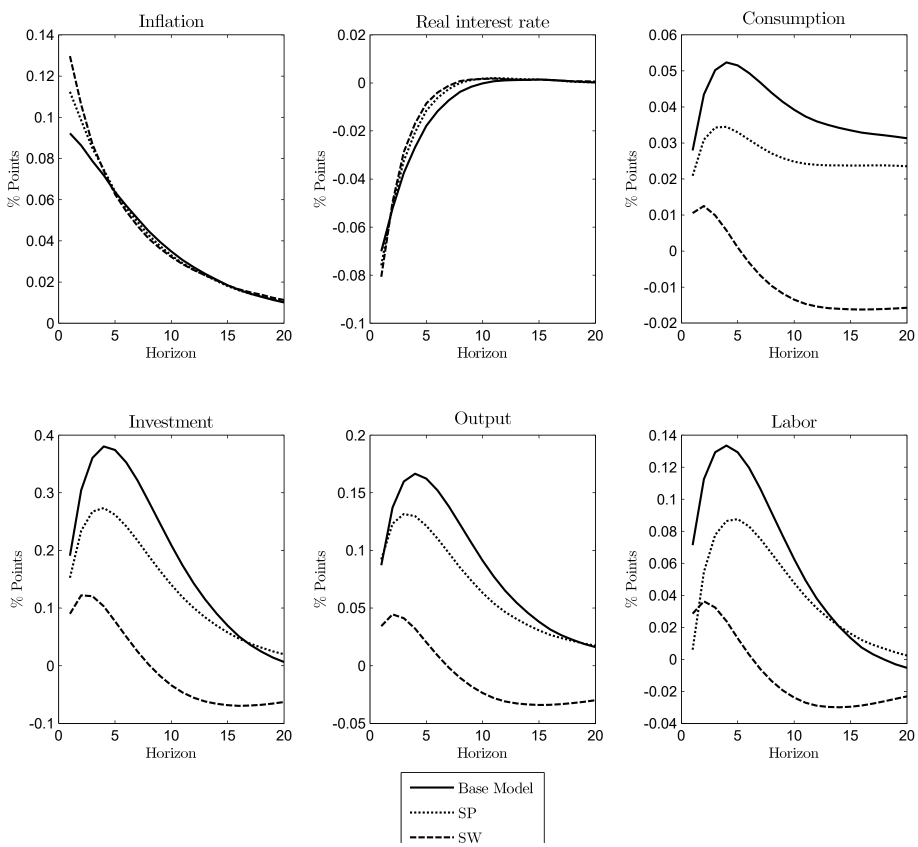
Note: This figure plots steady-state levels of variables at various annualized trend inflation rates. It illustrates how changes in trend inflation do affect these steady-state variables and bring about welfare implications. Variables are in percentage deviation from the zero inflation steady state. The dotted lines show stochastic steady state. The solid lines show deterministic steady state.

Figure 3.2: Shock to Trend inflation and Interest Rate



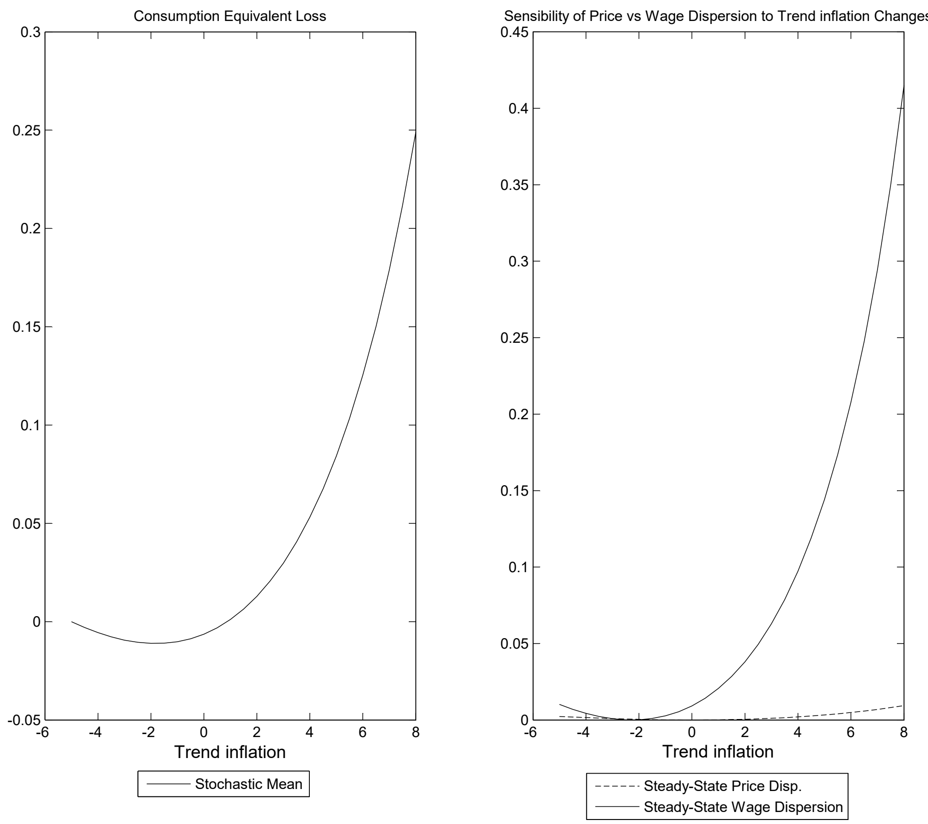
Note: This figure plots the average impulse responses of inflation, nominal interest rate and real interest rate to a positive trend inflation shock. The solid lines in the panels show responses relative to the baseline model ("SPSW"). The dotted lines in the panels depict responses relative to the sticky price model ("SP"). The dashed lines in the panels depict responses relative to the sticky wage model ("SW").

Figure 3.3: Shock to Trend Inflation and aggregate economic variables



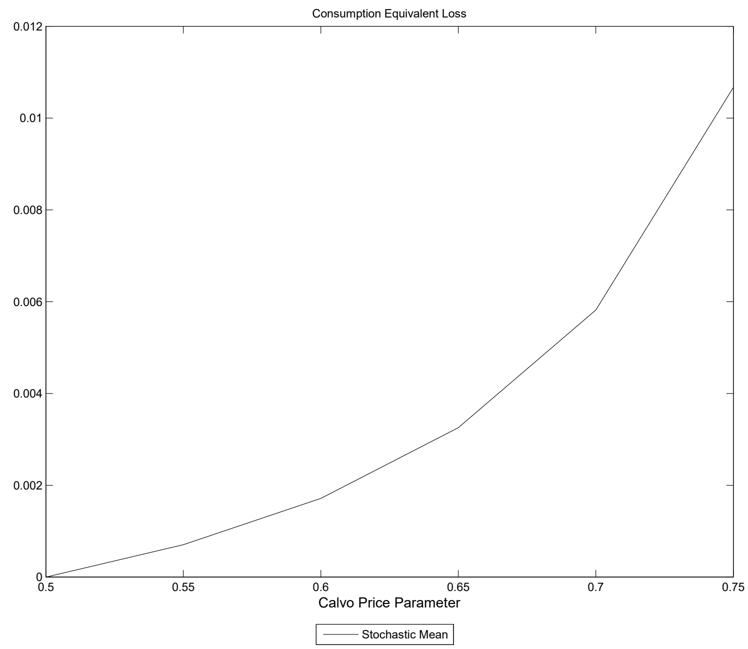
Note: This figure plots the average impulse responses of aggregate economic variables to a positive Trend inflation shock.The solid lines in the panels show responses relative to the baseline model (”SPSW”). The dotted lines in the panels depict responses relative to the sticky price model (”SP”). The dashed in the panels lines depict responses relative to the sticky wage model (”SW”).

Figure 3.4: Sensibility of Price and Wages Disperstion to change in Trend inflation



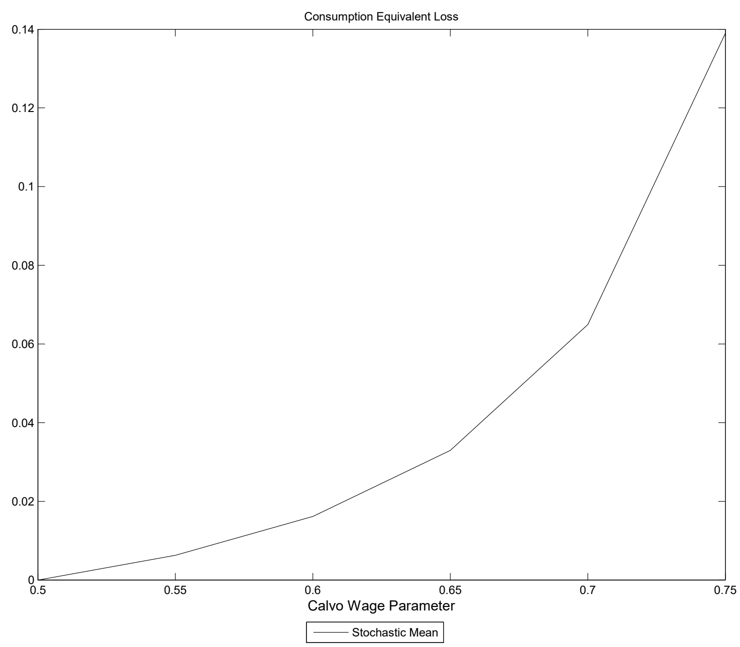
Note: This figure plots the sensibility of price and wages dispersion to change in Trend inflation (Right panel) and the corresponding welfare implication (Left panel).

Figure 3.5: Effect of Price Adjustment Frequency on the Welfare Costs of shifting Trend Inflation



Note: This figure shows the effect of price adjustment frequency on the welfare costs of shifting trend inflation.

Figure 3.6: Effect of Wages Adjustment Frequency on the Welfare Costs of shifting Trend Inflation



Note: This figure shows the effect of wages adjustment frequency on the welfare costs of shifting trend inflation.

Table 3.1: Parameter Values

Parameter	Description	Value
β	Discount factor	0.99
b	Internal habit formation	0.8
η	Labor disutility	6
χ	Frisch elasticity	1
κ	Investment adjustment cost	3
δ	Depreciation rate	0.025
γ_1	Utilization adjustment cost linear term	$Z^* = 1$
γ_2	Utilization adjustment cost squared term	0.05
ξ_p	Calvo price	0.66
ξ_w	Calvo wage	0.66
θ	Elasticity of substitution of goods	6
σ	Elasticity of substitution of labor	6
ϕ	Intermediate share	0.61
$\bar{Z}$	Fixed cost	$\pi^* = 0$
α	Capital share	1/3
ρ_i	Taylor rule smoothing	0.8
α_π	Taylor rule inflation	1.92
α_y	Taylor rule output growth	0.2
π^*	Trend Inflation (Gross)	1.0088
g_{ε^I}	Gross Growth of IST	1.0047
g_A	Gross Growth of Neutral Productivity	$1.0022^{1-\phi}$
ρ_A	AR(1) productivity	0.95
ρ_I	AR(1) MEI	0.81
ρ_π	AR(1) Trend inflation	0.95
σ_A	S.D productivity shock	0.0029
σ_I	S.D MEI shock	0.0180
σ_r	S.D monetary shock	0.0011
σ_π	S.D trend inflation shock	0.0572

Note: This table shows the key parameters used to solve the model.A description of each parameter is provided in the column.

Table 3.2: Selected Moments

	$E(\Delta Y)$	$\sigma(\Delta Y)$	$\sigma(\Delta I)$	$\sigma(\Delta C)$	$\rho_1(\Delta Y)$	$\rho_1(\pi)$	$\sigma(\pi)$	$\sigma(Y^{hp})$	$\sigma(C^{hp})$
Data	(0.0057)	(0.0078)	(0.0202)	(0.0047)	(0.3634)	(0.9071)	(0.0065)	(0.0156)	(0.0083)
Model	0.0057	0.0078	0.0200	0.0043	0.7489	0.9855	0.0150	0.0174	0.0090
	$\sigma(\Delta N)$	$\rho(\Delta Y,\Delta I)$	$\rho(\Delta Y,\Delta C)$	$\rho(\Delta Y,\Delta N)$	$\sigma(N^{hp})$	$\rho(Y^{hp},I^{hp})$	$\rho(Y^{hp},C^{hp})$	$\rho(Y^{hp},N^{hp})$	$\sigma(I^{hp})$
Data	(0.0079)	(0.9192)	(0.7542)	(0.6313)	(0.0171)	(0.9701)	(0.9053)	(0.8750)	(0.030)
Model	0.0086	0.9282	0.7013	0.4412	0.0132	0.9308	0.7122	0.6456	0.0448

Note: This table shows some statistics of selected moments from our baseline model. Moments on the data are computed from 1960q1-2007q3 and are shown in parentheses.

Table 3.3: Effects of Constant Non-Zero Inflation, Cost of going from 0 % to 4%

Model	π^*	V	V^c	V^n	V_{ss}	V_{ss}^c	V_{ss}^n	$\sigma(V)$	$\sigma(V^c)$	$\sigma(V^n)$	ψ_{ss}	ψ_m
Baseline	1.00	-569.013	-519.157	-106.245	-568.759	-519.005	-106.143	1.861	1.163	0.758		
	1.04	-575.037	-523.835	-107.590	-574.250	-523.364	-107.274	2.687	1.679	1.155	0.0534	0.0585
Sticky Price	1.00	-568.128	-518.676	-105.841	-568.139	-518.688	-105.839	1.592	1.0100	0.602		
	1.04	-568.662	-519.195	-105.855	-568.623	-519.173	-105.839	1.648	1.048	0.621	0.0048	0.0053
Sticky Wage	1.00	-568.905	-519.078	-106.215	-568.759	-519.005	-106.143	1.887	1.171	0.760		
	1.04	-574.304	-523.181	-107.511	-573.765	-522.880	-107.274	2.654	1.615	1.142	0.0488	0.0526

Note: This table shows the welfare costs of constant trend inflation (ψ_m) going from 0% to 4% for different models. We have π^* for trend inflation and V the total welfare and its components the welfare from consumption (V^c) and from labor (V^n). There is an auxiliary component (Φ) that we do not mention here. The subscript *ss* and $\sigma(.)$ stand for the steady-state and volatility. ψ_{ss} is the consumption-equivalent welfare loss based on steady-states and ψ_m on stochastic means.

Table 3.4: Effects of Constant Trend Inflation, Cost of going from 0 % to 4% (No PN, No Trend Growth)

Model	π^*	V	V^c	V^n	V_{ss}	V_{ss}^c	V_{ss}^n	$\sigma(V)$	$\sigma(V^c)$	$\sigma(V^n)$	ψ_{ss}	ψ_m
Baseline	1.00	-318.086	-215.107	-102.979	-318.051	-215.076	-102.976	0.817	0.524	0.355		
	1.04	-320.327	-216.678	-103.649	-320.129	-216.526	-103.603	0.951	0.633	0.446	0.0206	0.0222
Sticky Price	1.00	-317.994	-215.039	-102.956	-318.051	-215.076	-102.976	0.738	0.475	0.292		
	1.04	-318.203	-215.245	-102.958	-318.242	-215.267	-102.976	0.744	0.481	0.294	0.0019	0.0021
Sticky Wage	1.00	-318.067	-215.089	-102.978	-318.051	-215.076	-102.976	0.801	0.515	0.340		
	1.04	-320.096	-216.452	-103.644	-319.938	-216.335	-103.603	0.915	0.609	0.417	0.0187	0.0201

Note: This table shows the welfare costs of constant non-zero trend inflation (ψ_m) going from 0% to 4% for different models with no firm networking and no trend growth assumptions. We have π^* for trend inflation and V the total welfare and its components the welfare from consumption (V^c) and from labor (V^n). There is an auxiliary component (Φ) that we do not mention here. The subscript *ss* and $\sigma(.)$ stand for the steady-state and volatility. ψ_m is the consumption-equivalent welfare loss based on steady-states and ψ_m on stochastic means.

Table 3.5: Welfare Costs of Shifting Trend inflation

Model	V	V^c	V^n	V_{ss}	V_{ss}^c	V_{ss}^n	$\sigma(V)$	$\sigma(V^c)$	$\sigma(V^n)$	ψ_m
Baseline										
$\sigma_\pi = 0$	-573.6677	-522.7509	-107.3047	-573.0951	-522.4150	-107.0680	2.5758	1.6140	1.0723	
$\sigma_\pi > 0$	-581.3828	-527.5620	-110.2087	-573.0951	-522.4150	-107.0680	6.6421	3.7248	2.9651	0.0743
Sticky Price										
$\sigma_\pi = 0$	-568.5116	-519.0429	-105.8567	-568.4800	-519.0294	-105.8385	1.6875	1.0798	0.6262	
$\sigma_\pi > 0$	-569.6453	-519.8454	-106.1879	-568.4800	-519.0294	-105.8385	1.8371	1.1641	0.6905	0.0113
Sticky Wage										
$\sigma_\pi = 0$	-573.1110	-522.2626	-107.2364	-572.7537	-522.0736	-107.0680	2.5903	1.5814	1.0840	
$\sigma_\pi > 0$	-579.6972	-526.2829	-109.8022	-572.7537	-522.0736	-107.0680	5.9086	3.2677	2.6794	0.0637

Note: This table presents the characteristics of different economies:with constant non-zero inflation ($\sigma_\pi = 0$) and shifting trend inflation ($\sigma_\pi > 0$). The steady-state trend inflation is set to 3.52 percent annualized (i.e $\pi^* = 1.0352^{0.25}$).We have π^* for trend inflation and V the total welfare and its components the welfare from consumption (V^c) and from labor (V^n). There is an auxiliary component (Φ) that we do not mention here. The subscript *ss* and $\sigma(.)$ stand for the steady-state and volatility. ψ_m is the consumption equivalent welfare loss based on stochastic means.

Table 3.6: Welfare Costs of Shifting Trend inflation (No PN, No Trend Growth)

Model	V	V^c	V^n	V_{ss}	V_{ss}^c	V_{ss}^n	$\sigma(V)$	$\sigma(V^c)$	$\sigma(V^n)$	ψ_m
Baseline										
$\sigma_\pi = 0$	-319.7339	-216.2124	-103.5215	-319.6188	-216.1237	-103.4951	0.8752	0.5874	0.3861	
$\sigma_\pi > 0$	-322.5658	-218.2654	-104.3004	-319.6188	-216.1237	-103.4951	2.2481	1.2933	0.9953	0.0279
Sticky Price										
$\sigma_\pi = 0$	-318.1486	-215.1874	-102.9612	-318.1858	-215.2102	-102.9756	0.7076	0.4675	0.2696	
$\sigma_\pi > 0$	-318.4779	-215.4651	-103.0128	-318.1858	-215.2102	-102.9756	0.7491	0.4942	0.2827	0.0033
Sticky Wage										
$\sigma_\pi = 0$	-319.5700	-216.0524	-103.5176	-319.4843	-215.9892	-103.4951	0.8510	0.5700	0.3646	
$\sigma_\pi > 0$	-322.0810	-217.8338	-104.2472	-319.4843	-215.9892	-103.4951	2.0034	1.1353	0.9073	0.0248

Note: This table presents the characteristics of different economies:with constant non-zero inflation ($\sigma_\pi = 0$) and shifting trend inflation ($\sigma_\pi > 0$). The steady-state trend inflation is set to 3.52 percent annualized (i.e $\pi^* = 1.0352^{0.25}$). We have π^* for trend inflation and V the total welfare and its components the welfare from consumption (V^c) and from labor (V^n). There is an auxiliary component (Φ) that we do not mention here. The subscript ss and $\sigma(.)$ stand for the steady-state and volatility. ψ_m is the consumption equivalent welfare loss based on stochastic means.

