Price Stickiness and Intermediate Materials Prices

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Abstract

The standard New Keynesian model requires large degree of price stickiness to match observed inflation dynamics. This is contrary to micro-evidence on prices. This paper addresses this criticism of the standard model. Firstly, the price mark-up shock is replaced with a sector-specific intermediate input-price shock. Secondly, survey data on long-term inflation expectations are also used when estimating the new model. Estimation results show that marginal costs in the model with intermediate materials are stable unlike in the model without. As a result, the new model does not require a large degree of price stickiness to match marginal costs and observed inflation. The model is estimated for both the US and the Euro area, thus showing that this result is not specific to the US only.

Keywords: Intermediate Materials Prices; Price Stickiness; Inflation; DSGE.
JEL Classification Numbers: E12, E23, E31, E32.

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1 Introduction

In New Keynesian DSGE models the degree of price stickiness plays an important role in determining how firms change their prices in response to changes in marginal costs. As price stickiness increases, firms become more forward-looking and, therefore, less responsive to changes in current marginal costs. Several studies have shown that price stickiness, as estimated in New Keynesian models, increased after the Great Recession (Del Negro et al. (2015) and Linde et al. (2016)). Linde et al. note that this increasing trend in the estimated degree of price stickiness is also found in data for the period before the Great Rrecession. The estimates for price stickiness are even higher when financial frictions and the zero lower bound are incorporated in the model. Based on these results, Del Negro et al. conclude that the near stability of inflation during the Great Recession was a consequence of a flatter New Keynesian Phillips Curve (NKPC) implied by an increase in price stickiness in their estimated model.

However, micro-data on prices do not support the increase in the degree of price stickiness. Klenow and Malin (2011) do not find any shift in the duration of price contracts before and after the Great Recession. On the contrary, data in Klenow and Malin show a trend increase in the frequency of price changes (i.e. decrease in price stickiness) since 2000 for the US. This observed discrepancy between the micro-data and the macro-estimates points towards an important source of misspecification in New Keynesian models. As Linde et al. point out, the high degree of price stickiness required by macro models to match the near stability of inflation may "reflect some other mechanism that lowered the responsiveness of inflation to the slack in production capacity."

This paper shows that the high degree of price stickiness in the standard New Keynesian models is due to the absence of an important cost channel. Specifically, marginal costs in the standard model do not capture the effect of changes in the cost of intermediate materials in firms' production. Since intermediate materials are a significant fraction of firms' total costs, firms' marginal costs are very different in a model which incorporates intermediate materials than in a model which does not. The estimation results show that marginal costs in the model with intermediate materials are relatively stable over the sample period. Consequently, the new model does not require a large degree of price stickiness to match simultaneously the model-implied marginal costs and the near stability of observed inflation.[1]

In contrast, the standard model attempts to capture the effect of intermediate price changes on inflation through an exogenous price mark-up shock.[2] Linde et al. report that the magnitude of price mark-up shocks increases when the standard model is estimated using data including the Great Recession period - a period of increasing intermediate prices. However, introducing price mark-up shocks to capture changes in intermediate prices exacerbates the problem further. When prices are sticky, a positive price mark-up shock increases inflation but decreases firms' marginal costs. Since inflation and marginal costs move in opposite directions, the model

[1]Note that introducing intermediate materials prices as an additional factor price in firms' marginal costs decreases the relative weight of real wages in marginal costs and, therefore, in firms' pricing decisions. Klenow and Malin (2011) note that firms with a higher share of labour costs in total costs change their prices less frequently. Since the standard model over-emphasises the cost share of labour in finished goods firms' production, therefore, in this way parameter estimates for price stickiness from the standard model can be argued to be consistent with micro-evidence.

[2]The price mark-up shock in the New Keynesian model is a cost shock and can be argued to capture changes in energy prices, intermediate materials prices or firms' mark-up.

requires an even larger degree of price stickiness to simultaneously match marginal costs and inflation dynamics.

Price mark-up shocks in the New Keynesian model are also criticised for an additional reason. As Chari et al. (2009) (henceforth CKM) note, it is not clear what these shocks are. While Smets and Wouters (2007) (henceforth SW) interpret these shocks as fluctuations in the degree of monopolistic competition in product markets, CKM argue that these shocks are so large that they simply cannot be shifts in market power. They term price mark-up shocks as "dubiously structural" and "subject to multiple interpretations with very different policy implications." Bils et al. (2012), by using micro-data on prices, show that the presence of large price mark-up shocks in the model leads to firm-level pricing that is inconsistent with observed firm-level pricing decisions, providing further evidence of the empirical invalidity of these shocks.

In this paper, I address this shortcoming of the model. To do so, I first take a stand on price mark-up shocks. I remove the price mark-up shocks in the model and, following De Walque et al. (2006), Huang and Liu (2005) and Aoki (2001), consider supply-side shocks that arise from changes in relative prices of intermediate materials. I extend the SW model to have two sectors with an input-output linkage between the sectors. In one of the two sectors, intermediate materials are produced. The other sector produces finished goods. Intermediate materials are used as an input to produce finished goods. Finished goods are then combined with a small fraction of the intermediate materials to produce final consumption goods. Firms in both sectors adjust their prices according to Calvo (1983). I assume that the intermediate sector is subject to a sector-specific shock. Given this set-up, prices in the finished-goods sector are set on the basis of a mark-up over expected marginal costs of the finished goods producing firms and relative prices in the finished goods sector. The intermediate prices are also set on the basis of a mark-up over expected marginal costs of the intermediate-goods producing firms and relative prices in the intermediate materials sector. Additionally, intermediate prices are also subject to a sector-specific shock. The rest of the model is exactly the same as the SW model.

Secondly, in addition to standard macroeconomic variables, I also include data on long-term inflation expectations when estimating the model. The motivation for including survey expectations data is provided in Coibion et al. (2017), Milani (2012), Del Negro and Eusepi (2011) and Kilian (2008). Coibion et al. (2017) provide a recent survey on how incorporating survey data on inflation expectations can solve important puzzles that arise under the assumption of full-information rational expectations. Milani (2012) also observe how including survey expectations "can allow researchers to better estimate not only expectations themselves, but also the structural shocks in the model, news, as well as structural parameters." Finally, Del Negro and Eusepi (2011) and Kilian (2008) note that the inflation expectations data contain information about people's beliefs regarding the Fed's inflation objectives.

Other studies have looked at the role of intermediate materials in the context of international trade and global supply chains. Kose and Yi (2001) show that incorporating trade in intermediate materials in the standard trade model helps in matching observed business cycle synchronisation across trading partners. Burstein et al. (2008) highlight that the increase in intensity of trade in intermediate materials makes international business cycles more synchronised. Johnson (2014) looks further into the assumptions about trade elasticities which generate higher business cycle synchronization across trading partners in a model with trade in intermediate materials. Yi (2003) has also shown how an international business cycle model with intermediate materials can explain 50 percent of the observed U.S. trade growth between 1962 and 1999. On the contrary, the explanatory power of the model with no intermediate materials is only half as much.

This paper is also closely related to papers by Kara (2015), Gali et al. (2011) and Justiniano et al. (2011). Kara shows that a model with heterogeneous price durations no longer requires large price mark-up shocks unlike in the standard model. On the other hand, Gali et al. (2011) and Justiniano et al. (2011) focus on wage mark-up shocks. Justiniano et al. argue that wage mark-up shocks in the SW model represent measurement errors in wages. Gali et al. show that wage mark-up shocks become less important in the SW model when unemployment is used as an observed variable.

The results explained in this paper were also pointed out in Kara and Pirzada (2016). Kara and Pirzada showed that replacing price mark-up shock with intermediate input-price shock decreases the estimate for the degree of price stickiness in the model. However, the discussion in Kara and Pirzada focused on providing an explanation for the missing deflation puzzle. This paper specifically studies the transmission mechanism which leads to the decrease in the required degree of price stickiness for the New Keynesian model to match observed inflation. Moreover, here I also estimate the model for the Euro area, thus showing that this result is not specific to the US only.

The rest of the paper is organised as follows. Section 2 describes the model. Section 3 explains the estimation strategy. Section 4 presents the estimation results. Section 5 explains why including intermediate materials sector in the standard model helps the new model match observed inflation without requiring a large degree of price stickiness. Section 6 tests if the main results in this paper are robust to changes in structural parameters. Finally, section 7 concludes.

2 Model

This paper adopts the input-output framework developed in Kara and Pirzada (2016) and Pirzada (2017). Kara and Pirzada (2016) extends the model in SW to allow for input-output linkages between intermediate materials and finished goods producing sectors. While the production of intermediate materials requires labour and capital as inputs, the production of finished goods requires labour, capital and intermediate materials as inputs. Finished goods and a fraction of intermediate materials are combined to produce final consumption goods that are consumed by households.[3] Finally, the modelling of households and the monetary policy are standard New Keynesian.

In the rest of this section, I describe the behaviour of firms and the input-output linkages across the two sectors. All lower case variables are detrended variables and therefore considered as stationary processes with well-defined steady state. Detrending is done using deterministic labour-augmenting technological progress consistent

[3]The model in Kara and Pirzada (2016) also incorporate the financial frictions framework of Bernanke et al. (1999). I abstract from financial frictions in this paper.

with a balanced steady-state growth path.

2.1 Intermediate and Finished Goods

I assume two sectors in the economy: an input sector (m); and, an output sector (s). The input sector produces intermediate materials whereas the output sector produces finished consumption goods. There is a continuum of firms, $f \in [0,1]$, in both sectors. Firms in both sectors produce under an imperfectly competitive market and have monopoly power over a differentiated good. Intermediate materials produced in sector $'m'$ are used by finished goods producing firms to produce finished consumption goods. A small fraction of intermediate materials is combined with finished consumption goods to produce the final consumption good, C_t.[4] C_t enters the utility function of the representative household. Aggregation is done according to a Dixit-Stiglitz aggregator such that:

$$C_t = \left[(1-\bar{\alpha})(Y_t^s)^{\frac{1}{1+\rho}} + \bar{\alpha}(Y_t^m)^{\frac{1}{1+\rho}}\right]^{1+\rho} \tag{1}$$

where $\frac{1+\rho}{\rho}$ is the elasticity of substitution between finished goods, Y_t^s, and intermediate goods, Y_t^m. When estimating the model, the elasticity of substitution is assumed to equal 1. This reduces aggregation in equation (1) to the Cobb-Douglas case. $\bar{\alpha}$ is the weight on intermediate materials in the final consumption good. The corresponding price index is:

$$P_t = \left[(1-\bar{\alpha})^{\frac{1+\rho}{\rho}}(P_t^s)^{-\frac{1}{\rho}} + (\bar{\alpha})^{\frac{1+\rho}{\rho}}(P_t^m)^{-\frac{1}{\rho}}\right]^{-\rho} \tag{2}$$