Table 3.7: Alternative Welfare Cost of Shifting Trend Inflation, going from 0 to 4%

Model	π^*	V	V^c	V^n	V_{ss}	V_{ss}^c	V_{ss}^n	$\sigma(V)$	$\sigma(V^c)$	$\sigma(V^n)$	ψ_{ss}	ψ_m
Baseline	1.00	-569.1092	-519.2202	-106.2769	-3.6051	-1.0257	-3.6031	-1.0241	0.0438	0.0191		
	1.04	-575.6691	-524.2183	-107.8387	-3.6551	-1.0677	-3.6467	-1.0629	0.0645	0.0244	0.0534	0.0635
Sticky Price	1.00	-568.1925	-518.7198	-105.8607	-3.6002	-1.0211	-3.5999	-1.0209	0.0372	0.0149		
	1.04	-568.7993	-519.2912	-105.8959	-3.6059	-1.0209	-3.6048	-1.0209	0.0388	0.0165	0.0048	0.0060
Sticky Wage	1.00	-568.9926	-519.1332	-106.2473	-3.6042	-1.0257	-3.6031	-1.0241	0.0445	0.0167		
	1.04	-574.8725	-523.5181	-107.7423	-3.648	-1.0674	-3.6418	-1.0629	0.0614	0.0192	0.0488	0.0571

Note: This table shows the alternative welfare costs of shifting trend inflation (ψ_m) going from 0 to 4% for different models. We have π^* for trend inflation and V the total welfare and its components the welfare from consumption (V^c) and from labor (V^n). There is an auxiliary component (Φ) that we do not mention here. The subscript ss and $\sigma(.)$ stand for the steady-state and volatility. ψ_{ss} is the consumption-equivalent welfare loss based on steady-states and ψ_m on stochastic means.

Table 3.8: Alternative Welfare Cost of Shifting Trend Inflation, going from 0 % to 4% (No Growth)

Model	π^*	V	V^c	V^n	V_{ss}	V_{ss}^c	V_{ss}^n	$\sigma(V)$	$\sigma(V^c)$	$\sigma(V^n)$	ψ_{ss}	ψ_m
Baseline	1.00	-318.1308	-215.1425	-102.9883	-0.542	-1.0358	-0.5413	-1.0346	0.0173	0.0177		
	1.04	-320.5455	-216.84	-103.7055	-0.5589	-1.0502	-0.5558	-1.0472	0.0216	0.0194	0.0206	0.0239
Sticky Price	1.00	-318.0242	-215.0629	-102.9613	-0.5412	-1.0348	-0.5413	-1.0346	0.0152	0.0113		
	1.04	-318.2548	-215.2881	-102.9667	-0.5434	-1.0348	-0.5432	-1.0346	0.0154	0.0123	0.0019	0.0023
Sticky Wage	1.00	-318.1055	-215.1193	-102.9862	-0.5417	-1.0357	-0.5413	-1.0346	0.0169	0.0156		
	1.04	-320.2852	-216.5893	-103.6959	-0.5564	-1.0500	-0.5539	-1.0472	0.0204	0.0158	0.0187	0.0216

Note: This table shows the alternative welfare costs of shifting trend inflation (ψ_m) going from 0% to 4% for different models. We have π^* for trend inflation and V the total welfare and its components the welfare from consumption (V^c) and from labor (V^n). There is an auxiliary component (Φ) that we do not mention here. The subscript *ss* and $\sigma(.)$ stand for the steady-state and volatility. ψ_{ss} is the consumption-equivalent welfare loss based on steady-states and ψ_m on stochastic means.

Table 3.9: Sensitivity Analysis

σ_π	Welfare Costs	ρ_π	Welfare Costs	$\bar{\pi}^*$	Welfare Costs
0.000		0.900	0.0019	$1.02^{0.25}$	0.0069
0.025	0.0052	0.990	0.0279	$1.04^{0.25}$	0.0395
0.050	0.0214	0.995	0.0562	$1.06^{0.25}$	0.1307
0.075	0.0477				
0.100	0.0834				

Note: This table considers a simple version of the benchmark model i.e. under no trend growth and no production networking assumptions. The conclusion is the same as in the main model. σ_π is the volatility of trend inflation shock, ρ_π its persistence, and $\bar{\pi}^*$ the trend inflation.

APPENDIX

Appendix 3.A Full Set of Equilibrium Conditions

This appendix lists the full set of detrended equations. These equations are expressed in stationary transformations of variables, e.g. $\widetilde{X}_t = \frac{X_t}{\Psi_t}$ for most variables. $g_\Psi = \frac{\Psi_t}{\Psi_{t-1}}$ is the growth rate of the deterministic trend.

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

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

$$\widetilde{\lambda}_t^r = \widetilde{\mu}_t \vartheta_t \left(1 - \frac{k}{2}\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi\right)^2 - \kappa \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi\right) \frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi\right) + \dots$$
$$\beta E_t g_\Psi^{-1} \widetilde{\mu}_{t+1} \vartheta_{t+1} \kappa \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Psi - g_\Psi\right) \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Psi\right)^2 \tag{A3}$$

$$g_I g_\Psi \widetilde{\mu}_t = \beta E_t \widetilde{\lambda}_{t+1}^r \left(\widetilde{r}_{t+1}^k Z_{t+1} - \left(\gamma_1 (Z_{t+1} - 1) + \frac{\gamma_2}{2}(Z_{t+1} - 1)^2\right)\right) + \beta(1-\delta) E_t \widetilde{\mu}_{t+1} \tag{A4}$$

$$\widetilde{\lambda}_t^r = \beta g_\Psi^{-1} E_t (1 + i_t) \pi_{t+1}^{-1} \widetilde{\lambda}_{t+1}^r \tag{A5}$$

$$\widetilde{w}_t^* = \frac{\sigma}{\sigma - 1} \frac{\widetilde{h}_{1,t}}{\widetilde{h}_{2,t}} \tag{A6}$$

$$\widetilde{h}_{1,t} = \eta \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*}\right)^{\sigma(1+\chi)} N_t^{1+\chi} + \beta \xi_w E_t (\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*}\right)^{\sigma(1+\chi)} g_\Psi^{\sigma(1+\chi)} \widetilde{h}_{1,t+1} \tag{A7}$$

$$\widetilde{h}_{2,t} = \widetilde{\lambda}_t^r \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*}\right)^{\sigma} N_t + \beta \xi_w E_t (\pi_{t+1})^{\sigma-1} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*}\right)^{\sigma} g_\Psi^{\sigma-1} \widetilde{h}_{2,t+1} \tag{A8}$$

$$\widetilde{\widehat{K}}_t = g_I g_\Psi \alpha(1-\phi)\frac{mc_t}{\widetilde{r}_t^k}\left(s_t\widetilde{X}_t + \bar{Z}\right) \tag{A9}$$

$$N_t = (1-\alpha)(1-\phi)\frac{mc_t}{\widetilde{w}_t}\left(s_t\widetilde{X}_t + \bar{Z}\right) \tag{A10}$$

$$\widetilde{\Upsilon}_t = \phi mc_t\left(s_t\widetilde{X}_t + \bar{Z}\right) \tag{A11}$$

$$p_t^* = \frac{\theta}{\theta-1}\frac{m_{1,t}}{m_{2,t}} \tag{A12}$$

$$m_{1,t} = \widetilde{\lambda}_t^r mc_t\widetilde{X}_t + \xi_p\beta\left(\frac{1}{\pi_{t+1}}\right)^{-\theta} m_{1,t+1} \tag{A13}$$

$$m_{2,t} = \widetilde{\lambda}_t^r\widetilde{X}_t + \xi_p\beta\left(\frac{1}{\pi_{t+1}}\right)^{1-\theta} m_{2,t+1} \tag{A14}$$

$$1 = \xi_p\left(\frac{1}{\pi_t}\right)^{1-\theta} + (1-\xi_p)p_t^{*1-\theta} \tag{A15}$$

$$\widetilde{w}_t^{1-\sigma} = \xi_w g_\Psi^{\sigma-1}\left(\frac{\widetilde{w}_{t-1}}{\pi_t}\right)^{1-\sigma} + (1-\xi_w)\widetilde{w}_t^{*1-\sigma} \tag{A16}$$

$$\widetilde{Y}_t = \widetilde{X}_t - \widetilde{\Upsilon}_t \tag{A17}$$

$$s_t\widetilde{X}_t = \widetilde{\Upsilon}_t^{\phi}\widetilde{\widehat{K}}_t^{\alpha(1-\phi)} N_t^{(1-\alpha)(1-\phi)} g_\Psi^{\alpha(\phi-1)} - \bar{Z} \tag{A18}$$

$$\widetilde{Y}_t = \widetilde{C}_t + \widetilde{I}_t + g_\Psi^{-1}g_I^{-1}\left(\gamma_1(Z_t-1) + \frac{\gamma_2}{2}(Z_t-1)^2\right)\widetilde{K}_t \tag{A19}$$

$$\widetilde{K}_{t+1} = \vartheta_t\left(1 - \frac{\kappa}{2}\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}}g_\Psi - g_\Psi\right)^2\right)\widetilde{I}_t + (1-\delta)g_\Psi^{-1}g_I^{-1}\widetilde{K}_t \tag{A20}$$

$$\frac{1+i_t}{1+i} = \left(\left(\frac{\pi_t}{\bar{\pi}_t}\right)^{\alpha_\pi}\left(\frac{\widetilde{Y}_t}{\widetilde{Y}_{t-1}}\right)^{\alpha_y}\right)^{1-\rho_i}\left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i}\exp\left(\varepsilon_t^r\right) \tag{A21}$$

$$\widetilde{\widehat{K}}_t = Z_t\widetilde{K}_t \tag{A22}$$

$$s_t = (1-\xi_p)p_t^{*-\theta} + \xi_p\left(\frac{1}{\pi_t}\right)^{-\theta} s_{t-1} \tag{A23}$$

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

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

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

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

$$\Phi_t = \frac{\beta \ln g_{\Psi}}{(1-\beta)^2} \tag{A28}$$

$$\vartheta_t = (\vartheta_{t-1})^{\rho_I} \exp\left(\sigma_I u_t^I\right) \tag{A29}$$

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(\sigma_A u_t^A\right) \tag{A30}$$

$$\ln(\bar{\pi}_t) = (1-\rho_{\bar{\pi}})\ln(\bar{\pi}^*) + \rho_{\bar{\pi}}\ln(\bar{\pi}_{t-1}) + \sigma_{\bar{\pi}} u_t^{\bar{\pi}} \tag{A31}$$

Equation (A1) defines the real multiplier on the flow budget constraint. (A2) is the optimality condition for capital utilization. (A3) and (A4) 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 (A5). (A6)-(A8) describe optimal wage setting for households given the opportunity to adjust their wages. Optimal factor demands are given by equations (A9)-(A11). Optimal price setting for firms given the opportunity to change their price is described by equations (A12)-(A14). The evolutions of aggregate inflation and the aggregate real wage index are given by (A15) and (A16), respectively. Net output is gross output minus intermediates, as given by (A17). The aggregate production function for gross output is (A18). The aggregate resource constraint is (A19), and the law of motion for physical capital is given by (A20). The Taylor rule for monetary policy is (A21). Capital services are defined as the product of utilization and physical capital, as in (A22). The law of motion for price dispersion is (A23) and for wage dispersion is (A24). (A25) and (A26) are recursive utility from consumption and labor in the levels. The aggregate welfare is (A27) and (A28) a shift term. (A29)-(A31) give the assumed laws of motion for other exogenous variables.

CHAPTER IV

WELFARE COSTS OF SHIFTING TREND INFLATION AND STAGGERED NOMINAL CONTRACTS: TAYLOR VS. CALVO.

Abstract

The existing literature on shifting trend inflation has, for the most part, focused on the Calvo staggered nominal contracts to address welfare issues. This paper proposes alternative nominal contracts in the form of Taylor in a fully specified medium small-scale New Keynesian Model featuring trend productivity growth, production networking, and financial frictions. We then compare the resulting welfare costs conditioned on means between Taylor and Calvo staggered nominal contracts. We produce evidence that Taylor's nominal contracts offer a relevant alternative in assessing the New Keynesian model's normative properties. In addition, we perform some robustness exercises and conclude with concluding remarks.

JEL classification: C63, E31, E32.

Keywords: Medium-scale dsge model;

4.1 Introduction

The literature on shifting trend inflation has mainly focused on Calvo nominal rigidities (Calvo, 1983) to discuss welfare cost issues. In an early contribution, Nakata (2014) studies the welfare implications of exogenous variations in trend inflation in a Standard New Keynesian model with Calvo nominal price contracts. While Lê et al. (2019) develop a medium-scale DSGE model featuring Calvo staggered price and wage contracts to examine the welfare implications of time-varying trend inflation. However, in the papers mentioned above, the results show that welfare costs are more responsive to trend inflation and key model parameters. Phaneuf and Victor (2019b) reach a similar conclusion in a constant trend inflation environment and cast doubt in Calvo's nominal contracts' ability to assess the New Keynesian model's long-run properties. Furthermore, some critics advocate the use of other classes of models in which these costs are most likely lower (Nakata, 2014; Nakamura et al., 2018).

This paper proposes alternative nominal contracts in the form of Taylor (Taylor, 1980) and contrasts the results with those of nominal contracts à la Calvo. We then look at the transmission channel and how it leads to welfare costs in the two models. We further consider the cyclical implications.

In line with the above, a set of papers has investigated the comparisons between Taylor and Calvo's staggered nominal contracts. Chari et al. (2000) and Christiano et al. (2005) have focused on the effect of monetary shocks on output and inflation. In contrast, Phaneuf and Victor (2019b) consider the welfare and cyclical implications when trend inflation is positive. This paper completes the existing literature by proposing nominal contracts in Taylor's form to address the welfare effects of exogenous variations in trend inflation. We use a fully specified structural model inspired by Ascari et al. (2018) and extended to include Taylor staggered nominal contracts, and a stationary and highly persistence trend inflation process.

Furthermore, to compare the Taylor and Calvo nominal contracts, we put the two models on the same basis. For the non-shock calibration, we set structural parameters and, in particular, the average age of nominal wage and price contracts equal in the two models based on Dixon and Kara (2006). However, we assign a fixed percentage contribution [1] of shocks to neutral technology, investment, monetary policy, and trend inflation to match the output growth volatility for the shock parameters.

We first perform a qualitative analysis of the unconditional model and data moments match. We show that modeling trend inflation as an exogenous process constitutes an improvement in matching the volatilities of inflation and interest rates in the data and does better than in the constant trend inflation framework(Phaneuf and Victor, 2019a). Also, in the later, both models have difficulty in accounting for some key properties of the aggregate data, such as the comovement between first-differenced hours and inflation, which is positive. In contrast, it is negative in the data.

In this paper, we find a countercyclical correlation between first-differenced hours and inflation for the Taylor model. However, first-differenced hours' volatility matches the data in both models. Overall, the two models account for the basic qualitative properties of the aggregate data and explain the usual business-cycle dimensions.

Second, we focus on the cost of inflation and output loss based on the stochastic mean. We first consider the case when trend inflation is constant and passes from 0 to 2% and 2% to 4% inflation bands. The analysis highlights a nonlinear relationship between inflation cost and trend inflation in both models. We show that welfare costs and output losses are smaller and modest in the Taylor model (0.66% and 0.61%) compared to the Calvo model (3.6% and 3.1%) in the inflation bands of 0 to 2%. We also observe that rising trend inflation by 2% is more costly, going from 2 to 4% than from 0 to 2% (Ascari et al., 2018).

In the shifting trend inflation case, trend inflation is modeled as an exogenous shock process. We assume the steady-state level of trend inflation fixed at 2% annualized and compute the stochastic mean welfare cost and output loss by comparing an economy in which the standard deviation of shocks to trend inflation is zero to an econ-

1. Phaneuf and Victor (2019b) show that neither Total factor productivity shock nor investment shock is the key driver behind business cycle fluctuations. Therefore, we take a stand by placing more weight on the contribution of investment shocks.

omy in which it is positive (Nakata, 2014). We show that the Calvo nominal contracts model's inflation cost is about 7.81% and 5.76% for the output loss. These features are 1.07% and 0.87% in the Taylor model, respectively.

However, when wages are flexible, price dispersion is weakly correlated with trend inflation and explains the modest cost of inflation in the two models compared to the nominal wage contracts. Indeed, the steady-state price dispersion is about 0.05% in the Calvo model against 0.01% in the Taylor model. The mean price dispersion amounts to 0.06% and 0.03%, respectively. We find that price dispersion is sensitive to inflation changes in the Calvo model compared to the Taylor model. These findings are consistent with Nakata (2014) and the evidence produced by Nakamura et al. (2018).

The results are very different when prices are flexible. We find that wage dispersion is too responsive to changes in inflation in the Calvo model than in the Taylor model. We show that the steady-state wage dispersion amounts to 10.04% in the Calvo model and 0.01% in the Taylor model. The mean wage dispersion is 11.41% and 0.07%, respectively. This fact explains the importance of welfare costs in the former.

Furthermore, we show that the contemporaneous correlations between output and labor wedge are countercyclical in the Taylor (-0.285) and Calvo (-0.434) models against -0.68 in the data (Karabarbounis, 2014a). These correlations indicate that the household component of the labor wedge is more important than the firm component in both models (Karabarbounis, 2014b). In that spirit, wage dispersion plays a key determinant role in the transmission mechanism to bring about welfare costs and output losses in the two models as trend inflation increases. This result is consistent with Ascari et al. (2018) and Phaneuf and Victor (2019b). Galí (2011) approaches in the same direction. He produces evidence that the staggered wage setting provides some theoretical foundations to a Phillips-like relation between wage inflation and unemployment.

Third, we introduce two major changes in benchmark models specifications and examine the implications of the results. We first add financial frictions in the form of extended working capital. The results reveal that welfare costs are higher in the Taylor model with the introduction of a cost channel. Indeed, under this specification, higher trend inflation raises the average nominal interest rate. The latter leads to a direct positive effect on inflation through the extended working capital (cost) channel, given that increasing marginal costs of production feed into increasing product prices of optimally price-adjusting firms (Ravenna and Walsh, 2006; Christiano et al., 2010). However, we notice a different result in the case of the Calvo model. The welfare costs are lower with the cost channel compared to the initial case. Further, we model an asymmetric AR(1) process specification of the trend inflation. The results show that welfare costs with asymmetric trend inflation process are significant compared to the benchmark process in both models.