[4]Such use of the intermediate materials can be thought as packaging and transportation of the finished goods before they can be sold as final consumption goods.

where P_t is the general price index, P_t^m is the price of intermediate materials and P_t^s is the price level in the finished goods sector. Each firm within the two sectors produces a single differentiated good, $Y_{f,t}^s$ and $Y_{f,t}^m$, which are combined to produce a final good in each sector, Y_t^s and Y_t^m, respectively. Y_t^s and Y_t^m are given by:

$$Y_t^s = \left[\int_0^1 (Y_{f,t})^{1/(1+\rho)} df \right]^{1+\rho} \tag{3}$$

$$Y_t^m = \left[\int_0^1 (Y_{f,t}^m)^{1/(1+\rho)} df \right]^{1+\rho} \tag{4}$$

$(1+\rho)/\rho$ is the elasticity of substitution between the differentiated goods produced in each sector. The demand functions for differentiated goods in the two sectors are given by:

$$Y_{f,t}^s = \left((1-\bar{\alpha}) \frac{P_t}{P_{f,t}^s} \right)^{\frac{1+\rho}{\rho}} Y_t \tag{5}$$

$$Y_t^{f,m} = \left(\bar{\alpha} \frac{P_t}{P_{f,t}^m} \right)^{\frac{1+\rho}{\rho}} Y_t \tag{6}$$

In what follows, I will first describe the finished goods sector and then the intermediate sector. The production function of finished goods producing firms is of the form:

$$Y_{f,t}^s = \left(Y_{f,t}^m \right)^{\mu} \left[A_t (K_{f,t}^s)^{\alpha} (\gamma^t L_{f,t}^s)^{1-\alpha} \right]^{(1-\mu)} - \gamma^t \Phi \tag{7}$$

where, in the absence of fixed costs, μ and α has the interpretation of output elasticity with respect to intermediate materials and output-capital elasticity, respectively. $Y_{f,t}^m$ denotes intermediate sector goods used as inputs by firm f in the finished goods sector; $L_{f,t}^s$ is a composite of labour input; $K_{f,t}^s$ is capital services; and, Φ is the fixed cost. γ^t represents the labour-augmenting deterministic growth rate in the economy. A_t is the productivity shock which follows an AR(1) process where ρ_a is the persistence parameter and σ_a is the standard deviation of the shock.

Unlike the finished goods sector, firms in the intermediate sector have labor and capital as the only two factor inputs such that their production function is given by:

$$Y_{f,t}^m = A_t (K_{f,t}^m)^\alpha (\gamma^t L_{f,t}^m)^{1-\alpha} - E_t \gamma^t \Phi \tag{8}$$

where $L_{f,t}^m$ is a composite of labour input and $K_{f,t}^m$ is capital services used in the intermediate sector. E_t is a stochastic shock which imposes some form of fixed cost on intermediate materials producing firms. E_t can be interpreted to capture exogenous factors which disrupt the supply-chain. Such factors may include bad weather, rare disasters, wars and civil strife.[5] I assume that E_t follows an ARMA(1,1) process of the form:

$$e_t = \rho_e e_{t-1} + \epsilon_t^e - \mu_e \epsilon_{t-1}^e \tag{9}$$

where $e_t = \ln E_t$ and ϵ_t^e is an i.i.d. shock. In the impulse response analysis (not reported for brevity), a positive disruption shock decreases the supply of intermediate materials. Consequently, prices of intermediate materials increase. This increases the cost of production for finished goods producing firms. As a result, finished goods output contracts as well.[6]

[5]Barro (2006) and Gourio (2012) study disaster shocks as shocks to capital. I do not adopt this approach. As will become clear in section 5, the main channel through which intermediate materials prices affect the required degree of price rigidities in the model is through marginal costs. Introducing E_t as shock to capital stock will have direct implications for the rental rate of capital and, consequently, for firms' marginal costs. This will introduce an additional source of fluctuation in marginal costs and will, therefore, make it difficult to isolate the effect of intermediate materials prices.

[6]Another reason for including the E_t shock is a technical one. Since I include an additional data series on intermediate prices when estimating the model, I need an additional shock to ensure that the number of observed variables is equal to the number of shocks.