Fourth, we perform robustness exercises of welfare costs and wage dispersion to a set of parameter values. We show that welfare costs and wage dispersion are more responsive to the variations in trend inflation and trend growth in the Calvo model. In contrast, they are less sensitive in the Taylor model. Also, we notice a strong interaction between trend inflation, trend growth, and wage dispersion in the Calvo model than in the Taylor model, the more trend inflation increases.

Moreover, this sensitivity analysis also reveals that wage dispersion is a key determinant factor. In particular, when trend inflation rises, wages become more dispersed, affect aggregate macroeconomic variables, and have much larger effects on the welfare cost of shifting trend inflation than does price dispersion. However, the magnitude of this impact differs in both models and justifies the difference in welfare costs. (Phaneuf and Victor, 2019b) reach a similar conclusion. They explain that the gap between newly reset wages and outdated nominal wages may be large, inducing costly wage dispersion. It is not the case in the staggered contracting approach of Taylor (1980) in which nominal wages are set for a pre-determined period, imposing zero weight on expected future utilities beyond those of the contract length in the household's reset wage optimization.

Finally, we examine the cyclical implications of shifting trend inflation. We show that a positive shock to the trend inflation increases the cost of production and relative prices which negatively affects real wages, consumption, labor, and output more in the Calvo model than in the Taylor model.

The results of our paper should be of interest to both researchers and policymakers.

Indeed, we expand the existing literature on the welfare cost of shifting trend inflation by proposing the Taylor staggered nominal contracts (Taylor, 1980). Furthermore, we produce evidence that these nominal contracts offer a pertinent alternative in assessing the normative properties of the New Keynesian model compared to the Calvo model (Calvo, 1983).

The paper is organized as follows. In section 4.2, he medium-scale New Keynesian DSGE model is described. Section 4.3 discusses issues related to parametrization, and in 4.4, the goodness of fit of the model is examined. Section 4.5 presents the results and sensitivity analysis. The last section contains closing remarks.

4.2 A Medium-Scale DSGE Model with Shifting Trend Inflation

This section describes our medium-scale New Keynesian DSGE model inspired by Ascari et al. (2018) [2]. The key difference is that we incorporate a Taylor-style staggered price and wage contracts (Taylor, 1980) and endogenize trend inflation which we model as a highly persistent and stationary AR(1) process as in Kozicki and Tinsley (2001), Ireland (2007), Cogley and Sbordone (2008); Cogley et al. (2009), and Nakata (2014).

The model features physical capital accumulation, habit formation in consumption, variable capital utilization, a fixed cost of production, investment adjustment costs, trend growth in investment-specific technology and neutral technology, production networking, and shifting trend inflation. A Taylor rule governs monetary policy, and there are stochastic shocks to the policy rule, neutral productivity, the marginal efficiency of investment, and trend inflation. The full set of detrended equations characterizing the equilibrium conditions are shown in Appendix 4.A.

2. In Ascari et al. (2018), the inflation target is fixed and equal to trend inflation.

4.2.1 Households and Wage-setting

Households

Households maximize expected present discounted value of their lifetime utility function, subject to an inter-temporal budget constraint. Preferences are additively separable in consumption and labor and allow for habit formation in consumption. They own intermediate firms, lend capital services (the product of physical capital and utilization) to firms, and make investment and capital utilization decisions. Capital is predetermined at the beginning of a period, but households can adjust its utilization rate subject to adjustment costs. The household receives nominal dividend payments resulting from the ownership of intermediate-goods-producing firms at the end of each period. Additionally, they hold one-period state-contingent bonds as their financial wealth. Financial markets are assumed to be complete. The problem of an individual household can be written [3] :

$$\max_{C_t, N_t(h), K_{t+1}, B_{t+1}, I_t, Z_t} \quad E_0 \sum_{i=0}^{\infty} \beta^i \left(\ln\left(C_{t+i} - bC_{t+i-1}\right) - \eta \frac{N_{t+i}(h)^{1+\chi}}{1+\chi} \right), \tag{4.1}$$

subject to

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

and

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

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

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

3. Utility is separable, and we assume that households are identical to non-labor choices; hence we will drop the h subscripts in subsequent sections. For detail, see Erceg, Henderson and Levin (2000).

where $0 < \beta < 1$ is a discount factor, $0 < \delta < 1$ a depreciation rate, and $0 \leq b < 1$ is a parameter for habit formation. χ is the inverse Frisch elasticity of labor supply. κ is an investment adjustment cost parameter that is strictly positive. P_t is the nominal price of goods. C_t is consumption, I_t investment, $N_t(h)$ labor input, and K_t physical capital. R_t^k is a nominal rental rate on capital services, and i_t the nominal interest rate. B_t is the stock of nominal bonds with which a household enters a period, and B_{t+1} is a stock of nominal governmental bonds in period t+1. Π_t^n denotes (nominal) profits remitted by firms, and T_t is a lump sum taxes from the government. Z_t is the level of capital utilization, and $a(Z_t)$ is a function mapping utilization of capital into the depreciation rate, with parameters γ_1 and γ_2, providing that $a(1) = 0$, $a'(1) = 0$, and $a''(1) > 0$. $S\left(\frac{I_t}{I_{t-1}}\right)$ is an investment adjustment cost, satisfying $S(g_I) = 0$, $S'(g_I) = 0$, and $S''(g_I) > 0$, where $g_I \geq 1$ is the steady-state growth rate of investment.

The investment-specific term $\varepsilon_t^{I,\tau}$ follows the deterministic trend with no stochastic component [4]:

$$\varepsilon_t^{I,\tau} = g_{\varepsilon^I} \varepsilon_{t-1}^{I,\tau}, \tag{4.2}$$

where g_{ε^I} is the gross growth rate and grows at the gross rate $g_{\varepsilon^I} \geq 1$ in each period [5].

The exogenous variable ϑ_t captures the stochastic marginal efficiency of investment shock:

$$\vartheta_t = (\vartheta_{t-1})^{\rho_I} \exp\left(\sigma_I u_t^I\right), with\ u_t^I \sim iid\,(0,1). \tag{4.3}$$

The autoregressive parameter ρ_I governs the persistence of the process, and satisfies $0 \leq \rho_I < 1$. The shock is scaled by the known standard deviation equal to s_I and u_t^I is the innovation drawn from a mean zero normal distribution.

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4. For more details, see Justiniano, Primiceri and Tambalotti (2011), who have documented the distinction between the two types of investment shocks and their relative importance.

5. With the implicit normalization that it begins at 1 in period 0, i.e., $\varepsilon_0^{I,\tau} = 1$

Wage-setting

Let us consider the problem related to household wage-setting. We assume Taylor-style staggered wage contracts (Taylor, 1980) and no indexation. There are T_w equally sized household cohorts. Each contract duration is fixed for T_w periods, with a fraction $1/T_w$ of nominal wages being updated each period. The optimal wage $W_t(h)$ is obtained by maximizing:

$$E_t \sum_{i=0}^{T_w-1} (\beta)^i \left(-\frac{\eta}{1+\chi} \left(N_{t+i}(h)\right)^{-\sigma(1+\chi)} + \lambda_{t+i} W_t(h) N_{t+i}(h) \right), \tag{4.4}$$

subject to

$$N_{t+i}(h) = \left(\frac{W_t(h)}{W_{t+i}}\right)^{-\sigma} N^d_{t+i},$$

The first-order condition implies that all households will choose the same reset wage, denoted in real terms, w^*_t, and given by:

$$w_t^{*1+\sigma\chi} = \frac{\sigma}{\sigma-1} E_t \frac{\sum_{i=0}^{T_w-1} \beta^i \eta \pi_{t+1,t+i}^{\sigma(1+\chi)} w_{t+i}^{\sigma(1+\chi)} N_{t+i}^{1+\chi}}{\sum_{i=0}^{T_w-1} \beta^i \pi_{t+1,t+i}^{\sigma-1} w_{t+i}^{\sigma} \lambda^r_{t+i} N_{t+i}}, \tag{4.5}$$

where λ^r_t is the marginal utility of an additional unit of real income received by the household, and $\pi_{t+1,t+h}$ is cumulative inflation between t and $t+h-1$.

After simplifying, we ca write the expression:

$$w^*_t = \frac{\sigma}{\sigma-1} \frac{h_{1,t}}{h_{2,t}}, \tag{4.6}$$

and the terms $h_{1,t}$ and $h_{2,t}$ evolve recursively as follows

$$h_{1,t} = \sum_{i=0}^{T_w-1} \eta \beta^i \left(\frac{w_{t+i}}{w_t{}^*}\right)^{\sigma(1+\chi)} \pi_{t+1,t+i}^{\sigma(1+\chi)} N_{t+i}^{1+\chi}, \tag{4.7}$$

$$h_{2,t} = \sum_{i=0}^{T_w-1} \beta^i \pi_{t+1,t+i}^{(\sigma-1)} \left(\frac{w_{t+i}}{w_t{}^*} \right)^{\sigma} \lambda_{t+i}^r N_{t+i}. \tag{4.8}$$

4.2.2 Firms and Price-setting

Firms' production takes place in two phases. First, there is an infinitude of intermediate goods firms, each producing a differentiated material input under monopolistic competition using a production function with Cobb-Douglas technology and fixed costs. They set Taylor's nominal price contracts. Final goods producers then combine these inputs intermediate inputs according to a CES technology into output, which they put up for sale to households under perfect competition.

Intermediate Producers

Each intermediate-good firm, indexed by j, uses $\widehat{K}_t(j)$ [6] units of capital services, $N_t^d(j)$ units of labor, and intermediate inputs, $\Upsilon_t(j)$, to produce $X_t(j)$ units of the intermediate good j. Its production function is given by :

$$X_t(j) = \max\left\{ A_t \Upsilon_t(j)^{\phi} \left(\widehat{K}_t(j)^{\alpha} N_t^d(j)^{1-\alpha} \right)^{1-\phi} - \Psi_t \bar{Z}, 0 \right\}, \tag{4.9}$$

where $\phi \in (0,1)$ is the intermediate input share while $\alpha \in (0,1)$ and $(1-\alpha)$ are value-added share to capital services and labor inputs, $\bar{Z}$ is a fixed cost that is identical across firms. It is chosen so that steady-state profits equal to zero, given a growth factor Ψ_t.

The neutral technology A_t follows a process with both trending and stationary component :

$$A_t = A_t^{\tau} \widetilde{A}_t, \tag{4.10}$$

where the deterministic trend component A_t^{τ} grows at the gross rate $g_A \geq 1$ in each

6. It is the product of utilization and physical capital

period [7] such that :

$$A_t^{\tau} = g_A A_{t-1}^{\tau}. \tag{4.11}$$

The stochastic process driving the detrended level of technology $\widetilde{A}_t$ is given by

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(\sigma_A u_t^A\right), \tag{4.12}$$

The auto-regressive parameter ρ_A governs the persistence of the process and satisfies $0 \leq \rho_A < 1$. The shock is scaled by the known standard deviation equal to σ_A and u_t^A is the innovation, drawn from a mean zero normal distribution.

Profit Maximization and Price Setting

The producer of differentiated goods j is assumed to set its price, $P_t(j)$, according to Taylor pricing (Taylor, 1980) and decide in every period its quantities of intermediates, capital services, and labor input. Each period a fraction of $1/T_p$ firms reset their price for T_p periods. The cost of the intermediate is just the aggregate price level, P_t. The user cost of capital and labor are R_t^k and W_t (in nominal terms), respectively.

The cost-minimization problem of a typical firm choosing its inputs is given by :

$$\min \quad P_t \Upsilon_t(j) + R_t^k \widehat{K}_t + W_t N_t^d(j) \tag{4.13}$$

subject to

$$A_t \Upsilon_t(j)^{\phi} \left(\widehat{K}_t(j)^{\alpha} N_t^d(j)^{1-\alpha}\right)^{1-\phi} - \Psi_t \bar{Z} \geq \left(\frac{P_t(j)}{P_t}\right)^{-\theta} X_t$$

There are T_p firm cohorts of equally size with T_p-period price contracts. Each intermediate producing firm chooses its price $P_t(j)$ that maximizes the expected present

7. With the implicit normalization that it begins at 1 in period 0 i.e $A_0^{\tau} = 1$

discount value of its future profit. The firm problem is given by :

$$\max_{P_t(j)} \quad E_t \sum_{i=0}^{T_p-1} (\beta)^i D_{t,t+i} \left(P_t(j) X_{t+i}(j) - V(X_{t+i}(j))\right) \tag{4.14}$$

subject to

$$X_{t+i}(j) = \left(\frac{P_t(j)}{P_{t+i}}\right)^{-\theta} X_{t+i}$$

where $D_{t,t+i}$ is the discount rate for future profits and $V(X_t(j))$ is the total cost of producing good $X_t(j)$. Note that $D_{t,t+i} = \frac{\beta^i \lambda_{t+i}}{\lambda_t}$. Written in real terms, it is $\frac{P_{t+i} D_{t,t+i}}{P_t}$. Hence, the real discount factor is $\frac{\beta^i P_{t+i} \lambda_{t+i}}{P_t \lambda_t}$, which we can write as: $\frac{\beta^i \lambda^r_{t+i}}{\lambda^r_t}$, where $\lambda^r_t = P_t \lambda_t$. The first-order condition for $p^*_t(j)$ is :

$$p^*_t(j) = \frac{\theta}{\theta - 1} E_t \frac{\sum_{i=0}^{T_p-1} (\beta)^i \lambda^r_{t+i} mc_{t+i}(j) \pi^{\theta}_{t+1,t+i} X_{t+i}}{\sum_{i=0}^{T_p-1} (\beta)^i \lambda^r_{t+i} \pi^{\theta-1}_{t+1,t+i} X_{t+i}}, \tag{4.15}$$

where $p^*_t(j) = \frac{P_t(j)}{P_t}$ is the real optimal price and mc_t the real marginal cost, which is equal to $\frac{V'(X_{t+i}(j))}{P_{t+i}}$.

Since all updating firms will choose the same reset price, the optimal reset price relative to the aggregate price index becomes $p^*_t \equiv \frac{P^*_t}{P_t}$. Then the optimal pricing condition becomes :

$$p^*_t = \frac{\theta}{\theta - 1} \frac{m_{1,t}}{m_{2,t}}, \tag{4.16}$$

where $m_{1,t}$ and $m_{2,t}$ are auxiliary variables and can be written recursively as

$$m_{1,t} = \sum_{i=0}^{T_p-1} \beta^i \lambda^r_{t+i} mc_{t+i} \pi^{\theta}_{t+1,t+i} X_{t+i}, \tag{4.17}$$

$$m_{2,t} = \sum_{i=0}^{T_p-1} \beta^i \lambda^r_{t+i} \pi^{\theta-1}_{t+1,t+i} X_{t+i}. \tag{4.18}$$

The term λ_t^r in these equations is the marginal utility of an additional unit of real income received by households, and X_t is the aggregate gross output.

4.2.3 Monetary Policy

Monetary policy consists of a Taylor rule that includes time-varying target inflation. It responds to the inflation gap, $\frac{\pi_t}{\bar{\pi}_t}$, and deviations of output growth, $\frac{Y_t}{Y_{t-1}}$, from its trend level, g_{Ψ}.

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i} \left[\left(\frac{\pi_t}{\bar{\pi}_t}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y_{t-1}} g_{\Psi}^{-1}\right)^{\alpha_y}\right]^{1-\rho_i} \varepsilon_t^r, \tag{4.19}$$

where $\bar{\pi}_t$ is time-varying target inflation, i the steady-state level of i_t. $\varepsilon_t^r \sim iid\left(0, \sigma_{\varepsilon^r}^2\right)$ is a shock to the policy rule. The interest rate smoothing parameter is given by ρ_i, and α_π, and α_y are the control parameters. To ensure determinacy, we assume that $0 \leq \rho_i < 1$, $\alpha_\pi > 1$ and $\alpha_y \geq 0$.

Following Kozicki and Tinsley (2001), Ireland (2007), Cogley et al. (2009), and Nakata (2014), we model time-varying trend inflation as a stationary and highly persistent AR(1) process.

$$\ln(\bar{\pi}_t) = (1-\rho_{\bar{\pi}})\ln(\bar{\pi}^*) + \rho_{\bar{\pi}} \ln(\bar{\pi}_{t-1}) + \sigma_{\bar{\pi}} u_t^{\bar{\pi}}, \tag{4.20}$$

where $0 < \rho_{\bar{\pi}} < 1$, $\bar{\pi}$ steady-state trend inflation and $u_t^{\bar{\pi}}$ a shock to trend inflation, $\sim iid\left(0, \sigma_{\bar{\pi}}^2\right)$.

4.2.4 Measuring Welfare Costs

We consider the approach taken by Sims (2013), and Ascari et al. (2018) by using a second-order approximation and directly calculate the value function of the unconditional expected utility of the representative household. The value function of the h^{th}

household is given by:

$$V_t(h) = \ln(C_t - bC_{t-1}) - \eta \frac{N_t(h)^{1+\chi}}{1+\chi} + \beta E_t V_{t+1}(h), \tag{4.21}$$

Given household heterogeneity in labor supply, we assume that a central bank's welfare function is equal to the sum of welfare across households, as in Erceg et al. (2000).

The consumption-equivalent welfare loss measures the welfare cost of shifting trend inflation, ψ, as the constant fraction of consumption that makes households in an economy with no variation in trend inflation as well-off as the one in another economy with variation in trend inflation (Nakata, 2014). Specifically, we define a measure of consumption-equivalent welfare loss [8] based on stochastic means ψ_m. It can be written:

$$\psi_m = 1 - \exp\left[(1-\beta)\left(E\left(V_A^m\right) - E\left(V_B^m\right)\right)\right], \tag{4.22}$$

where B stands for a constant trend inflation economy [9] ($\sigma_{\bar{\pi}} = 0$) and A is the alternative case i.e an economy with time-varying trend inflation ($\sigma_{\bar{\pi}} > 0$). $E(.)$ is the unconditional expectations operator.

4.3 Parametrization

To solve the model, we use the calibration procedure. Table 4.1 lists key standard parameter estimates in line with existing literature. These parameter values are calibrated to match features of U.S. data over the sample period 1960:1-2007:3.

The factor of discount, (β), is equal to 0.99, and the depreciation rate on physical capital (δ) is set to 0.025 consistent with an annual rate of 10 percent. The share of capital services (α) is equal to $1/3$, the scaling parameter on disutility from labor (η) to 6 and the inverse Frisch elasticity of labor supply (χ) is set to 1. Consumption habit

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8. For more details, see Ascari et al. (2018).

9. The baseline case, i.e., with no variation in trend inflation.

formation (b) is equal to 0.8 (Fuhrer, 2000) and the value of investment adjustment cost (κ) to 3 (Christiano, Eichenbaum and Evans, 2005). The squared term in the cost of utilization (γ_2) is set to 0.05 to match the capital utilization elasticity of 1.5 (Basu and Kimball, 1997; Dotsey and King, 2006). The linear term (γ_1) is set to 0.0457 so that steady-state utilization is equal to 1.

The elasticity parameters of demand for intermediate goods (θ) and labor (σ) are set to a uniform value of 6, implying a steady-state price and wage markups of 20 percent with zero trend inflation (Liu and Phaneuf, 2007). Following Nakamura and Steinsson (2010), the weighted average revenue share of intermediate inputs in the U.S. private sector using the Consumer Price Index (CPI) expenditure weights is roughly 51% in 2002. So the cost share of intermediate inputs is equal to this revenue share times the markup. Thus, with a theta-value of 6, this implies a price markup of 1.2 and a weighted average cost share of intermediate inputs (ϕ) of 0.61. The fixed cost of production $(\bar{Z})$ is set to 0.0183 so that profits equal to zero in the steady-state.

Like in Dixon and Kara (2006), we compare the average age of Taylor contracts with an average of Calvo [10]. The link between them is given by $T_x = \frac{(1+\xi_x)}{1-\xi_x}$ where $x = (p, w)$, T_x the number of contract-periods of variable x, and $1 - \xi_x$ the Calvo probability of re-optimization of x. The Calvo price (ξ_p) is set to 0.66, and the Calvo wage (ξ_w) to 0.75 consistent with Phaneuf and Victor (2019b). Hence, the baseline basis of comparison with Taylor contracting in terms of the average age of nominal contracts is $T_p = 5$ and $T_w = 7$.

We assume that firms have to borrow the entirety of their factor payments each period. Thus, we define γ_l, $l = \Upsilon, K, N$, as the fraction of payments to a factor, and set $\gamma_l = 1$ for all l. We refer to this case as extended working capital [11]. Phaneuf et al. (2018) show that this form of extended borrowing can help models generate hump-shaped inflation dynamics conditional on a monetary policy shock without relying on backward price and wage indexation. For monetary policy rule, the smoothing coeffi-

10. Refer to previous chapters for Calvo specification.

11. See appendix 4.B for full specification.

cient (ρ_i) enters with a weight of 0.8, the coefficient on inflation (α_π) with a weight of 1.5, and the coefficient on output growth (α_y) weights of 0.2. These values are standard in the literature.

Following Ascari et al. (2018), trend growth and inflation are calibrated to fit the data's observable features. The average growth rate of the price index over the period 1960:I-2007:III is 0.008675. It implies a steady-state level of trend inflation of 3.52 percent annualized (i.e., $\pi^* = 1.0352^{0.25}$). The output per capita's average growth rate, over the same period, is 0.005712, which corresponds to an output growth rate of $g_Y = 1.005712$ or 2.28 at an annual frequency. The average growth rate of the relative price of investment over the period is -00472. It suggests the value of $g_I = 1.00472$. Given the values of g_I and ϕ, we set gross growth to neutral productivity (g_A) equal to 1.0022 $(i.e., g_A^{1-\phi} = 1.0022)$ to generate the appropriate output volatility observed in the data.

The model features four shocks: to neutral technology(σ_A), the marginal efficiency of investment (σ_I), monetary policy (σ_r), and trend inflation $(\sigma_{\bar{\pi}})$. All these shocks follow an AR(1) process with persistence parameters and standard deviations. For the shock sizes, we proceed as follows. Given the growth rate of real GDP and trend inflation, we set shocks to match output growth volatility over the sample period. It requires taking a stand on the percentage contribution of each type of shocks to output growth volatility. We set the marginal efficiency of investment shock contribution to 50 percent of output volatility based on evidence produced by Justiniano et al. (2011) and others (Fisher, 2006a; Justiniano and Primiceri, 2008a; Justiniano et al., 2010b; Altig et al., 2011), 35% for the neutral technology, 10% for the monetary policy shock and 5% for the shock to the trend inflation.

Consistent with the literature, we set the AR(1) coefficients of investment (ρ_I) to 0.81 and of neutral technology (ρ_A) to 0.95. For the persistence of the trend inflation process (ρ_π), we set the AR(1) coefficient to 0.95 [12]. The corresponding volatility for different shocks is shown in table 4.1.

12. Cogley et al. (2009) and Nakata (2014) set it to 0.995, and we find it to be highly persistent.

4.4 Second Moments Analysis

This section focuses on the goodness of fit of the Taylor and Calvo models to assess their empirical relevance. We express all series in per capita, [13] transformed into real terms, then into natural logs to approximate their percentage changes. The consumption and investment series [14] are from the U.S. Bureau of Economic Analysis (BEA) accounts. The growth rate of the price index is referred to as inflation. The nominal interest rate is the effective Federal Funds rate set by the Federal Open Market Committee (FOMC). The total hours worked measures total hours worked in the non-farm business sector from the U.S. Bureau of Labor Statistics (BLS). The sample period includes 1960:1-2007:3.

Table 4.2 reports selected model-generated unconditional moments for both models. These moments are first-order differenced to facilitate comparison with unconditional data moments. In particular, we report the standard deviation (volatility), contemporaneous correlations, and the first order and second auto-correlation (persistence).

The empirical standard deviation of consumption growth $(\sigma(\Delta C))$ deviates about 0.47 percent from its mean value in the data against 0.38 percent in the Calvo and 0.29 percent in the Taylor models. For investment growth, the magnitude of its variability $(\sigma(\Delta I))$ is about 2.02 in the data, 1.76 percent in the Calvo model against 2.08 percent in the Taylor model. The estimated average percentage deviation of first-differenced hours $(\sigma(\Delta N))$ almost matches the data in both cases. Overall, we denote that in both models, investment growth is about two times more volatile than output growth and that the latter is more volatile than consumption growth. The first-differenced total hours worked is about as volatile as the output growth.

For contemporaneous correlation, the results in table 4.2 show that the comovement between output growth and first-differenced total hours ($\rho(\Delta Y, \Delta N)$) is high and

13. By dividing by the civilian non-institutionalized population aged 16 and over.

14. We compute the real GDP and its growth rate following the procedure in Ascari et al. (2018). See their appendix for more details.

positive in both models. The correlation between investment growth and output growth $(\rho(\Delta Y, \Delta I))$ is displaying a clear positive comovement but slightly greater than in the data in both cases. Furthermore, we observe a procyclical correlation between consumption growth and output growth in both models. For the correlation between consumption growth and investment growth, although positive, is slightly greater in the Calvo model (0.4964) compared to the Taylor model (0.211).

We further focus on the matching of comovements between nominal and real variables, which are countercyclical in the data. The Taylor model does better than Calvo model in matching the sign of correlations between investment growth and inflation $(\rho(\Delta I, \pi))$, first-differenced hours and inflation $(\rho(\Delta N, \pi))$, output growth and interest rate $(\rho(\Delta Y, i))$, consumption growth and interest rate $(\rho(\Delta C, i))$, investment growth and interest rate $(\rho(\Delta I, i))$, and first-differenced hours and interest rate $(\rho(\Delta N, i))$. However, the Calvo model predicts these comovements as weakly procyclical except for the correlation between output growth and interest rate.

The degree of persistence of output growth $(\rho_1(\Delta Y))$ is somewhat higher in both models 0.69 in the Calvo model and 0.65 in the Taylor model) relative to the data (0.363). This feature gives an idea of the strength of the endogenous business-cycle propagation mechanisms incorporated in the two models (Cogley and Nason, 1995). We also observe that the empirical coefficient of the first-order autocorrelation in inflation $(\rho_1(\pi))$ is slightly higher in the Taylor model (0.9666) relative to the data (0.9071), while it almost matches in the data in the Calvo model (0.8882). For the nominal interest rate $(\rho_1(i))$ the Calvo model (0.9557) is very close to the data (0.9521) and does better than the Taylor model (0.9779).

In summary, we note that modeling trend inflation as an exogenous process improves the volatilities of inflation and interest rates match in the data and do better than in the constant trend inflation framework [15]. Furthermore, in Phaneuf and Victor (2019b), both models imply that the comovement between first-differenced hours and inflation is positive, nearly 0 for the Taylor model, and moderately positive for the

15. See Phaneuf and Victor (2019b) for more details on the constant trend inflation framework.

Calvo model while it is negative in the data. However, in the shifting trend inflation framework, the Taylor model predicts this correlation is countercyclical. We also note that for the volatility of first-differenced hours, both models match in the data. Overall, the two models take into account some key properties of the aggregate data and the usual aspects of the business cycle.

4.5 Results

This section examines issues related to welfare costs of shifting trend inflation under Taylor and Calvo staggered nominal contracts. We first analyze some normative aspects (i.e., its welfare) of time-varying trend inflation (4.5.1) and then examine its cyclical implications (4.5.2).

4.5.1 Welfare Effects

To measure the welfare effects, we consider the consumption-equivalent welfare loss [16] metric based on stochastic means denoted ψ_{mc} for the Calvo model and ψ_{mt} for the Taylor model. Additionally, we are also interested in output loss conditioned on stochastic means (denoted ψ_{yt} for the Taylor model and ψ_{yc} for the Calvo model) as a measure of the negative effect of trend inflation on output (Ascari and Sbordone, 2014; Phaneuf and Victor, 2019a). Furthermore, based on the evidence produced by Golosov and Lucas Jr (2007) and Alvarez et al. (2019) as reported in Phaneuf and Victor (2019b) that the average age of nominal wage and price contracts is not affected by the level of trend inflation ranging from 0 to 8%, we take it for granted and assume it invariant in our models.

In what follows, we first discuss the welfare effects and output losses conditioned on stochastic means of constant non-zero trend inflation and then those of shifting trend inflation). We further assess whether adding in financial frictions or modeling alternative specification of the trend inflation process will modify the results. Finally, we will

16. How much one would have to give up in the baseline to have the same welfare in the alternative.

conduct a number of robustness exercises.

Constant Non-Zero Trend Inflation

Table 4.3 describes the welfare costs and output losses conditioned on stochastic means in the 0 - 2% and 2 - 4% inflation bands [17] for the Taylor and Calvo models. Both models feature nominal frictions in the goods and labor markets, shifting trend inflation, production networking, and trend growth, among others. As such, they nest different model specifications and we examine three of them: nominal price and wage contracts, nominal price contracts and nominal wage contracts.

The results of both nominal price and wage contracts model (ξ_p=0.66, ξ_w=0.75, N_p=5, N_w=7, ϕ=0.5 and Trend Growth) are reported in Table 4.3. It indicates that the welfare cost of going 0 to 2% is 3.6% and the output loss is 3.1% in the Calvo model. These features are substantially smaller in the Taylor model: 0.66% for the welfare cost and 0.61% for the output loss. The same observation can be made when increasing trend inflation from 2 to 4%. The consumption-equivalent welfare loss is increased by 9.19% in the Calvo model while it is about 1.112% in the Taylor model. The corresponding output losses are 8.125% against 1.0634% respectively.

Two key features of these results are worth mentioning. We first notice that the welfare costs and output losses vary with the level of trend inflation in both models. To be more specific, an increase in the steady-state level of trend inflation results in an increase in the welfare cost and output loss when trend inflation passes from 0 to 2% and from 2% to 4%. This impact is much larger in the Calvo model than in the Taylor. Second, the welfare costs and output losses of trend inflation are significantly higher with the Calvo model than with the Taylor model.

In line with the first observation, Ascari et al. (2018) argued that rising trend inflation by 2% is more costly from 2-4% than from 0-2%. Nakata (2014) went further and

17. Within inflation bands, we compare an economy in which trend inflation is constant at 0% to the one in which trend inflation is constant at 2%. Likewise, an economy at 2% constant trend inflation to the one at 4%.

spoke of a nonlinear relationship between trend inflation and welfare cost. The same is true of output loss. This nonlinearity can also be noticed when taking into account alternative model specifications: no production networking (No PN), no trend growth (No Growth), and both no production networking and trend growth (No PN - Growth). In particular, we note that when we remove the trend growth from the nominal price and wage contracts model (No Growth), the welfare costs and output losses values significantly reduced in both inflation bands 0 - 2% and 2 - 4% for the Taylor and Calvo models. We will return to this aspect later in the text.

In what follows, we are interested in understanding the effects of nominal contracts either in price or wage on the consumption-equivalent welfare loss and output loss. Table 4.3 displays results of both nominal price contracts (ξ_p=0.66, ξ_w=0, N_p=5, N_w=0) and nominal wage contracts (ξ_p=0, ξ_w=0.75, N_p=0, N_w=7) models. The welfare cost and output loss in the nominal price contracts are smaller and modest both in the Taylor and Calvo models compared to the nominal wage contracts. This is consistent with Nakata (2014) and Phaneuf and Victor (2019b) who also find modest welfare costs when wages are flexible.

To understand this last result, we refer to Table 4.4 on price and wage dispersion in the constant trend inflation economy. When trend inflation is in the inflation band of 0 to 2%, price dispersion is about 0.04% in the mean, and it passes to 0.09% in the trend inflation of 2% to 4% in the Calvo model. These figures are 0.02% and 0% respectively in the Taylor model. Thus, in both models price dispersion is weakly correlated with trend inflation and this explains the modest cost of constant trend inflation when wages are flexible. These findings are consistent with the evidence produced by Nakamura et al. (2018).

The results are different when it comes to wage dispersion in the nominal wage contracting models. For the Calvo model, we find that steady-state wage dispersion amounts to 2.12% and mean dispersion to 2.77% when the inflation band is between 0 to 2%. For the inflation band of 2% to 4%, these figures are 10.04% and 11.36%, respectively. However, in the Taylor model, we observe that steady-state wage dispersion is about 1.9% and mean wage dispersion amounts to 2.11% in the inflation band of 2% to 4%.

With 0 to 2% trend inflation, steady-state wage dispersion and mean dispersion are 0% (Table 4.4). Overall, we observe that wage dispersion is very sensible to the level of trend inflation than price dispersion, and particularly in the Calvo model. This fact also explains why the welfare costs of trend inflation and output losses are higher with the Calvo model than with the Taylor model.

The analysis of constant trend inflation highlights the nonlinear relationship between welfare cost and trend inflation, as well as the relative role of wage and price dispersion in the two contracting models. This analysis opens the way to understanding the source of welfare costs of shifting trend inflation, which we examine in the next section.

Shifting Trend Inflation

The constant trend inflation case highlights the nonlinear relationship between welfare cost and trend inflation, as trend inflation augments. In the shifting trend inflation, trend inflation is modeled as an exogenous shock process and affects the point around which the model is log-linearly approximated (Nakata, 2014).

Table 4.5 compares an economy in which the standard deviation of shocks to trend inflation is positive ($\sigma_\pi > 0$) to an economy in which it is zero ($\sigma_\pi = 0$) in both the Calvo and Taylor models. Following Nakata (2014), we set the steady-state level of trend inflation to 2 percent annualized (i.e., $\pi^* = 1.02^{0.25}$) in both economies. We assess whether the transmission channel is through price dispersion or wage dispersion and how it brings about the welfare cost and output loss in both contracting models.

The consumption-equivalent welfare loss in the Calvo nominal price and wage contracts model is about 7.81% and 5.76% for the output loss. In the Taylor model, these features are 1.07% and 0.87% respectively. The welfare cost and output loss are lower in the no trend growth assumption as trend inflation increases, with a larger impact in the Calvo model. Whereas in the Taylor model, these features decrease when we assume that there is no production networking (Table 4.5).

When wages are flexible i.e. the nominal price contracts (ξ_p=0.66, ξ_w=0, N_p=5, N_w=0), consumption-equivalent welfare loss with price rigidity is smaller and about 0.40% in the Calvo model against 0.19% in the Taylor model. The output loss amounts to 0.33% and 0.16% respectively (Table 4.5). We find that the results are smaller and modest but much more in the Taylor model than in the Calvo model. This is due to the fact that steady-state price dispersion is about 0.05% in the Calvo model against 0.01% in the Taylor model. The mean price dispersion amounts to 0.06% and 0.03% respectively as described in Table 4.6, under 2% trend inflation and *SP* column. We find that price dispersion is sensitive to changes in inflation in the Calvo model compared to the Taylor model. In line with this, Nakata (2014) advocates a class of state-dependent pricing models with the endogenous frequency of price adjustment than in the Calvo model. Nakamura, Steinsson, Sun and Villar (2018) also reach a similar conclusion.

Moreover, when we remove production networking from the nominal price contracts specification, the welfare cost decreases down to 0.18% in the Calvo model and 0.085% in the Taylor model. While it is about 0.398% and 0.187% respectively when we assume there is no trend growth. We find that production networking plays an important role in the nominal price contracts compared to the no trend growth case. The main reason is that production networking serves as an amplification source for real shocks resulting in more volatility [18], which tends to make an increase in trend inflation more costly.

The results are very different when prices are flexible i.e., in the nominal wage contracts (ξ_p=0, ξ_w=0.75, N_p=0, N_w=7). The welfare cost of shifting trend inflation is about 7.5% and 0.90% respectively in the Calvo and Taylor models. The output loss amounts to 5.50% and 0.72% respectively. These results are larger in the Calvo model compared to the Taylor model. Indeed, Table 4.6 reports under 2% trend inflation and SW column that, steady-state wage dispersion is about 10.04% in the Calvo model and 0.01% in the Taylor model. The mean wage dispersion is 11.41% and 0.07% respectively. We find that wage dispersion is too sensitive to changes in inflation in the Calvo model than in the Taylor model. This fact explains the importance of welfare

18. i.e. price stickiness multiplier in line with Basu (1995).

costs in the former.

However, when we assume that there is no trend growth, these costs lower from 7.5% down to 2.97% in the Calvo model but not in the Taylor model. Likewise, the output loss decreases from 5.49% to 2.27% in the Calvo model but not in the Taylor model. We find that trend growth plays an important role in the Calvo model and has relatively no impact on the welfare cost in the Taylor model. This can be explained by the fact that in the Calvo model, as trend inflation gets higher, inefficiencies in labor wedge grow larger and are welfare-reducing. More importantly, trend growth interacts with nominal rigidity in labor to produce volatile wage dispersion higher than average wage markups (see Table 4.6, column SW) which in turn, results in large welfare costs.

In summary, wage dispersion plays a substantial role in the transmission mechanism and has implications on the welfare costs and output losses as trend inflation increases in both models. However, the impact is much greater in the Calvo model than in the Taylor model, since the extent of wage dispersion differs. We find that wage dispersion is very sensitive to changes in trend inflation in the Calvo model. In the next point, we are interested in understanding whether adding financial frictions would affect the results found so far.

Adding a Cost Channel

We examine the welfare implications of adding financial frictions in the form of extended working capital [19] (hereafter EWC) channel in which firms need to finance in advance the costs of all of their variable inputs and not just the wage bill.In fact, this induces the need for credit from a financial intermediary. The intuition behind extended working capital is that it introduces a cost channel to identify a supply-side transmission mechanism (supply-driven fluctuations) for monetary policy as the nominal interest rate now affects the marginal cost (Fuerst, 1992; Barth III and Ramey, 2002; Christiano et al., 1997, 2005). Therefore, we wonder whether this can affect the results found so far. Full details on adding financial friction are presented in appendix 4.B.