Prices in both sectors are set according to Calvo pricing with no partial indexation. Profit maximisation by the price-setting firms in the finished goods sector gives the following (log-linearised) sectoral NKPC:

$$\pi_t^s = \beta\gamma^{1-\sigma_c}\pi_{t+1}^s + \kappa^s(\bar{mc}_t^s - \bar{p}_t^s) \tag{10}$$

where $\bar{p}_t^s = p_t^s - p_t$ is the relative price in the finished goods sector. κ^s is the slope coefficient of the form:

$$\kappa^s = \frac{(1-\zeta_p\beta\gamma^{1-\sigma_c})(1-\zeta_p)}{\zeta_p((\phi_p - 1)\epsilon_p + 1)} \tag{11}$$

and $\bar{mc}_t^s$ is the real marginal cost in the finished goods sector:

$$\bar{mc}_t^s = (1-\mu)\big[\alpha r_t^k + (1-\alpha)w_t - a_t\big] + \mu\bar{p}_t^m \tag{12}$$

ζ_p in equation (11) is the Calvo parameter for price stickiness. β is the discount factor. σ_c is the inverse of intertemporal elasticity of substitution. In equation (12), w_t is the real wage and r_t^k is the real rental rate of capital.

The log-linearised NKPC in the intermediate sector is given by:

$$\pi_t^m = \beta\gamma^{1-\sigma_c}\pi_{t+1}^m + \kappa^m(\bar{mc}_t^m - \bar{p}_t^m) + a_t^f \tag{13}$$

where $\bar{p}_t^m = p_t^m - p_t$ is the relative price in the intermediate materials sector. κ^m is the slope coefficient of the form:

$$\kappa^m = \frac{(1-\zeta_p^m\beta\gamma^{1-\sigma_c})(1-\zeta_p^m)}{\zeta_p^m((\phi_p - 1)\epsilon_p + 1)} \tag{14}$$

and $\bar{mc}_t^m$ is the real marginal cost in the intermediate sector:

$$\bar{mc}_t^m = \alpha r_t^k + (1-\alpha)w_t - a_t \tag{15}$$

ζ_p^m is the Calvo parameter for price stickiness specific to the intermediate sector.

I replace the price mark-up shock in the finished goods sector with an input-price shock in the intermediate materials sector. As a result, intermediate materials prices are subject to an exogenous input-price shock, a_t^f. a_t^f follows an ARMA(1,1) process of the form:

$$a_t^f = \rho_{a^f} a_{t-1}^f + \epsilon_t^{a^f} - \mu_{a^f} \epsilon_{t-1}^{a^f} \tag{16}$$

Finally, the aggregation of value-added output, labor and capital is done according to Cobb-Douglas. The log-linearised aggregate output is given by

$$y_t = (1 - \Psi) y_t^s + \Psi y_t^m \tag{17}$$

where Ψ is the weight on intermediate materials in GDP.[7] The log-linearised version of aggregate labour and capital are given by:

$$\begin{aligned} l_t &= \mu^u l_t^s + (1 - \mu^u) l_t^m \\ k_t &= \mu^u k_t^s + (1 - \mu^u) k_t^m \end{aligned} \tag{18}$$

where μ^u is the weight on labor and capital employed in the intermediate materials sector.

The rest of the model equations are similar to SW and are given in Appendix A. In the next section, I describe the data and the estimation strategy.

[7]In the rest of this paper, I assume that the weight on intermediate materials in GDP is the same as the weight on intermediate materials in aggregate consumption index. This approximation simplifies calibration. As a result, when all of the intermediate materials are used by the finished goods producing firms (i.e. $\bar{\alpha} = 0$), GDP equals finished sector output.

3 Estimation Strategy

I use Bayesian estimation techniques, as in Smets and Wouters (2003), to estimate the model in this paper.[8] [9] The model is estimated for both the US and the EU over the sample period of 1985Q1-2013Q4. In the rest of the paper, the models for the US and the EU are referred to as KP-US and KP-EU, respectively. I also estimate the model variants without the intermediate sector as my baseline models for both regions, SW-US and SW-EU.

3.1 Data

I use nine macroeconomic series at the quarterly frequency for the US economy. Seven of the data series are the same as in SW: the log difference of real GDP, real consumption, real investment, real wage, log hours worked, log difference of the GDP deflator and the federal funds rate. In addition, I also include data on 10-year inflation expectations and the log difference of real intermediate materials prices. The Blue Chip Economic Indicators survey and the Survey of Professional Forecasters are used to obtain data for 10-year inflation expectations. For data on intermediate materials prices, seasonally-adjusted intermediate price data are obtained from the St. Louis FED database which is then deflated using the GDP deflator.[10]

[8] See An and Schorfheide (2007) for an excellent survey on these methods.

[9] I ensure an acceptance rate of around 30% and allow for 20,000 replications for the Metropolis-Hastings algorithm. Estimation is done in Dynare 4.3.3.

[10] Producer Price Index by Commodity Intermediate Materials: Supplies & Components (PPI-ITM).

Measurement equations relating data to model variables are:

$$
\begin{aligned}
&OutputGrowth && = \bar{\gamma} + 100(y_t - y_{t-1}) \\
&ConsumptionGrowth && = \bar{\gamma} + 100(c_t - c_{t-1}) \\
&InvestmentGrowth && = \bar{\gamma} + 100(i_t - i_{t-1}) \\
&RealWageGrowth && = \bar{\gamma} + 100(w_t - w_{t-1}) \\
&IntermediateInflation && = \bar{\gamma} + 100(\bar{p}^m_t - \bar{p}^m_{t-1}) \\
&HoursWorked && = \bar{l} + 100 l_t \\
&Inflation && = \pi_* + 100\pi_t \\
&FederalFundsRate && = R_* + 100 R_t \\
&10yrInflExp && = \pi_* + E_t \frac{1}{40}\left(\Sigma_{k=1}^{40}\pi_{t+k}\right)
\end{aligned}
\tag{19}
$$

where all the variables are in percent. $\bar{\gamma} = 100(\gamma - 1)$ is the quarterly trend growth rate of real output, consumption, investment, wages and intermediate goods prices. $\bar{l}$ is the steady-state hours worked. π_* and R_* are the steady state level of inflation and the nominal interest rate, respectively.

Following Smets and Wouters (2003) and Smets and Wouters (2005), data for the EU is obtained from the Area-Wide Model (AWM) database developed by the ECB. I use data from the 14th update of the AWM database with Euro area composition fixed to 18 members. The EU model is estimated using the same macro variables as the US except for two differences. Firstly, the data for inflation expectations are the 5-year ahead inflation expectations from the ECB Survey of Professional Forecasters. Furthermore, the inflation expectations series only starts from 1999Q1. Secondly, due to lack of data on hours worked, employment data are used instead.

The measurement equations relating inflation expectaions and employment data to the model are:

$$\begin{aligned} 5yrInflExp &= \pi_* + E_t \frac{1}{20} \left(\Sigma_{k=1}^{20} \pi_{t+k} \right) \\ EmploymentGrowth &= \bar{e} + 100(e_t - e_{t-1}) \end{aligned} \tag{20}$$

As in Smets and Wouters (2003), I relate labour hours in the model to employment data using the following relation:

$$e_t = \beta e_{t+1} + \frac{(1-\beta\zeta_e)(1-\zeta_e)}{\zeta_e}(l_t - e_t) \tag{21}$$

where e_t is the number of people employed and ζ_e is the fraction of firms able to adjust employment to their desired level of total labour input. Intermediate price data for the Euro area are obtained from the *Eurostat* database which is then deflated using the GDP deflator. Intermediate price data for the Euro area start from 1991Q1.[11]

3.2 Calibration and Prior Distributions

I calibrate structural parameters governing the intermdiate materials sector in the model. Following Basu (1995), μ is calibrated to target the revenue share of intermediate inputs in gross output. The revenue share of intermediate inputs in gross output is 44% and 53% for the US and the Euro area, respectively.[12] This implies μ to equal 0.484 for the US and 0.582 for the EU. The weight on intermediate materials in the final consumption good, $\bar{\alpha}$, is kept fixed at 2%.

[11] Euro area 18 (fixed composition) - Producer Price Index, domestic sales, MIG Intermediate Goods Industry.

[12] The revenue share for the US is obtained from the Input-Output tables provided by the Bureau of Economic Analysis. For the Euro area, I take the weighted average of revenue shares for Germany, France, Italy and Spain. The Input-Output tables for these Euro area economies are obtained from the OECD database.

Finally, following Woodford (2003) and De Walque et al. (2006), the elasticity of substitution between finished and intermediate goods, $(1+\rho)/\rho$, is assumed to equal 1. Table 1 reports the values for the parameters that are fixed in estimation.

Parameter	Definition	Values
β	Discount factor	0.9995
δ	Depreciation rate	0.025
ϵ_w	Curvature of the Kimball labour market aggregator	10
ϵ_p	Curvature of the Kimball goods market aggregator	10
g_y	Government spending-output ratio	0.18
μ	Output-Intermediate materials elasticity for the US	0.484
μ	Output-Intermediate materials elasticity for the EU	0.582
$\bar{\alpha}$	Weight on intermediate materials in the final consumption good	0.02
$(1+\rho)/\rho$	Elasticity of substitution between differentiated goods	1

Table 1: **Calibrated Parameters**

Note: This table gives the values for the parameters which are fixed in the model.

Assumptions regarding prior distributions on structural parameters are summarised in Tables 2 and 3 for the US and in Tables 4 and 5 for the EU. Prior distributions for identical parameters are the same for both the US and the EU.

Most of the assumptions are the same as those in SW. Here I will discuss the ones where I depart from SW. I assume that the share of labor and capital employed in the intermediate sector, μ^u, is similar to the share of intermediate revenue in gross output. However, in the absence of data on how much labour and capital is employed in the intermediate materials producing sector, I specify a relatively loose prior. I, therefore, assume that μ^u has a Normal prior distribution with mean 0.5 and standard deviation 0.25.

Calvo parameters for intermediate and finished goods sectors follow a Beta prior distribution with standard deviation of 0.10. However, prices in the intermediate sector are relatively more flexible with a prior mean of 0.40. The prior mean for the Calvo parameter in the finished goods sector is 0.50. This is in line with the micro-evidence on observed price duration reported in Nakamura and Steinsson (2008). Contrary to SW, the price mechanism in the model with intermediate materials does not include price indexation. This is in line with Kara (2015) and Bils et al. (2012). Bils, Klenow and Malin find no evidence of price indexation in the micro-level data on prices. Instead, prices remain fixed for several periods.