19. For the specification of financial frictions, see appendix 4.B.

Table 4.8 reports the welfare costs and output losses of shifting trend inflation with EWC in the Taylor and Calvo models. The consumption-equivalent loss is around 1.25% and 1.02% for the output loss in the Taylor nominal price and wage contracts model. By comparison to the results in Table 4.5, we find that the welfare cost with EWC (1.25%) is greater than that of the case without EWC (1.07%). This is because, under our baseline specification featuring extended working capital, higher trend inflation raises the average nominal interest rate. This rise of the average nominal interest rate has a direct positive effect on inflation through the extended working capital (cost) channel, given that increasing marginal costs of production feed into increasing product prices of optimally price-adjusting firms (Ravenna and Walsh, 2006; Christiano et al., 2010). This rise is a direct distortion on the first-order conditions for optimal inputs. As a result, extended working capital has to raise welfare costs.

However, the results are different in the Calvo model. The welfare cost in the case with EWC (Table 4.8) is lower than in the case without EWC (Table 4.5). Indeed, the consumption-equivalent loss is about 4.15% in the former against 7.81% in the latter. The output loss is 3.10% with EWC and 5.76% without EWC. Furthermore, we find that the economy with EWC features less volatility than the economy without EWC conditioned on shocks. As a result, this affects welfare costs based on means in the former.

It's worth mentioning that for the parameters governing the shock process, we calibrated the standard deviations so as to match the observed volatility of per capita output growth and the specified variance decomposition in both models. The alternative proportions of variance decomposition give the same result, that is to say, that welfare costs are higher in the economy without EWC than in that with EWC in the Calvo model.

Given the specified variance decomposition, a plausible explanation could be that the Calvo model is very sensitive to changes in inflation compared to the Taylor model. Therefore, by increasing the interest rate, extended working capital induces a negative effect on inflation through negative effects operating on output. This negative effect dominates over the cost channel mechanism and exerts pressure on inflation volatility.

The latter in turn, lowers the welfare cost of shifting trend inflation with extended working capital (Ravenna and Walsh, 2006; Christiano et al., 2010). Whereas in the Taylor case, it is the cost channel mechanism that dominates. Next, we consider an asymmetric specification of the trend inflation process and assess whether this can change current results.

A Modified Process for Trend Inflation

In the baseline specification in equation (4.20), trend inflation evolves symmetrically around 3.52 percent steady-state level, the average rate over the period 1960:1-2007:3. As trend inflation increases over time, this symmetric assumption may not be realistic (Nakata, 2014). Therefore, we consider an asymmetric trend inflation [20] process given by

$$\ln\left[\bar{\pi}_t - 1\right] = \left(1 - \rho_{\bar{\pi}}\right)\ln\left[\bar{\pi}^* - 1\right] + \rho_{\bar{\pi}}\ln\left[\bar{\pi}_{t-1} - 1\right] + \sigma_{\bar{\pi}} u_t^{\bar{\pi}} \tag{4.1}$$

where $u_t^{\bar{\pi}} \sim iid\left(0, \varpi\sigma_{\bar{\pi}}^2\right)$ with ϖ a constant chosen so that the variance of trend inflation is the same as in equation (4.20).

The consumption-equivalent welfare losses of shifting trend inflation are larger under the modified process (Tables 4.9 and 4.10) than under the benchmark process (Tables 4.5 and 4.8) by construction. Indeed, under the modified trend inflation process, the variation in trend inflation also increases the average level of trend inflation.

In the following, we compare the welfare costs and output losses of an economy with EWC (Table 4.10) to those of an economy without EWC (Table 4.9) under the modified trend inflation process.We find that in the Taylor model, welfare costs of shifting trend inflation are higher in the economy with EWC than in the economy without EWC as in the benchmark process case. Likewise, in the Calvo model, welfare costs are lower in the economy with EWC than in the economy without EWC. Therefore, the

20. In which the instability in trend inflation is associated with an increase in the average trend inflation and the inflation rate is bounded to be positive as suggested by Nakata (2014).

asymmetric specification of the trend inflation process does not affect the results found in the benchmark case.

Sensitivity Analysis

In our results, we find that welfare costs and output losses are higher in the Calvo model than in the Taylor model, as trend inflation level increases. We also find that wage dispersion rather than price dispersion plays a key role and it's larger in the Calvo model. In the following, we assess how different values of parameters can affect these features under a given set of assumptions.

We first analyze the sensitivity of welfare costs and set a range of different values for the elasticity of substitution of labor, $\sigma = [4, 6, 8, 10]$, volatility of trend inflation process, $\sigma_{\bar{\pi}} = [0.025, 0.05, 0.075, 0.10]$, its persistence, $\rho_{\bar{\pi}} = [0.9, 0.95, 0.99, 0.995]$, and trend inflation, $\bar{\pi}^* = \left[1.02^{0.25}, 1.04^{0.25}, 1.06^{0.25}, 1.07^{0.25}\right]$. Table 4.11 reports the sensitivity of welfare cost of shifting trend inflation to the elasticity of substitution of labor (σ), volatility of the trend inflation process ($\sigma_{\bar{\pi}}$), its persistence ($\rho_{\bar{\pi}}$), and to the level of trend inflation ($\bar{\pi}^*$) in both the Calvo and Taylor model. With $\sigma = 4$ in the first column, the welfare cost in the Calvo model (ψ_{mc}) is around 2.28% and 0.61% in the Taylor model (ψ_{mt}). When $\sigma = 6$, $\psi_{mc} = 7,81\%$ and $\psi_{mt} = 1.07\%$. With a value of $\sigma = 10$, ψ_{mc} passes to 61.46% while ψ_{mt} is around 2.42%. We observe that the welfare costs in the Calvo model get higher as ψ_{mc} increases compared to ψ_{mt} in the Taylor model.

In the fourth column, we analyze the effect of varying the standard deviation of shocks to trend inflation ($\sigma_{\bar{\pi}}$) on the welfare costs in both models. With $\sigma_{\bar{\pi}} = 0.025$, $\psi_{mc} = 4.06\%$ and $\psi_{mt} = 0.35\%$ the welfare costs in the Calvo and Taylor models respectively. When $\sigma_{\bar{\pi}} = 0.075$, $\psi_{mc} = 31.16\%$ and $\psi_{mt} = 3.09\%$, The welfare costs increase to 48.51% in the Calvo model and 5.42% in the Taylor when $\sigma_{\bar{\pi}} = 0.10$. We find that the consumption-equivalent welfare losses in both models are sensitive to the level of volatility of trend inflation shock but much more in the Calvo model than in the Taylor.

The sensitivity of welfare costs to different values of the persistence of shocks to trend inflation ($\rho_{\bar{\pi}}$) is considered from the seventh column. The welfare costs are from $\psi_{mc} =$

0.25% and $\psi_{mt} = 0.056\%$ for $\rho_{\bar{\pi}} = 0.90$ degree of persistence, up to $\psi_{mc} = 15..16\%$ and $\psi_{mt} = 2.21\%$ with a higher degree of $\rho_{\bar{\pi}} = 0.995$, respectively in the Calvo and Taylor models.

Finally, the tenth column displays the effect of the trend inflation level ($\bar{\pi}^*$) on the welfare costs in both the Calvo and Taylor models. With $\bar{\pi}^* = 2\%$ annualized, the welfare costs are about 0.97% in the Calvo model (ψ_{mc}) and 0.16% in the Taylor model (ψ_{mt}). They go up to $\psi_{mc} = 37.62\%$ and $\psi_{mt} = 0.17\%$ when the level of trend inflation augments to $\bar{\pi}^* = 7\%$ annualized. We observe a nonlinear relationship between the welfare cost of shifting trend inflation and the level of trend inflation as trend inflation increases. This nonlinear relationship is more pronounced in the Calvo model than in the Taylor model.

Let us now turn to the sensitivity analysis of price dispersion and wage dispersion. Table 4.6 reports the sensitivity of price dispersion (s) and wage dispersion (v^w) to changes in trend inflation ($\bar{\pi}^*$). In the Calvo model (Table 4.6, panel SPSW), steady-state price dispersion (s_{ss}) is 0.05% and mean price dispersion (s_m) around 0.06%, under $\bar{\pi}^* = 2\%$. When $\bar{\pi}^* = 4\%$, these features amount to 0.2% and 0.21% respectively. Whereas, steady-state wage dispersion (v^w_{ss}) is 10.04% and mean wage dispersion of about 11.41%, under $\bar{\pi}^* = 2\%$. With $\bar{\pi}^* = 4\%$, steady-state and mean wage dispersion (v^w_m) increase to 33.10% and 37.71% respectively. However in the Taylor model, under $\bar{\pi}^* = 2\%$, panel 'SPSW' in Table 4.6, we observe that steady-state (s_{ss}) and mean (s_m) price dispersion are around 0.01% and 0.03% respectively. When trend inflation is set to $\bar{\pi}^* = 4\%$, these features increase to 0.06% and 0.07% respectively. For wage dispersion, the steady-state (v^w_{ss}) and mean (v^w_m) are 0.01% and 0.07% respectively, under $\bar{\pi}^* = 2\%$. We observe that a rise in $\bar{\pi}^*$ from 2 to 4% leads to an increase in v^w_{ss} from 0.01% to 0.06%, and from 0.07% to 0.12% in v^w_m.

We further examine the role of trend growth (g_Ψ). Table 4.7 shows[21] the sensitivity of price dispersion and wage dispersion to trend growth in the Calvo and Taylor models (SPSW). We observe that the steady-state and mean price dispersion are not

21. Table 4.7 is built from Table 4.6.

affected when we maintain (g_Ψ column) or remove trend growth (No g_Ψ column) from the benchmark models, in both $\bar{\pi}^* = 2\%$ and $\bar{\pi}^* = 4\%$ (Table 4.7). In other words, the results are the same compared to their respective baseline models (SPSW). The same is also true for the steady-state and mean wage dispersion in the Taylor model.

However, the results change with the sensitivity of wage dispersion to trend growth in the Calvo model. Under $\bar{\pi}^* = 2\%$ and column g_Ψ, i.e., when we remove intermediate share (ϕ) from the baseline specification and maintain solely trend growth, steady-state wage dispersion is about the same as in the 'SPSW' column. Whereas the mean wage dispersion changes from 11.41% to 10.93%. In the No g_Ψ column, we consider a no trend growth option. The steady-state wage dispersion decreases to 1.54% and 2.04% for mean wage dispersion compared to the 'SPSW' column 10.04% and 11.41% respectively. Moreover, when $\bar{\pi}^* = 4\%$ in column g_Ψ we observe that steady-state wage dispersion amounts to 33.10% and is about 35.77% for mean wage dispersion against 33.10% and 37.71% respectively in the 'SPSW' column. In the No g_Ψ column, we note 8.03% for steady-state wage dispersion and 9.05% for mean wage dispersion.

Overall, we find that welfare cost and wage dispersion are more sensitive to the changes in trend inflation and trend growth in the Calvo model. Whereas they are less sensitive in the Taylor model. We also note a weak interaction between price dispersion, trend growth and trend inflation as trend inflation increases in both models. However, we observe a strong interaction between trend inflation, trend growth, and wage dispersion in the Calvo model than in the Taylor model, the more trend inflation increases.

4.5.2 Cyclical Implications of Shifting Trend Inflation

In section 4.5.1, the normative aspects of shifting trend inflation have been considered. We now turn to its cyclical implications, the positive aspects, and examine how it affects macroeconomic variables in both the Calvo and Taylor models.

Figure 4.1 plots the average impulse response functions of output, consumption, and investment to shocks of neutral technology, the marginal efficiency of investment, monetary policy and trend inflation in both models. Indeed, in point 4.5.1 we show that in a shifting trend inflation economy the log-linear dynamics of the models adjust. As a result, the persistence and volatility of macroeconomic variables increase. This is what happens to output, consumption, and investment in the Calvo model for neutral technology, the marginal efficiency of investment and monetary policy shocks (Figure 4.1). We find that the magnitude of the impact of these three shocks differs in the Taylor model. This is because the latter is less sensitive to changes in trend inflation than the former as shown in 4.5.1.

However, things are different with shock to the trend inflation as illustrated in Figures 4.1 and 4.2. We find that a positive shock to the trend inflation leads to a larger increase in the level of wage dispersion more than price dispersion when trend inflation is higher. This impacts wages more than the productivity of labor and thereby raises the cost of production (marginal cost). In turn, firms have high relative prices which affect the real wage (labor income). The combined effect of the rise in relative prices and the fall in real wages affects demand for consumption, investment (since the incentive to save decreases), and gives rise to inefficiencies in the allocation of labor input. Therefore, the demand for labor decreases ass some firms adapt to maintain their profit margins. As a result, output falls. Indeed, these negative effects are greater in the Calvo model than in the Taylor model which displays less sensitivity to changes in trend inflation. This is illustrated by the response of inflation which differs at the impact in the two models (Figure 4.2).

Figure 4.3 plots the responses of output, labor wedge, consumption and labor demand to a positive shock to the trend inflation. The panel 'Labor wedge' shows that it varies as trend inflation increases indicating inefficiencies in the allocation of labor input (Sala et al., 2010). In our case, we find that these inefficiencies reflect fluctuations of the gap between the real wage and the marginal rate of substitution (MRS) as the contemporaneous correlations between output and labor wedge are countercyclical in both

Taylor (-0.285) and Calvo (-0.434) models [22] against -0.68 in the US data [23] and -0.25 across countries (Karabarbounis, 2014b). This is also illustrated by the responses of both output and labor wedge in figure 4.3. Furthermore, these countercyclical correlations show that the household component of the labor wedge is more important relative to the firm component in both models. That is to confirm the findings in point 4.5.1 that wage dispersion plays an important role in the transmission mechanism and has many implications than price dispersion as trend inflation increases. However, its magnitude is larger in the Calvo model than in the Taylor model as shown by our model-based coefficients of contemporaneous correlation.

In short, the cyclical analysis of shifting trend inflation in the Calvo and Taylor models shows that a positive shock to the trend inflation results in greater wages dispersion, which in turn, affects aggregate macroeconomic variables more than would price dispersion. However, we observe that the magnitude of these effects differs in both models.

22. These values are computed based on $\xi_p = 0.66$ and $\xi_w = 0.75$ for the Calvo model and $N_p = 5$ and $N_w = 7$ for the Taylor model. However, when we assume that $\xi_p = 0.66$, $\xi_w = 0.66$, $N_p = 5$ and $N_w = 5$, we get for Taylor (-0.2370) and Calvo (-0.2886).

23. For the sample period 1971(1)-2007(4) (Karabarbounis, 2014a).

4.6 Conclusion

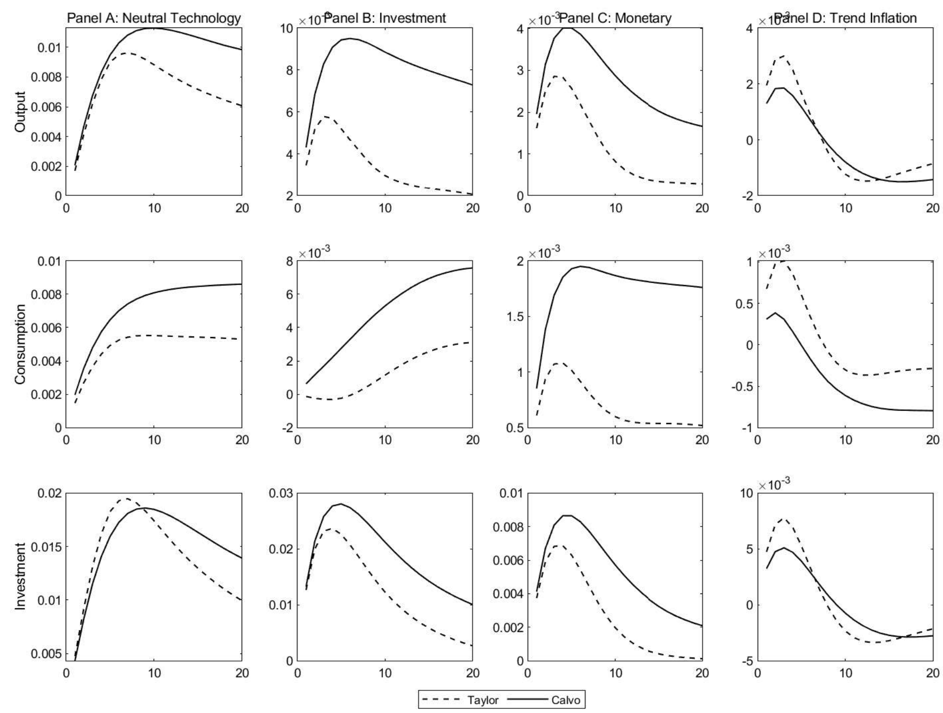
This study examined the welfare effects of the changes in trend inflation. The existing literature used both nominal price contracts and nominal price and wage contracts à la Calvo to discuss this issue. Within these frameworks, welfare costs are very sensitive to the level of trend inflation and variation in key model parameters. Critics advocate other classes of models in which these costs are most likely to be lower. In this perspective, we proposed an alternative nominal contracts model à la Taylor and contrasted its results with those à la Calvo. We then look at the main transmission channel and how it leads to welfare costs and output losses in the two models. We further considered cyclical implications.

The results showed that welfare costs are smaller and modest in the Taylor model and that the latter is immune to variation in trend inflation, unlike the Calvo model. Furthermore, we find that wage dispersion is a key determinant factor in the transmission mechanism to bring about welfare costs and output losses in the two models. Next, we examined the implications of adding financial frictions in the form of extended working capital and modeling an asymmetric specification of the trend inflation process on these results. The results reveal that welfare costs are higher with the introduction of a cost channel than in the case without, in the Taylor model. However, we notice a counter-intuitive result in the Calvo case. Also, the welfare costs with an asymmetric trend inflation process are significant compared to the symmetrical process but do not affect the nature of the conclusion of the above results.

We also performed robustness exercises on the sensitivity of welfare costs and wage dispersion to a set of parameter values. The sensitivity analysis shows that prices are less dispersed than wages and that welfare costs and wage dispersion are more responsive to the variations in trend inflation and trend growth in the Calvo model. Whereas they are less sensitive in the Taylor model. As a result, welfare costs are lower in the Taylor model than in the Calvo model. Finally, we assessed the cyclical implications of shifting trend inflation. We show that a positive shock to the trend inflation increases the cost of production and relative prices which in turn, negatively affect real wages, consumption, labor, and output much more in the Calvo model than in the Taylor model.