In the model with intermediate materials, I replace the price mark-up shock with two supply side shocks, e_t and a_t^f. The persistence parameters, ρ_e and ρ_{a^f}, for these two shocks follow a Beta prior distribution with mean 0.50 and standard deviation 0.20. Prior distributions for μ_e and μ_{a^f} also follow a Beta prior distribution with mean 0.50 and standard deviation 0.20. The standard deviation of the intermediate input shock, σ_{a^f}, follows an Inverse Gamma distribution with mean 2.50 and standard deviation 2.0. σ_e also follows an Inverse Gamma distribution with mean 0.10 and standard deviation 2.0.

Prior distributions for the remaining parameters in the model are identical to those in SW.

4 Estimation Results

Including survey data on long-term inflation expectations significantly improves the fit of the model to data. For the US, the log data density of the model with intermediate materials improves from -905.30 to -681.82 when data on inflation expectations are included. Similarly, for the EU, the log data density improves from -773.60 to -664.44. In the rest of this section, I compare the posterior mean for parameters in the model with and without intermediate materials for both the US and the EU.

Table 2 and Table 4 report the posterior means for the structural parameters from the models for the US and the EU. The posterior means for the parameters governing the shock processes are reported in Table 3 and Table 5. The prior and posterior standard deviations are also reported for the corresponding parameters.

4.1 The U.S.

Most structural parameters are similar across the models with and without intermediate materials. However, there are important differences in parameters governing the price setting behaviour of firms; the labor market; and monetary policy. I discuss the implication for price setting behaviour of firms in more detail in section 5. Here I will discuss the implication for the labour market and monetary policy. Labour, in the KP-US, is more elastic than in the SW-US. σ_l has a posterior mean of 2.24 in the KP-US against 1.38 in the SW-US. Wages in the KP-US are more rigid with the Calvo parameter for wages, ζ_w, estimated at 0.84. Even though ζ_w is lower in

	Prior Distribution			Posterior Distribution			
				SW-US		KP-US	
	type	Mean	st. dev.	Mean	st. dev.	Mean	st. dev
structural parameters:							
φ	Normal	4.000	1.500	4.971	1.015	5.577	1.236
σ_c	Normal	1.500	0.375	1.665	0.258	1.416	0.196
h	Beta	0.700	0.100	0.493	0.064	0.605	0.072
ζ_w	Beta	0.500	0.100	0.785	0.038	0.836	0.034
σ_l	Normal	2.000	0.750	1.385	0.499	2.247	0.618
ζ_p	Beta	0.500	0.100	0.859	0.031	0.616	0.041
ζ_p^m	Beta	0.400	0.100	-	-	0.469	0.076
ι_w	Beta	0.500	0.150	0.407	0.148	0.364	0.145
ψ	Beta	0.500	0.150	0.889	0.045	0.928	0.029
ϕ_p	Normal	1.250	0.120	1.463	0.077	1.149	0.048
r_π	Normal	1.500	0.250	1.802	0.199	2.188	0.192
ρ_r	Beta	0.750	0.100	0.875	0.019	0.854	0.020
r_y	Normal	0.130	0.050	0.073	0.022	0.009	0.009
$r_{\triangle y}$	Normal	0.125	0.050	0.151	0.019	0.067	0.020
π_*	Gamma	0.625	0.100	0.682	0.072	0.716	0.052
$\bar{l}$	Normal	0.000	2.000	0.938	1.032	-0.453	0.997
γ	Normal	0.400	0.100	0.417	0.047	0.296	0.062
α	Normal	0.300	0.050	0.191	0.035	0.073	0.040
μ^u	Normal	0.500	0.250	-	-	0.713	0.020

Table 2: **Prior and Posterior Estimates of Structural Parameters for the US**

Note: This table reports the prior and posterior estimates for the structural parameters from the models for the US. The parameter estimates are reported for both the models - with intermediate materials (i.e. KP-US) and without intermediate materials (i.e. SW-US).

the SW-US, it comes at the cost of high wage indexation. ι_w has a posterior mean of 0.41 in the SW-US which is higher than 0.36 in the KP-US.

Posterior estimates for the parameters on the Taylor rule are also significantly different across the two models. In KP-US, the Federal Reserve responds more aggressively to inflation and less aggressively to *output gap* and *change in output gap*. The degree of interest rate smoothing, ρ_r, is similar in both SW-US and KP-US. Another important difference worth highlighting is the estimate for the output-capital elasticity. Posterior mean for α is lower in the KP-US than in the SW-US. With an estimate of only 0.07, α is significantly smaller in the KP-US than in the data. In another exercise, instead of estimating, I calibrate α to equal 0.3. The results in this paper are robust to changes in the value of α. Finally, the weight on intermediate labour and capital in total labour and capital is estimated at 0.71.

The replacement of the price mark-up shock with the input-price shock and the supply-chain shock in the KP-US also has important implications for other shock processes. The standard deviation of the productivity shock in the KP-US is more than twice of that in the SW-US. This is in line with Basu (1995). Basu (1995) shows that changes in productivity are larger as intermediate materials become more important in firms' production. The standard deviation of the inflation targeting shock, σ_{π^*}, is also significantly higher in the KP-US. However, the standard deviation of the monetary policy shock decreases from 0.10 to 0.02. On the other hand, the inflation targeting shock is less persistent whereas the monetary policy shock is more persistent in the KP-US.

Reflecting the volatility in intermediate materials prices, the standard deviation

	Prior Distribution			Posterior Distribution			
				SW-US		KP-US	
	type	Mean	st. dev.	Mean	st. dev.	Mean	st. dev
persistence of exogenous shocks:							
ρ_a	Beta	0.500	0.200	0.988	0.003	0.992	0.004
ρ_{a^f}	Beta	0.500	0.200	-	-	0.994	0.002
ρ_e	Beta	0.500	0.200	-	-	0.986	0.005
ρ_b	Beta	0.500	0.200	0.796	0.049	0.702	0.062
ρ_g	Beta	0.500	0.200	0.964	0.011	0.957	0.012
ρ_μ	Beta	0.500	0.200	0.871	0.024	0.780	0.081
ρ_r	Beta	0.500	0.200	0.461	0.067	0.964	0.008
ρ_π	Beta	0.500	0.200	0.827	0.042	-	-
ρ_{π^*}	Beta	0.500	0.200	0.984	0.006	0.500	0.059
ρ_w	Beta	0.500	0.200	0.565	0.154	0.656	0.101
μ_p	Beta	0.500	0.200	0.692	0.073	-	-
μ_w	Beta	0.500	0.200	0.865	0.054	0.860	0.040
μ_{a^f}	Beta	0.500	0.200	-	-	0.821	0.053
μ_e	Beta	0.500	0.200	-	-	0.170	0.067
ρ_{ga}	Normal	0.500	0.250	0.479	0.097	0.017	0.048
σ_a	Inv.Gamma	0.100	2.000	0.402	0.028	0.978	0.084
σ_{a^f}	Inv.Gamma	1.000	2.000	-	-	2.738	0.334
σ_e	Inv.Gamma	0.100	2.000	-	-	2.566	0.298
σ_b	Inv.Gamma	0.100	2.000	0.077	0.011	0.093	0.015
σ_g	Inv.Gamma	0.010	2.000	0.426	0.028	0.471	0.032
σ_μ	Inv.Gamma	0.100	2.000	0.298	0.060	0.310	0.031
σ_r	Inv.Gamma	0.100	2.000	0.103	0.008	0.017	0.002
σ_π	Inv.Gamma	0.100	2.000	0.120	0.015	-	-
σ_{π^*}	Inv.Gamma	0.100	2.000	0.038	0.006	0.362	0.039
σ_w	Inv.Gamma	0.100	2.000	0.540	0.045	0.533	0.039

Table 3: **Prior and Posterior Estimates of Shock Processes for the US**
Note: This table reports the prior and posterior estimates for the parameters governing the shock processes from the models for the US. The parameter estimates are reported for both the models - with intermediate materials (i.e. KP-US) and without intermediate materials (i.e. SW-US).

of the input-price shock, σ_{a^f}, has a posterior mean of 2.74. The input-price shock is also highly persistent. While the supply-chain shock is also highly persistent and has a standard deviation of 2.57, it only has a limited role in explaining business cycle fluctuations. The variance decomposition analysis shows that the supply-chain shock only explains 1.11% and 0.94% of the variation in output growth and inflation, respectively. More importantly, e_t only explains 0.16% of the variation in finished goods producing firms' marginal costs.[13] On the other hand, the input-price shock explains 14.4%, 32.8% and 37.6% of the variation in output growth, inflation and finished goods producing firms' marginal costs, respectively.

4.2 The EU

The differences in the posterior mean for structural parameters from models for the EU are similar to those for the US. In KP-EU, the ECB targets inflation more aggressively. r_π has a posterior mean of 2.45 which is significantly greater than the posterior mean of 1.55 in SW-EU. On the other hand, the posterior estimate for parameters on the *output gap* and *change in output gap* is only 0.04 and .01, respectively. The estimate for α is also less than in SW-EU. It is also worth highlighting that the trend growth rate, γ, is lower for both the US and the EU in the model with intermediate materials than in the model wiithout intermediate materials.

Similarly, as in the case of US, replacing the price mark-up shock with the two supply side shocks increases the standard deviation of the productivity shock from 0.29 in the SW-EU to 1.56 in the KP-EU. Likewise, while the standard deviation

[13]Recall that the motivation for introducing the e_t shock as a shock to fixed costs instead of capital stock was to avoid introducing additional sources of fluctuations in firms marginal costs.