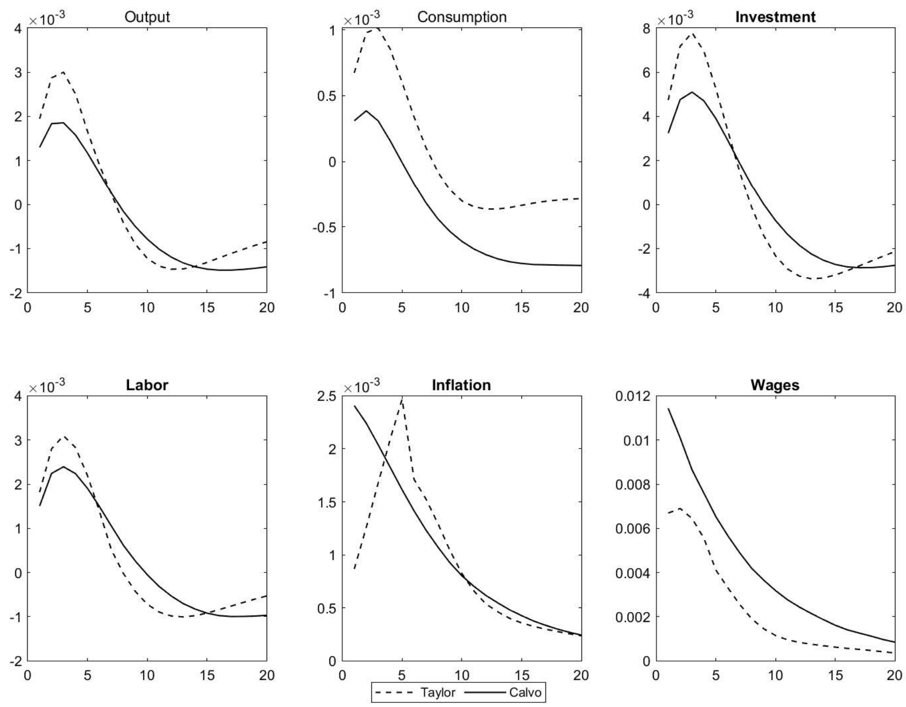
The results provide convincing evidence that Taylor's nominal contracts model offers a relevant alternative to Calvo's nominal contracts model to assess the long-run properties of the New Keynesian model. For future research, a Bayesian approach can be used to estimate both models and assess whether this affects the results obtained so far.

Figure 4.1: Impulse Response Functions of Aggregate Economic Variables



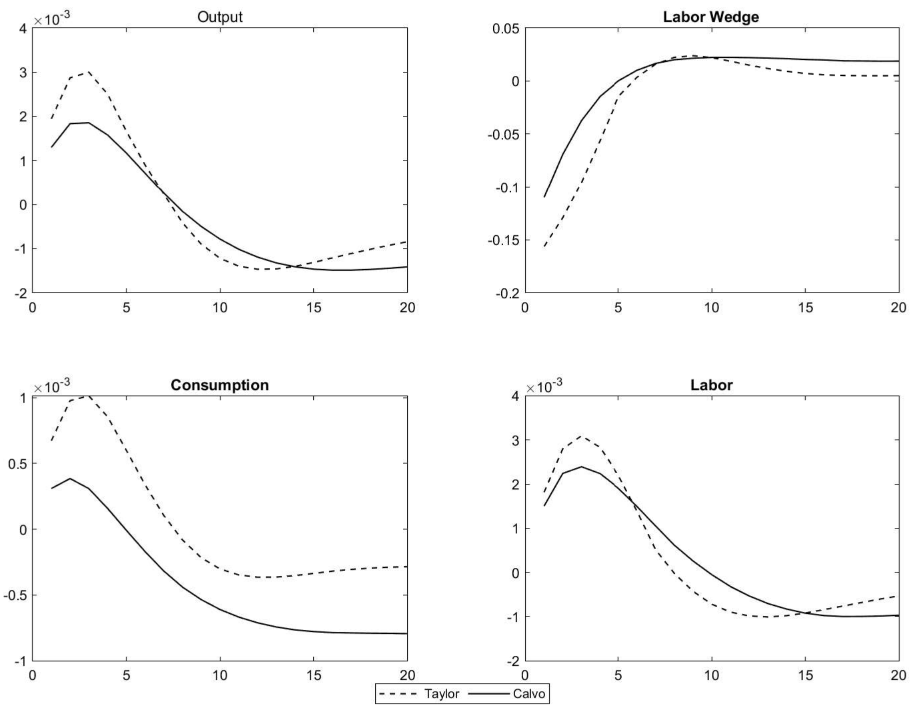
Note: This figure plots the average impulse responses of aggregate economic variables to shocks of neutral technology, marginal efficiency to investment, monetary policy and trend inflation. The dotted lines show the Taylor nominal price and wage contracts model. The solid lines show the Calvo nominal price and wage contracts model.

Figure 4.2: A Positive Shock To Trend Inflation



Note: This figure plots the average impulse responses of macroeconomic variables to a positive shock to the trend inflation. The dotted lines show the Taylor nominal price and wage contracts model. The solid lines show the Calvo nominal price and wage contracts model.

Figure 4.3: Shocks to Trend Inflation, Output and Labor Wedge



Note: This figure plots the average impulse responses of output, consumption, labor and labor wedge to a positive Trend inflation shock. The dotted lines show the Taylor nominal price and wage contracts model. The solid lines show the Calvo nominal price and wage contracts model.

Table 4.1: Parameter Values

Parameter	Description	Value
β	Discount factor	0.99
b	Internal habit formation	0.8
η	Labor disutility	6
χ	Frisch elasticity	1
κ	Investment adjustment cost	3
δ	Depreciation rate	0.025
γ_1	Utilization adjustment cost linear term	$Z^* = 1$
γ_2	Utilization adjustment cost squared term	0.05
T_p	Length of Taylor price contracts	5
T_w	Length of Taylor wage contracts	7
θ	Elasticity of substitution of goods	6
σ	Elasticity of substitution of labor	6
ϕ	Intermediate share	0.61
$\bar{Z}$	Fixed cost	$\pi^* = 0$
α	Capital share	1/3
ρ_i	Taylor rule smoothing	0.8
α_π	Taylor rule inflation	1.5
α_y	Taylor rule output growth	0.2
π^*	Trend Inflation (Gross)	1.0088
g_{ε^I}	Gross Growth of IST	1.0047
g_A	Gross Growth of Neutral Productivity	$1.0022^{1-\phi}$
	Calvo shock parameters	
ρ_A	AR(1) productivity	0.95
ρ_I	AR(1) MEI	0.81
ρ_π	AR(1) Trend inflation	0.95
$100\sigma_A$	S.D productivity shock	0.3267
$100\sigma_I$	S.D MEI shock	1.7657
$100\sigma_r$	S.D monetary shock	0.1550
$100\sigma_\pi$	S.D trend inflation shock	0.0350
	Pointed to unconditional std of trend inflation of 2	(Ann.%)
	Taylor shock parameters	
$100\sigma_A$	S.D productivity shock	0.3933
$100\sigma_I$	S.D MEI shock	2.3665
$100\sigma_r$	S.D monetary shock	0.1976
$100\sigma_\pi$	S.D trend inflation shock	0.0440
	Pointed to unconditional std of trend inflation of 2	(Ann.%)

Note: This table lists key parameters used to solve the model. A description of each parameter is provided in the second column and the corresponding value in the third column.

Table 4.2: Selected Moments

	$\sigma(\Delta Y)$	$\sigma(\Delta C)$	$\sigma(\Delta I)$	$\sigma(\Delta N)$	$\sigma(\pi)$	$\sigma(i)$
Data	0.0078	0.0047	0.0202	0.0079	0.0065	0.0082
Calvo	0.0078	0.0038	0.0176	0.0079	0.0061	0.0049
Taylor	0.0078	0.0029	0.0208	0.0078	0.0051	0.0048
	$\rho(\Delta Y,\Delta C)$	$\rho(\Delta Y,\Delta I)$	$\rho(\Delta Y,\Delta N)$	$\rho(\Delta C,\Delta I)$	$\rho(\Delta Y,\pi)$	$\rho(\Delta C,\pi)$
Data	0.7542	0.9192	0.6312	0.4362	-0.3714	-0.4196
Calvo	0.7042	0.9596	0.5674	0.4964	0.1004	-0.1313
Taylor	0.4447	0.9600	0.5956	0.2110	-0.1673	-0.3665
	$\rho(\Delta I,\pi)$	$\rho(\Delta N,\pi)$	$\rho(\Delta Y,i)$	$\rho(\Delta C,i)$	$\rho(\Delta I,i)$	$\rho(\Delta N,i)$
Data	-0.2633	-0.1308	-0.3318	-0.2983	-0.2811	-0.2024
Calvo	0.1905	0.2703	-0.0208	0.0437	0.0002	-0.0192
Taylor	-0.0131	-0.0012	-0.2485	-0.1319	-0.1779	-0.2463
	$\rho(\Delta Y_t,\Delta Y_{t-1})$	$\rho(\Delta Y_t,\Delta Y_{t-2})$	$\rho(\pi_t,\pi_{t-1})$	$\rho(\pi_t,\pi_{t-2})$	$\rho(i_t,i_{t-1})$	$\rho(i_t,i_{t-2})$
Data	0.3605	0.3430	0.9063	0.8632	0.9521	0.8857
Calvo	0.6731	0.4251	0.8710	0.7507	0.9493	0.8797
Taylor	0.6299	0.3312	0.9114	0.7758	0.9313	0.8352

Note: Table 4.2 shows some selected moments from the Calvo and the Taylor models. These statistics are computed using the symmetric specification of trend inflation process. Moments in the data are calculated over the sample period 1960:1-2007:3. All series are expressed in per capita, transformed in real terms then in the natural logs to approximate their percentage changes. Δ indicates first difference filter, $\sigma(.)$ refers to the standard deviation, and $\rho(.)$ denotes the coefficient of correlation.

Table 4.3: Welfare Effects of Constant Non-Zero Inflation

Model	$\pi^{\star} = 1.0 \rightarrow 1.02$				$\pi^{\star} = 1.02 \rightarrow 1.04$			
	ψ_{mc}	ψ_mt	ψ_{yc}	ψ_{yt}	ψ_{mc}	ψ_{mt}	ψ_{yc}	ψ_{yt}
Nominal price and wage contracts	3.6049	0.6681	3.1349	0.6158	9.1926	1.1117	8.1245	1.0634
-No PN	3.5674	0.6605	3.1023	0.6084	8.9885	1.0619	7.9343	1.0138
-No Growth	0.7489	0.2030	0.5374	0.1503	3.2899	0.6764	2.8922	0.6263
-No PN and Growth	0.7192	0.1956	0.5096	0.1431	3.1030	0.6267	2.7090	0.5767
Nominal Price Contract	0.0759	0.0184	0.0714	0.0176	0.3939	0.1036	0.3878	0.1028
-No PN	0.0454	0.0096	0.0441	0.0094	0.2058	0.0521	0.2041	0.0519
-No Growth	0.0833	0.0195	0.0776	0.0183	0.4039	0.1046	0.3962	0.1035
-No PN and Growth	0.0509	0.0102	0.0489	0.0098	0.2129	0.0526	0.2103	0.0523
Nominal Wage Contract	3.9612	0.6614	3.3735	0.6052	9.9374	1.0193	8.5105	0.9675
-No PN	3.9632	0.6646	3.4087	0.6087	9.9169	1.0221	8.5904	0.9706
-No Growth	0.9375	0.2010	0.6662	0.1428	3.4262	0.5886	2.8986	0.5333
-No PN and Growth	0.9409	0.2033	0.6859	0.1460	3.4266	0.5907	2.9338	0.5363

Note: This table shows the welfare costs and output losses (in %) in the 0 - 2% and 2 - 4% inflation bands for the Calvo and Taylor models. π^{*} denotes trend inflation, ψ_{mc} is the consumption equivalent welfare loss based on stochastic means and ψ_{yc} the output loss conditioned on stochastic means in the Calvo model and ψ_{mt} and ψ_{yt} are their equivalent in the Taylor model. '*PN*' stands for production networking or roundabout production structure.

Table 4.4: Constant Trend Inflation: Price and Wage Dispersion

Model		$\pi^\star = 1.0 \to 1.02$			$\pi^\star = 1.02 \to 1.04$		
		SPSW	SP	SW	SPSW	SP	SW
Calvo	s_{ss}	1.0000	1.0000	1.0000	1.0005	1.0005	1.0000
	s_m	1.0000	1.0004	1.0000	1.0005	1.0009	1.0000
	v^w_{ss}	1.0212	1.0000	1.0212	1.1004	1.0000	1.1004
	v^w_m	1.0214	1.0000	1.0277	1.1009	1.0000	1.1136
Taylor	s_{ss}	1.0000	1.0000	1.0000	1.0054	1.0000	1.0000
	s_m	1.0000	1.0002	1.0000	1.0055	1.0000	1.0000
	v^w_{ss}	1.0001	1.0000	1.0000	1.0190	1.0000	1.0190
	v^w_m	1.0002	1.0000	1.0000	1.0191	1.0000	1.0211

Note: This table displays price and wage dispersion in the constant trend inflation economy following 0-2% and 2-4% inflation bands. s_{ss} denotes steady-state price dispersion, s_m is mean price dispersion. v^w_{ss} stands for steady-state wage dispersion and v^w_m the mean wage dispersion. SPSW is the nominal price and wage contracts model, SP denotes the nominal price contracts model, and SW for nominal wage contracts model.

Table 4.5: Welfare Effects of Shifting Trend Inflation

Model	$\pi^{\star} = 1.02^{0.25}$			
	ψ_{mc}	ψ_{mt}	ψ_{yc}	ψ_{yt}
Nominal price and wage contracts	7.8096	1.0746	5.7648	0.8706
-No PN	6.6316	0.8683	5.2780	0.7660
-No Growth	3.3509	1.0749	2.5881	0.8830
-No PN and Growth	2.8010	0.8767	2.3163	0.7789
Nominal Price Contract	0.4016	0.1880	0.3320	0.1600
-No PN	0.1768	0.0848	0.1612	0.0802
-No Growth	0.3988	0.1870	0.3341	0.1609
-No PN and Growth	0.1761	0.0846	0.1616	0.0803
Nominal Wage Contract	7.5002	0.9035	5.4973	0.7242
-No PN	6.5039	0.7957	5.1547	0.6967
-No Growth	2.9772	0.9086	2.2726	0.7390
-No PN and Growth	2.6401	0.8060	2.1674	0.7110

Note: This table shows the welfare costs and output losses (in %) in the 2% trend inflation in the Calvo and Taylor models. π^{*} denotes trend inflation, ψ_{mc} is the consumption equivalent welfare loss based on stochastic means and ψ_{yc} the output loss conditioned on stochastic means in the Calvo model and ψ_{mt} and ψ_{yt} are their equivalent in the Taylor model. '*PN*' stands for production networking or roundabout production structure.

Table 4.6: Shifting Trend Inflation: Price and Wage Dispersion

Model		$\pi^\star = 1.02^{0.25}$			$\pi^\star = 1.04^{0.25}$		
		SPSW	SP	SW	SPSW	SP	SW
Calvo	s_{ss}	1.0005	1.0005	1.0000	1.0020	1.0020	1.0000
	s_m	1.0006	1.0007	1.0000	1.0021	1.0022	1.0000
	v^w_{ss}	1.1004	1.0000	1.1004	1.3310	1.0000	1.3310
	v^w_m	1.1141	1.0000	1.1141	1.3771	1.0000	1.3771
Taylor	s_{ss}	1.0001	1.0001	1.0000	1.0006	1.0006	1.0000
	s_m	1.0003	1.0003	1.0000	1.0007	1.0007	1.0000
	v^w_{ss}	1.0001	1.0000	1.0001	1.0006	1.0000	1.0006
	v^w_m	1.0007	1.0000	1.0007	1.0012	1.0000	1.0012

Note: This table displays price and wage dispersion in the shifting trend inflation economy with 2% and 4%. s_{ss} denotes steady-state price dispersion, s_m is mean price dispersion. v^w_{ss} stands for steady-state wage dispersion and v^w_m the mean wage dispersion. SPSW is the nominal price and wage contracts model, SP denotes the nominal price contracts model, and SW for nominal wage contracts model.

Table 4.7: Sensitivity of Price and Wage Dispersion to Trend Growth

Model		$\bar{\pi}^* = 2\%$				$\bar{\pi}^* = 4\%$			
		SPSW	g_Ψ	No g_Ψ	No g_Ψ-ϕ	SPSW	g_Ψ	No g_Ψ	No g_Ψ-ϕ
Calvo	s_{ss}	1.0005	1.0005	1.0005	1.0005	1.0020	1.0020	1.0020	1.0020
	s_m	1.0006	1.0006	1.0006	1.0006	1.0021	1.0021	1.0021	1.0021
	v^w_{ss}	1.1004	1.1004	1.0154	1.0154	1.3310	1.3310	1.0803	1.0803
	v^w_m	1.1141	1.1093	1.0204	1.0190	1.3771	1.3577	1.0905	1.0879
Taylor	s_{ss}	1.0001	1.0001	1.0001	1.0001	1.0006	1.0006	1.0006	1.0006
	s_m	1.0003	1.0002	1.0003	1.0003	1.0007	1.0007	1.0007	1.0007
	v^w_{ss}	1.0001	1.0001	1.0001	1.0001	1.0006	1.0006	1.0006	1.0006
	v^w_m	1.0007	1.0007	1.0007	1.0007	1.0012	1.0011	1.0012	1.0011

Note: This table describes the sensitivity of price and wage dispersion to trend growth in the Calvo and Taylor models. π^* denotes trend inflation, g_Ψ is the trend productivity growth, ϕ the intermediate share and symbolizes the production networking or roundabout production structure, SPSW the nominal price and wage contracts, s_{ss} and s_m steady-state and mean price dispersion respectively, and v^w_{ss} and v^w_m for steady-state and mean wage dispersion.

Table 4.8: Welfare Effects of Cost Channel

Model	$\pi^{\star} = 1.02^{0.25}$			
	ψ_{mc}	ψ_{mt}	ψ_{yc}	ψ_{yt}
Nominal price and wage contracts	4.1513	1.2492	3.1026	1.0168
-No PN	3.5981	1.0229	2.8741	0.9022
-No Growth	1.7849	1.2540	1.3913	1.0303
-No PN and Growth	1.5081	1.0368	1.2507	0.9189
Nominal Price Contract	0.2223	0.2377	0.1833	0.1918
-No PN	0.0972	0.1048	0.0875	0.0933
-No Growth	0.2199	0.2347	0.1832	0.1916
-No PN and Growth	0.0966	0.1041	0.0876	0.0933
Nominal Wage Contract	4.0404	1.0458	2.9984	0.8393
-No PN	3.5391	0.9348	2.8151	0.8174
-No Growth	1.6045	1.0563	1.2353	0.8566
-No PN and Growth	1.4245	0.9511	1.1725	0.8361

Note: This table shows the welfare costs and output losses (in %) in the 2% trend inflation in the Calvo and Taylor models. π^{*} denotes trend inflation, ψ_{mc} is the consumption equivalent welfare loss based on stochastic means and ψ_{yc} the output loss conditioned on stochastic means in the Calvo model and ψ_{mt} and ψ_{yt} are their equivalent in the Taylor model. '*PN*' stands for production networking or roundabout production structure.

Table 4.9: Alternative Welfare Costs of Shifting Trend inflation

Model	$\pi^{\star} = 1.02^{0.25}$			
	ψ_{mc}	ψ_{mt}	ψ_{yc}	ψ_{yt}
Nominal price and wage contracts	9.2054	1.3720	6.7959	1.0857
-No PN	7.8966	1.1342	6.2747	0.9748
-No Growth	3.6783	1.0880	2.7939	0.8700
-No PN and Growth	3.0838	0.8911	2.5025	0.7680
Nominal Price Contract	0.4452	0.1839	0.3577	0.1517
-No PN	0.1978	0.0831	0.1736	0.0755
-No Growth	0.4415	0.1827	0.3601	0.1526
-No PN and Growth	0.1967	0.0827	0.1742	0.0757
Nominal Wage Contract	8.8533	1.2018	6.5014	0.9448
-No PN	7.7468	1.0608	6.1373	0.9078
-No Growth	3.2628	0.9214	2.4522	0.7304
-No PN and Growth	2.9021	0.8190	2.3403	0.7018

Note: This table shows the welfare costs and output losses (in %) in the 2% trend inflation in the Calvo and Taylor models. π^{*} denotes trend inflation, ψ_{mc} is the consumption equivalent welfare loss based on stochastic means and ψ_{yc} the output loss conditioned on stochastic means in the Calvo model and ψ_{mt} and ψ_{yt} are their equivalent in the Taylor model. '*PN*' stands for production networking or roundabout production structure.

Table 4.10: Alternative Welfare Effects of Cost Channel

Model	$\pi^{\star} = 1.02^{0.25}$			
	ψ_{mc}	ψ_{mt}	ψ_{yc}	ψ_{yt}
Nominal price and wage contracts	5.5162	2.2109	4.2404	2.0898
-No PN	4.7136	1.5611	3.8312	1.5552
-No Growth	2.3096	1.8672	1.8833	1.8102
-No PN and Growth	1.8572	1.2642	1.5815	1.2886
Nominal Price Contract	0.4489	0.7822	0.4712	0.9500
-No PN	0.1717	0.2666	0.2211	0.4434
-No Growth	0.4483	0.7853	0.4697	0.9452
-No PN and Growth	0.1736	0.2740	0.2199	0.4394
Nominal Wage Contract	5.3609	2.0030	4.1045	1.9146
-No PN	4.6344	1.4693	3.7572	1.4709
-No Growth	2.0869	1.6632	1.6968	1.6371
-No PN and Growth	1.7539	1.1741	1.4886	1.2055

Note: This table shows the welfare costs and output losses (in %) in the 2% trend inflation in the Calvo and Taylor models. π^* denotes trend inflation, ψ_{mc} is the consumption equivalent welfare loss based on stochastic means and ψ_{yc} the output loss conditioned on stochastic means in the Calvo model and ψ_{mt} and ψ_{yt} are their equivalent in the Taylor model. '*PN*' stands for production networking or roundabout production structure.

Table 4.11: Sensibility Analysis

σ	ψ_{mc}	ψ_{mt}	σ_π	ψ_{mc}	ψ_{mt}	ρ_π	ψ_{mc}	ψ_{mt}	$\bar{\pi}^*$	ψ_{mc}	ψ_{mt}
4	2.2827	0.6054	0.00025	4.0638	0.3482	0.90	0.2572	0.0556	$1.02^{0.25}$	0.9741	0.1630
6	7.8096	1.0746	0.00050	15.2909	1.3855	0.950	0.9741	0.1630	$1.04^{0.25}$	2.6026	0.1682
8	24.5448	1.6894	0.00075	31.1598	3.0903	0.990	7.8096	1.0746	$1.06^{0.25}$	10.0471	0.1712
10	61.4626	2.4242	0.00100	48.5104	5.4277	0.995	15.6475	2.2078	$1.07^{0.25}$	37.6204	0.1719

Note: This table considers the shifting trend inflation benchmark model version. σ is the elasticity of substitution of labor, σ_π is the volatility of trend inflation shock, ρ_π its persistence, and $\bar{\pi}^*$ denotes trend inflation.

APPENDIX

Appendix 4.A Full Set of Equilibrium Conditions

This appendix lists the full set of detrended equations. These equations are expressed in stationary transformations of variables, e.g. $\widetilde{X}_t = \frac{X_t}{\Psi_t}$ for most variables. $g_\Psi = \frac{\Psi_t}{\Psi_{t-1}}$ is the growth rate of the deterministic trend.

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

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

$$\widetilde{\lambda}_t^r = \widetilde{\mu}_t \vartheta_t \left(1 - \frac{k}{2} \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi \right)^2 - \kappa \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi - g_\Psi \right) \frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Psi \right) + \dots$$
$$\beta E_t g_\Psi^{-1} \widetilde{\mu}_{t+1} \vartheta_{t+1} \kappa \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Psi - g_\Psi \right) \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Psi \right)^2 \tag{A3}$$

$$g_I g_\Psi \widetilde{\mu}_t = \beta E_t \widetilde{\lambda}_{t+1}^r \left(\widetilde{r}_{t+1}^k Z_{t+1} - \left(\gamma_1 (Z_{t+1} - 1) + \frac{\gamma_2}{2} (Z_{t+1} - 1)^2 \right) \right) + \beta (1 - \delta) E_t \widetilde{\mu}_{t+1} \tag{A4}$$

$$\widetilde{\lambda}_t^r = \beta g_\Psi^{-1} E_t (1 + i_t) \pi_{t+1}^{-1} \widetilde{\lambda}_{t+1}^r \tag{A5}$$

$$\widetilde{w}_t^* = \frac{\sigma}{\sigma - 1} \frac{\widetilde{h}_{1,t}}{\widetilde{h}_{2,t}} \tag{A6}$$

$$\widetilde{h}_{1,t} = \sum_{i=0}^{T_w - 1} \eta \beta^i g_\Psi^{i\sigma(1+\chi)} \left(\frac{\widetilde{w}_{t+i}}{\widetilde{w}_t{}^*} \right)^{\sigma(1+\chi)} \pi_{t+1,t+i}^{\sigma(1+\chi)} N_{t+i}^{1+\chi} \tag{A7}$$

$$\widetilde{h}_{2,t} = \sum_{i=0}^{T_w-1} \beta^i g_{\Psi}^{i(\sigma-1)} \pi_{t+1,t+i}^{(\sigma-1)} \left(\frac{\widetilde{w}_{t+i}}{\widetilde{w}_t^{\,*}}\right)^{\sigma} \widetilde{\lambda}_{t+i}^{r} N_{t+i} \tag{A8}$$

$$\widetilde{\widetilde{K}}_t = g_I g_{\Psi} \alpha (1-\phi) \frac{mc_t}{\widetilde{r}_t^k} \left(s_t \widetilde{X}_t + \bar{Z}\right) \tag{A9}$$

$$N_t = (1-\alpha)(1-\phi) \frac{mc_t}{\widetilde{w}_t} \left(s_t \widetilde{X}_t + \bar{Z}\right) \tag{A10}$$

$$\widetilde{\Upsilon}_t = \phi mc_t \left(s_t \widetilde{X}_t + \bar{Z}\right) \tag{A11}$$

$$p_t^* = \frac{\theta}{\theta-1} \frac{m_{1,t}}{m_{2,t}} \tag{A12}$$

$$m_{1,t} = \sum_{i=0}^{T_p-1} \beta^i \widetilde{\lambda}_{t+i}^{r} mc_{t+i} \pi_{t+1,t+i}^{\theta} X_{t+i} \tag{A13}$$

$$m_{2,t} = \sum_{i=0}^{T_p-1} \beta^i \widetilde{\lambda}_{t+i}^{r} \pi_{t+1,t+i}^{\theta-1} X_{t+i} \tag{A14}$$

$$1 = \frac{1}{T_p} \sum_{i=0}^{T_p-1} \left(\frac{p_{t-i}^*}{\pi_{t,t-i+1}}\right)^{1-\theta} \tag{A15}$$

$$\widetilde{w}_t^{1-\sigma} = \frac{1}{T_w} \sum_{i=0}^{T_w-1} \left(\frac{\widetilde{w}_{t-i}^* g_{\Psi}^{-i}}{\pi_{t,t-i+1}}\right)^{1-\sigma} \tag{A16}$$

$$\widetilde{Y}_t = \widetilde{X}_t - \widetilde{\Upsilon}_t \tag{A17}$$

$$s_t \widetilde{X}_t = \widetilde{\Upsilon}_t^{\phi} \widetilde{\widetilde{K}}_t^{\alpha(1-\phi)} N_t^{(1-\alpha)(1-\phi)} g_{\Psi}^{\alpha(\phi-1)} - \bar{Z} \tag{A18}$$

$$\widetilde{Y}_t = \widetilde{C}_t + \widetilde{I}_t + g_{\Psi}^{-1} g_I^{-1} \left(\gamma_1 (Z_t - 1) + \frac{\gamma_2}{2} (Z_t - 1)^2\right) \widetilde{K}_t \tag{A19}$$

$$\widetilde{K}_{t+1} = \vartheta_t \left(1 - \frac{\kappa}{2} \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_{\Psi} - g_{\Psi}\right)^2\right) \widetilde{I}_t + (1-\delta) g_{\Psi}^{-1} g_I^{-1} \widetilde{K}_t \tag{A20}$$

$$\frac{1+i_t}{1+i} = \left(\left(\frac{\pi_t}{\bar{\pi}_t}\right)^{\alpha_\pi}\left(\frac{\widetilde{Y}_t}{\widetilde{Y}_{t-1}}\right)^{\alpha_y}\right)^{1-\rho_i}\left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i}\exp\left(\varepsilon_t^r\right) \tag{A21}$$

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

$$s_t = \frac{1}{T_p}\sum_{i=0}^{T_p-1}\left(\frac{p_{t-i}^*}{\pi_{t,t-i+1}}\right)^{-\theta} \tag{A23}$$

$$v_t^w = \frac{1}{T_w}\sum_{i=0}^{T_w-1}\left(\frac{w_t}{w_{t-i}^*}\pi_{t,t-i+1}\right)^{\sigma(1+\chi)} \tag{A24}$$

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

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

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

$$\Phi_t = \frac{\beta\ln g_\Psi}{(1-\beta)^2} \tag{A28}$$

$$\vartheta_t = \left(\vartheta_{t-1}\right)^{\rho_I}\exp\left(\sigma_I u_t^I\right) \tag{A29}$$

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A}\exp\left(\sigma_A u_t^A\right) \tag{A30}$$

$$\ln\left(\bar{\pi}_t\right) = \left(1-\rho_{\bar{\pi}}\right)\ln\left(\bar{\pi}^*\right) + \rho_{\bar{\pi}}\ln\left(\bar{\pi}_{t-1}\right) + \sigma_{\bar{\pi}}u_t^{\bar{\pi}} \tag{A31}$$

Equation (A1) defines the real multiplier on the flow budget constraint. (A2) is the optimality condition for capital utilization. (A3) and (A4) 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 (A5). (A6)-(A8) describe optimal wage setting for households given the opportunity to adjust their wages. Optimal factor demands are given by equations (A9)-(A11). Optimal price setting for firms given the opportunity to change their price is described by equations (A12)-(A14). The evolutions of aggregate inflation and the aggregate real wage index are given by (A15) and (A16), respectively. Net output is gross output minus intermediates, as given by (A17). The aggregate production function for gross output is (A18). The aggregate resource constraint is

(A19), and the law of motion for physical capital is given by (A20). The Taylor rule for monetary policy is (A21). Capital services are defined as the product of utilization and physical capital, as in (A22). The law of motion for price dispersion is (A23) and for wage dispersion is (A24). (A25) and (A26) are recursive utility from consumption and labor in the levels. The aggregate welfare is (A27) and (A28) a shift term. (A29)-(A31) give the assumed laws of motion for other exogenous variables.

Appendix 4.B Adding Financial Frictions

The cost-minimization problem of a typical firm is:

$$\min_{\Upsilon_t(j),\widehat{K}_t(j),N_t^d(j)} \quad (1-\gamma_\Upsilon+\gamma_\Upsilon(1+i_t))P_t\Upsilon_t(j)+(1-\gamma_K+\gamma_K(1+i_t))R_t^k\widehat{K}_t(j)+ \\ (1-\gamma_N+\gamma_N(1+i_t))W_tN_t^d(j)$$

s.t.

$$A_t\Upsilon_t(j)^{\phi}\left(\widehat{K}_t(j)^{\alpha}N_t^d(j)^{1-\alpha}\right)^{1-\phi}-\Psi_t\bar{Z}\geq\left(\frac{P_t(j)}{P_t}\right)^{-\theta}X_t. \tag{A1}$$

where γ_l, $l=\Upsilon,K,N$, denotes the fraction of payments to a factor that must be financed at the gross nominal interest rate, $1+i_t$. With $\gamma_l=1$ for all l, firms must borrow the entirety of their factor payments each period (Phaneuf et al., 2018). We refer to this case as extended working capital. We define $\Gamma_{l,t}=(1-\gamma_l+\gamma_l(1+i_t))$ for $l=\Upsilon,K,N$. The aggregate factor demands can be written:

$$\Upsilon_t=\phi mc_t\Gamma_{\Upsilon,t}^{-1}\left(s_tX_t+\Psi_t\bar{Z}\right), \tag{A2}$$

$$\widehat{K}_t=\alpha(1-\phi)\frac{mc_t}{\Gamma_{K,t}r_t^k}\left(s_tX_t+\Psi_t\bar{Z}\right), \tag{A3}$$

$$N_t^d=(1-\alpha)(1-\phi)\frac{mc_t}{\Gamma_{L,t}w_t}\left(s_tX_t+\Psi_t\bar{Z}\right). \tag{A4}$$

CONCLUSION

Cette thèse a examiné les effets macroéconomiques d'une inflation tendancielle positive. En utilisant un modèle DSGE Néo-Keynésian à échelle moyenne qui inclut l'inflation tendancielle, la croissance tendancielle et la structure de production avec biens intermédiaires, il fournit des éléments de réponse aux trois questions centrales de notre recherche à savoir: L'inflation tendancielle non nulle affecte-t-elle la dynamique des variables macroéconomiques? Le canal de transmission passe-t-il par une dispersion des prix ou des salaires? Comment cela affecte-t-il des coûts en bien-être?

Les résultats montrent que l'inflation tendancielle positive a des implications sur les variables macroéconomiques agrégées et que le mécanisme de transmission passe principalement par la dispersion des salaires pour entraîner des coûts en bien-être. En particulier, lorsque l'inflation tendancielle augmente, le markup des salaires devient plus important que celui des prix pour expliquer la dynamique des chocs. De plus, à mesure que l'inflation tendancielle augmente, l'interaction entre la croissance tendancielle et la rigidité nominale des salaires rend les salaires plus dispersés, ce qui à son tour entraîne des inefficacités dans l'allocation de la main-d'œuvre, puis de l'output, et par conséquent affecte les coûts en bien-être.

Par ailleurs, d'autres résultats substantiels ont été trouvés. Premièrement, lorsque le trend d'inflation et la croissance exogène sont combinés à la rigidité nominale des salaires, répondre à l'output gap ou à l'écart de production devient très coûteux en termes de bien-être, bien plus que dans le cas de rigidité nominale des prix. Deuxièmement, les coûts en bien-être du trend d'inflation variable dans le temps sont plus importants que ceux du trend d'inflation constant et positif. Enfin, les pertes en consommation équivalente sont plus faibles et modestes dans les contrats échelonnés de Taylor, et ces derniers sont moins sensibles aux variations du trend d'inflation et aux paramètres clés du modèle.

Les contributions principales de cette thèse sont entre autres: 1) Elle montre que la modélisation du trend d'inflation positif est importante; 2) elle documente la cyclicité de markup des salaires; 3) elle révèle que réagir à l'output gap est très coûteux en termes de bien-être, dans un modèle incluant les contrats nominaux échelonnés de Calvo, le trend d'inflation positif, et la croissance exogène; 4) elle décrit le canal de transmission par lequel le trend d'inflation positif affecte les variables macroéconomiques agrégées pour générer des coûts en bien-être dans les cas de contrats nominaux échelonnés de Calvo et de Taylor; 5) Enfin, elle complète la littérature existante sur le trend d'inflation variable dans le temps en proposant des contrats nominaux échelonnés de Taylor pour examiner les problèmes des coûts en bien-être. En outre, elle montre que ces contrats de Taylor offrent une alternative pertinente pour évaluer les propriétés de bien-être des modèles Néo-Keynésiens.

Les résultats de cette thèse ont des implications plus larges pour les banques centrales, les chercheurs, et les universitaires. En effet, nos résultats mettent en évidence plusieurs caractéristiques essentielles omises dans la plupart des études sur les questions des coûts en bien-être, dont l'absence se traduit par des coûts d'inflation modestes ou inférieurs. En outre, l'analyse de sensibilité a montré que les coûts en bien-être basés sur le modèle contractuel nominal de Calvo sont très sensibles aux variations du trend d'inflation et des paramètres clés du modèle.

Pour les recherches futures, approfondir cette analyse par l'approche d'estimation bayésienne. Cet approfondissement permettra d'évaluer les effets du trend d'inflation positif sur les variables macroéconomiques agrégées et les implications sur les coûts en bien-être. Cela permettra de porter un jugement sur les résultats obtenus dans la présente recherche.

BIBLIOGRAPHY

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

[2] Alvarez, Fernando, Martin Beraja, Martin Gonzalez-Rozada, and Pablo Andrés Neumeyer, "From hyperinflation to stable prices: Argentina's evidence on menu cost models," *The Quarterly Journal of Economics*, 2019, *134* (1), 451–505.

[3] Amano, Robert, Kevin Moran, Stephen Murchison, and Andrew Rennison, "Trend inflation, wage and price rigidities, and productivity growth," *Journal of Monetary Economics*, 2009, *56* (3), 353–364.

[4] ——, Steve Ambler, and Nooman Rebei, "The macroeconomic effects of nonzero trend inflation," *Journal of Money, Credit and Banking*, 2007, *39* (7), 1821–1838.

[5] Arias, Jonas, Guido Ascari, Nicola Branzoli, and Efrem Castelnuovo, "Monetary policy, trend inflation and the Great Moderation: An alternative interpretation-Comment," *FRB International Finance Discussion Paper*, 2014, (1127).

[6] Ascari, Guido, "Staggered prices and trend inflation: some nuisances," *Review of Economic dynamics*, 2004, *7* (3), 642–667.

[7] —— and Argia M Sbordone, "The macroeconomics of trend inflation," *Journal of Economic Literature*, 2014, *52* (3), 679–739.

[8] —— and Tiziano Ropele, "Optimal monetary policy under low trend inflation," *Journal of monetary Economics*, 2007, *54* (8), 2568–2583.

[9] ——, Louis Phaneuf, and Eric R Sims, "On the welfare and cyclical implications of moderate trend inflation," *Journal of Monetary Economics*, 2018, *99*, 56–71.

[10] ——, ——, and Eric Sims, "On the welfare and cyclical Implications of moderate trend Inflation," Technical Report, National Bureau of Economic Research 2015.

[11] Ball, Laurence M, *The case for a long-run inflation target of four percent* number 14-92, International Monetary Fund, 2014.

[12] Barattieri, Alessandro, Susanto Basu, and Peter Gottschalk, "Some evidence on the importance of sticky wages," Technical Report, National Bureau of Economic Research 2010.

[13] Basu, Susanto, "Intermediate goods and business cycles: Implications for productivity and welfare," *The American Economic Review*, 1995, pp. 512–531.

[14] ——— and Miles S Kimball, "Cyclical productivity with unobserved input variation," Technical Report, National Bureau of Economic Research 1997.

[15] Bils, Mark, "The cyclical behavior of marginal cost and price," *The American Economic Review*, 1987, pp. 838–855.

[16] ——— and James A Kahn, "What Inventory Behavior Tells Us about Business Cycles," *American Economic Review*, 2000, *90* (3), 458–481.

[17] ——— and Peter J Klenow, "Some evidence on the importance of sticky prices," *Journal of political economy*, 2004, *112* (5), 947–985.

[18] ——— , ——— , and Benjamin A Malin, "Resurrecting the Role of the Product Market Wedge in Recessions," Technical Report, National Bureau of Economic Research 2014.

[19] ——— , ——— , and ——— , "Resurrecting the role of the product market wedge in recessions," *American Economic Review*, 2018, *108* (4-5), 1118–46.

[20] Blanchard, Olivier, Giovanni Dell'Ariccia, and Paolo Mauro, "Rethinking macroeconomic policy," *Journal of Money, Credit and Banking*, 2010, *42*, 199–215.

[21] Blanchard, Olivier J, "The state of macro," Technical Report, National Bureau of Economic Research 2008.

[22] Boivin, Jean and Marc P Giannoni, "Has monetary policy become more effective?," *The Review of Economics and Statistics*, 2006, *88* (3), 445–462.

[23] Calvo, Guillermo A, "Staggered prices in a utility-maximizing framework," *Journal of monetary Economics*, 1983, *12* (3), 383–398.

[24] Canova, Fabio, "What explains the great moderation in the US? A structural analysis," *Journal of the European Economic Association*, 2009, *7* (4), 697–721.

[25] Chari, Varadarajan V, Patrick J Kehoe, and Ellen R McGrattan, "Sticky price models of the business cycle: can the contract multiplier solve the persistence problem?," *Econometrica*, 2000, *68* (5), 1151–1179.

[26] ——— , ——— , and ——— , “Business cycle accounting,” *Econometrica*, 2007, *75* (3), 781–836.

[27] Chirinko, Robert S and Steven M Fazzari, “Economic fluctuations, market power, and returns to scale: Evidence from firm-level data,” *Journal of Applied Econometrics*, 1994, *9* (1), 47–69.

[28] Christiano, Lawrence J, Martin Eichenbaum, and Charles L Evans, “Sticky price and limited participation models of money: A comparison,” *European Economic Review*, 1997, *41* (6), 1201–1249.

[29] ——— , ——— , and ——— , “Nominal rigidities and the dynamic effects of a shock to monetary policy,” *Journal of political Economy*, 2005, *113* (1), 1–45.

[30] ——— , Martin S Eichenbaum, and Mathias Trabandt, “Unemployment and business cycles,” *Econometrica*, 2016, *84* (4), 1523–1569.

[31] ——— , ——— , and ——— , “On DSGE models,” *Journal of Economic Perspectives*, 2018, *32* (3), 113–40.

[32] ——— , Mathias Trabandt, and Karl Walentin, “DSGE models for monetary policy analysis,” in “Handbook of monetary economics,” Vol. 3, Elsevier, 2010, pp. 285–367.

[33] Clarida, Richard, Jordi Galí, and Mark Gertler, “The Science of Monetary Policy: A New Keynesian Perspective,” *Journal of Economic Literature*, 1999, *37*, 1661–1707.

[34] ——— , ——— , and ——— , “Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory,” *The Quarterly journal of economics*, 2000, *115* (1), 147–180.

[35] Cochrane, John H, “Do Higher Interest Rates Raise or Lower Inflation?,” *Unpublished paper, February, https://faculty. chicagobooth. edu/john. cochrane/research/papers/fisher. pdf*, 2016.

[36] Cogley, T, G Primiceri, and T Sargent, “Inflation-gap persistence in the us American Economic Journal: Macroeconomics,” 2009.

[37] Cogley, Timothy and Argia M Sbordone, “Trend inflation, indexation, and inflation persistence in the New Keynesian Phillips curve,” *American Economic Review*, 2008, *98* (5), 2101–26.

[38] ——— and James M Nason, “Output dynamics in real-business-cycle models,” *The American Economic Review*, 1995, pp. 492–511.

[39] Coibion, Olivier and Yuriy Gorodnichenko, “Monetary Policy, Trend Inflation, and the Great Moderation: An Alternative Interpretation,” *The American Economic Review*, 2011, *101* (1), 341–370.

[40] ___ and ___ , “Why are target interest rate changes so persistent?,” *American Economic Journal: Macroeconomics*, 2012, *4* (4), 126–62.

[41] Coric, Bruno, “The sources of the Great Moderation: a survey,” 2011.

[42] Dixon, Huw David and Engin Kara, “How to compare Taylor and Calvo contracts: a comment on Michael Kiley,” *Journal of Money, credit, and Banking*, 2006, *38* (4), 1119–1126.

[43] Domowitz, Ian, R Glenn Hubbard, and Bruce C Petersen, “Business cycles and the relationship between concentration and price-cost margins,” *The RAND Journal of Economics*, 1986, pp. 1–17.

[44] Dotsey, Michael and Robert G King, “Pricing, production, and persistence,” *Journal of the European Economic Association*, 2006, *4* (5), 893–928.

[45] Dou, Winston, Andrew W Lo, Ameya Muley, and Harald Uhlig, “Macroeconomic Models for Monetary Policy: A Critical Review from a Finance Perspective,” *Available at SSRN 2899842*, 2017.

[46] Eberly, Janice, James H Stock, and Jonathan H Wright, “The Federal Reserve’s Current Framework for Monetary Policy: A Review and Assessment,” *NBER Working Paper*, 2019, (w26002).

[47] Eo, Yunjong and Denny Lie, “Changes in the inflation target and the comovement between inflation and the nominal interest rate,” 2019.

[48] Erceg, Christopher J, Dale W Henderson, and Andrew T Levin, “Optimal monetary policy with staggered wage and price contracts,” *Journal of monetary Economics*, 2000, *46* (2), 281–313.

[49] Fisher, Jonas, “The Dynamic Effects of Neutral and Investment-Specific Technology Shocks,” *Journal of Political Economy*, 2006, *114(3)*, 413–451.

[50] Fisher, Jonas DM, “The dynamic effects of neutral and investment-specific technology shocks,” *Journal of political Economy*, 2006, *114* (3), 413–451.

[51] Fuerst, Timothy S, “Liquidity, loanable funds, and real activity,” *Journal of monetary economics*, 1992, *29* (1), 3–24.

[52] Fuhrer, Jeffrey C, “Habit formation in consumption and its implications for monetary-policy models,” *American Economic Review*, 2000, pp. 367–390.

[53] Gagnon, Etienne, "Price setting during low and high inflation: Evidence from Mexico," *The Quarterly Journal of Economics*, 2009, *124* (3), 1221–1263.

[54] Galí, Jordi, "The return of the wage Phillips curve," *Journal of the European Economic Association*, 2011, *9* (3), 436–461.

[55] ___ and Luca Gambetti, "On the sources of the great moderation," *American Economic Journal: Macroeconomics*, 2009, *1* (1), 26–57.

[56] Gali, Jordi, Mark Gertler, and J David Lopez-Salido, "Markups, gaps, and the welfare costs of business fluctuations," *The review of economics and statistics*, 2007, *89* (1), 44–59.

[57] García-Schmidt, Mariana and Michael Woodford, "Are low interest rates deflationary? A paradox of perfect-foresight analysis," *American Economic Review*, 2019, *109* (1), 86–120.

[58] Garín, Julio, Robert Lester, and Eric Sims, "Raise Rates to Raise Inflation? Neo-Fisherianism in the New Keynesian Model," *Journal of Money, Credit and Banking*, 2018, *50* (1), 243–259.

[59] Golosov, Mikhail and Robert E Lucas Jr, "Menu costs and Phillips curves," *Journal of Political Economy*, 2007, *115* (2), 171–199.

[60] Goodfriend, Marvin and Robert King, "The new neoclassical synthesis and the role of monetary policy," in "NBER Macroeconomics Annual 1997, Volume 12," MIT Press, 1997, pp. 231–296.

[61] Ha, Le Thanh, "SHIFTING, ESSAYS ON WELFARE COSTS OF." PhD dissertation, National Graduate Institute for Policy Studies 2018.

[62] Hall, Robert E, "Macroeconomic fluctuations and the allocation of time," *Journal of labor Economics*, 1997, *15* (1, Part 2), S223–S250.

[63] Haskel, Jonathan, Christopher Martin, and Ian Small, "PRICE, MARGINAL COST AND THE BUSINESS CYCLE†," *Oxford Bulletin of Economics and Statistics*, 1995, *57* (1), 25–39.

[64] Hirose, Yasuo, Takushi Kurozumi, and Willem Van Zandweghe, "Monetary Policy, Trend Inflation, and the Great Moderation: An Alternative Interpretation: Comment Based on System Estimation," *Federal Reserve Bank of Kansas City Working Paper*, 2015, (15-17).

[65] Huang, Kevin XD, Zheng Liu, and Louis Phaneuf, "Why Does the Cyclical Behavior of Real Wages Change over Time?," *American Economic Review*, 2004, pp. 836–856.

[66] III, Marvin J Barth and Valerie A Ramey, "The Cost Channel of Monetary Transmission," in "NBER Macroeconomics Annual 2001, Volume 16," MIT Press, 2002, pp. 199–256.

[67] Ireland, Peter N, "Changes in the Federal Reserve's inflation target: Causes and consequences," *Journal of Money, credit and Banking*, 2007, *39* (8), 1851–1882.

[68] Jr, Robert E Lucas and Leonard A Rapping, "Real wages, employment, and inflation," *Journal of political economy*, 1969, *77* (5), 721–754.

[69] Justiniano, Alejandro and Giorgio E Primiceri, "The time-varying volatility of macroeconomic fluctuations," *American Economic Review*, 2008, *98* (3), 604–41.

[70] ____ and Giorgio Primiceri, "Potential and natural output," *Manuscript, Northwestern University*, 2008.

[71] ____ , Giorgio E Primiceri, and Andrea Tambalotti, "Investment shocks and business cycles," *Journal of Monetary Economics*, 2010, *57* (2), 132–145.

[72] ____ , ____ , and ____ , "Investment shocks and the relative price of investment," *Review of Economic Dynamics*, 2011, *14* (1), 102–121.

[73] ____ , Giorgio Primiceri, and Andrea Tambalotti, "Investment Shocks and Business Cycles," *Journal of Monetary Economics*, 2010, *57(2)*, 132–145.

[74] Karabarbounis, Loukas, "Home production, labor wedges, and international business cycles," *Journal of Monetary Economics*, 2014, *64*, 68–84.

[75] ____ , "The labor wedge: MRS vs. MPN," *Review of Economic Dynamics*, 2014, *17* (2), 206–223.

[76] Keynes, John Maynard, "The general theory of interest, employment and money," 1936.

[77] Kiley, Michael T, "A Quantitative Comparison of Sticky-Price and Sticky-Information Models of Price Setting," *Journal of Money, Credit and Banking*, 2007, pp. 101–125.

[78] Kozicki, Sharon and PA Tinsley, "Shifting endpoints in the term structure of interest rates," *Journal of Monetary Economics*, 2001, *47* (3), 613–613.

[79] Krugman, Paul, "Inflation targets reconsidered," in "ECB Forum on Central Banking, Conference Proceedings" 2014, pp. 110–122.

[80] Lê, Thanh Hà, Trung Thành Tô, and Ngoc Thang Doan, "Welfare Costs of Shifting Trend Inflation: Staggered Wage and Price Contracts," *Bulletin of Economic Research*, 2019, *71* (2), 136–159.

[81] Lester, Robert, Michael Pries, and Eric Sims, "Volatility and welfare," *Journal of Economic Dynamics and Control*, 2014, *38*, 17–36.

[82] Liu, Zheng and Louis Phaneuf, "Technology shocks and labor market dynamics: Some evidence and theory," *Journal of Monetary Economics*, 2007, *54* (8), 2534–2553.

[83] Lubik, Thomas A and Frank Schorfheide, "Testing for indeterminacy: an application to US monetary policy," *American Economic Review*, 2004, pp. 190–217.

[84] Matos, Silvia, Marco Bonomo, Carlos Carvalho, and Rebecca Barros, "Price setting in a variable macroeconomic environment: Evidence from Brazilian CPI," in "31º Meeting of the Brazilian Econometric Society" 2009.

[85] Monti, Francesca, Riccardo Maria Masolo et al., "Ambiguity, Monetary Policy and Trend Inflation," in "2017 Meeting Papers" number 508 Society for Economic Dynamics 2017.

[86] Morrison, Catherine J, "The cyclical nature of markups in Canadian manufacturing: a production theory approach," *Journal of Applied Econometrics*, 1994, *9* (3), 269–282.

[87] Nakamura, Emi and Jon Steinsson, "Monetary non-neutrality in a multisector menu cost model," *The Quarterly journal of economics*, 2010, *125* (3), 961–1013.

[88] ___ , Jón Steinsson, Patrick Sun, and Daniel Villar, "The elusive costs of inflation: Price dispersion during the US great inflation," *The Quarterly Journal of Economics*, 2018, *133* (4), 1933–1980.

[89] Nakata, Taisuke, "Welfare costs of shifting trend inflation," *Journal of Macroeconomics*, 2014, *41*, 66–78.

[90] Negro, Marco Del and Stefano Eusepi, "Fitting observed inflation expectations," *Journal of Economic Dynamics and control*, 2011, *35* (12), 2105–2131.

[91] ___ , Marc P Giannoni, and Frank Schorfheide, "Inflation in the great recession and new keynesian models," *American Economic Journal: Macroeconomics*, 2015, *7* (1), 168–96.

[92] Nekarda, Christopher J and Valerie A Ramey, "The cyclical behavior of the price-cost markup," Technical Report, National Bureau of Economic Research 2013.

[93] Omari, S El and Louis Phaneuf, "The Multiplier for Price Stickiness," Technical Report, Working Paper, Université du Québeca Montréal 2011.

[94] Orphanides, Athanasios, "Monetary policy rules, macroeconomic stability, and inflation: A view from the trenches," *Journal of Money, credit, and Banking*, 2004, *36* (2), 151–175.

[95] Pancrazi, Roberto, "How beneficial was the Great Moderation after all?," *Journal of Economic Dynamics and Control*, 2014, *46*, 73–90.

[96] Phaneuf, Louis and Jean Gardy Victor, "Long-Run Inflation and the Distorting Effects of Sticky Wages and Technical Change," *Journal of Money, Credit and Banking*, 2019, *51* (1), 5–42.

[97] ___ and ___ , "Nominal Contracting In Macroeconomics Which Way to Go? Taylor or Calvo?," *UQAM Working Paper*, 2019.

[98] ___ , Eric Sims, and Jean Gardy Victor, "Inflation, output and markup dynamics with purely forward-looking wage and price setters," *European Economic Review*, 2018, *105*, 115–134.

[99] Portes, Luis San Vicente, "Aggregate gains of international diversification through foreign direct investment: An inquiry into the moderation of US business cycles," *Global Economy Journal*, 2007, *7* (4).

[100] Primiceri, Giorgio E, "Time varying structural vector autoregressions and monetary policy," *The Review of Economic Studies*, 2005, *72* (3), 821–852.

[101] Ravenna, Federico and Carl E Walsh, "Optimal monetary policy with the cost channel," *Journal of Monetary Economics*, 2006, *53* (2), 199–216.

[102] Rotemberg, Julio J, "Monopolistic price adjustment and aggregate output," *The Review of Economic Studies*, 1982, *49* (4), 517–531.

[103] ___ and Michael Woodford, "The cyclical behavior of prices and costs," *Handbook of macroeconomics*, 1999, *1*, 1051–1135.

[104] Rudebusch, Glenn D and Eric T Swanson, "The bond premium in a DSGE model with long-run real and nominal risks," *American Economic Journal: Macroeconomics*, 2012, *4* (1), 105–43.

[105] Sala, Luca, Ulf Söderström, and Antonella Trigari, "The output gap, the labor wedge, and the dynamic behavior of hours," 2010.

[106] Sbordone, Argia M, "Prices and unit labor costs: a new test of price stickiness," *Journal of Monetary Economics*, 2002, *49* (2), 265–292.

[107] Schmitt-Grohé, Stephanie and Martin Uribe, "Optimal simple and implementable monetary and fiscal rules," *Journal of monetary Economics*, 2007, *54* (6), 1702–1725.

[108] Shimer, Robert, "Convergence in macroeconomics: The labor wedge," *American Economic Journal: Macroeconomics*, 2009, *1* (1), 280–97.

[109] Sims, Christopher A and Tao Zha, "Were there regime switches in US monetary policy?," *American Economic Review*, 2006, *96* (1), 54–81.

[110] Sims, Eric, "Growth or the Gap? Which Measure of Economic Activity Should be Targeted in Interest Rate Rules?," Technical Report, Tech. rep 2013.

[111] Smets, Frank and Raf Wouters, "An estimated dynamic stochastic general equilibrium model of the euro area," *Journal of the European economic association*, 2003, *1* (5), 1123–1175.

[112] ____ and ____ , "Shocks and frictions in US business cycles: A Bayesian DSGE approach," *American Economic Review*, 2007, *97* (3), 586–606.

[113] Stiroh, Kevin J, "Volatility accounting: A production perspective on increased economic stability," *Journal of the European Economic Association*, 2009, *7* (4), 671–696.

[114] Stock, James H and Mark W Watson, "Has the business cycle changed? Evidence and explanations," *Monetary policy and uncertainty: adapting to a changing economy*, 2003, pp. 9–56.

[115] Stock, James H. and Mark W. Watson, "Why Has U.S. Inflation Become Harder to Forecast?," *Journal of Money, Credit and Banking*, 2007, *39*, 3–33.

[116] Taylor, John B, "Aggregate dynamics and staggered contracts," *Journal of political economy*, 1980, *88* (1), 1–23.

[117] Uribe, Martín, "The Neo-Fisher Effect: Econometric Evidence from Empirical and Optimizing Models," Technical Report, National Bureau of Economic Research 2018.

[118] Williamson, Stephen et al., "Neo-Fisherism: A Radical Idea, or the Most Obvious Solution to the Low-Inflation Problem?," *The Regional Economist*, 2016, *24* (3), 2–23.

[119] Woodford, Michael, "Interest and Prices : Foundations of A Theory of Monetary Policy," Technical Report, Princeton, N.J. Princeton University Press 2003.