	Prior Distribution			Posterior Distribution			
				SW-EU		KP-EU	
	type	Mean	st. dev.	Mean	st. dev.	Mean	st. dev
structural parameters:							
φ	Normal	4.000	1.500	4.935	0.971	4.107	0.364
σ_c	Normal	1.500	0.375	1.928	0.250	0.955	0.043
h	Beta	0.700	0.100	0.459	0.039	0.588	0.029
ζ_e	Beta	0.500	0.100	0.125	0.049	0.673	0.027
ζ_w	Beta	0.500	0.100	0.824	0.026	0.520	0.017
σ_l	Normal	2.000	0.750	2.165	0.394	3.544	0.193
ζ_p	Beta	0.500	0.100	0.844	0.023	0.591	0.019
ζ_p^m	Beta	0.400	0.100	-	-	0.637	0.018
ι_w	Beta	0.500	0.150	0.238	0.092	0.248	0.033
ψ	Beta	0.500	0.150	0.131	0.063	0.017	0.005
ϕ_p	Normal	1.250	0.120	1.863	0.077	1.301	0.018
r_π	Normal	1.500	0.250	1.550	0.173	2.446	0.044
ρ_r	Beta	0.750	0.100	0.891	0.020	0.864	0.018
r_y	Normal	0.130	0.050	0.165	0.033	0.041	0.008
$r_{\triangle y}$	Normal	0.125	0.050	0.118	0.023	0.011	0.002
π_*	Gamma	0.625	0.100	0.423	0.048	0.629	0.018
$\bar{l}$	Normal	0.000	2.000	0.070	0.017	0.021	0.014
γ	Normal	0.400	0.100	0.258	0.030	0.121	0.014
α	Normal	0.300	0.050	0.260	0.041	0.126	0.014
μ^u	Normal	0.500	0.250	-	-	0.630	0.023

Table 4: **Prior and Posterior Estimates of Structural Parameters for the EU**

Note: This table reports the prior and posterior estimates for the structural parameters from the models for the EU. The parameter estimates are reported for both the models - with intermediate materials (i.e. KP-EU) and without intermediate materials (i.e. SW-EU).

	Prior Distribution			Posterior Distribution			
				SW-EU		KP-EU	
	type	Mean	st. dev.	Mean	st. dev.	Mean	st. dev
persistence of exogenous shocks:							
ρ_a	Beta	0.500	0.200	0.971	0.003	0.850	0.018
ρ_{a^f}	Beta	0.500	0.200	-	-	0.665	0.036
ρ_e	Beta	0.500	0.200	-	-	0.962	0.020
ρ_b	Beta	0.500	0.200	0.868	0.093	0.847	0.018
ρ_g	Beta	0.500	0.200	0.998	0.000	0.997	0.001
ρ_μ	Beta	0.500	0.200	0.735	0.035	0.286	0.037
ρ_r	Beta	0.500	0.200	0.512	0.073	0.924	0.013
ρ_π	Beta	0.500	0.200	0.643	0.096	-	-
ρ_{π^*}	Beta	0.500	0.200	0.978	0.006	0.358	0.040
ρ_w	Beta	0.500	0.200	0.780	0.055	0.993	0.001
μ_p	Beta	0.500	0.200	0.475	0.159	-	-
μ_w	Beta	0.500	0.200	0.936	0.024	0.642	0.052
μ_{a^f}	Beta	0.500	0.200	-	-	0.329	0.076
μ_e	Beta	0.500	0.200	-	-	0.129	0.028
ρ_{ga}	Normal	0.500	0.250	0.472	0.173	0.179	0.055
σ_a	Inv.Gamma	0.100	2.000	0.288	0.022	1.556	0.141
σ_{a^f}	Inv.Gamma	1.000	2.000	-	-	1.055	0.098
σ_e	Inv.Gamma	0.100	2.000	-	-	2.003	0.192
σ_b	Inv.Gamma	0.100	2.000	0.070	0.022	0.086	0.010
σ_g	Inv.Gamma	0.010	2.000	0.675	0.044	0.688	0.052
σ_μ	Inv.Gamma	0.100	2.000	0.317	0.030	0.504	0.039
σ_r	Inv.Gamma	0.100	2.000	0.123	0.009	0.022	0.003
σ_π	Inv.Gamma	0.100	2.000	0.145	0.016	-	-
σ_{π^*}	Inv.Gamma	0.100	2.000	0.044	0.007	0.415	0.041
σ_w	Inv.Gamma	0.100	2.000	0.186	0.013	0.177	0.022

Table 5: **Prior and Posterior Estimates of Shock Processes for the EU**
Note: This table reports the prior and posterior estimates for the parameters governing the shock processes from the models for the EU. The parameter estimates are reported for both the models - with intermediate materials (i.e. KP-EU) and without intermediate materials (i.e. SW-EU).

of the inflation targeting shock increases from 0.04 to 0.42, the standard deviation of the monetary policy shock decreases from 0.12 to 0.02. The inflation targeting shock also becomes less persistent, whereas the monetary policy shock becomes more persistent in the KP-EU.

The input-price shock in the KP-EU is significantly less persistent than in the KP-US. The posterior mean of the standard deviation of the input-price shock is 1.06 in the KP-EU which is also smaller than the posterior mean of 2.74 in the KP-US. The parameter estimates for the supply-chain shock in the KP-EU are close to those in the KP-US. Similar to the US, the supply-chain shock only explains 2.37%, 0.58% and 0.35% of the variation in output growth, inflation and finished goods producing firms' marginal costs, respectively. The input-price shock plays an important role in explaining business cycle fluctions. It explains 13.4%, 28.02% and 24.48% of the variation in output growth, inflation and finished goods producing firms' marginal costs, respectively.

The fraction of firms able to adjust employment to their desired level of total labour input, ζ_e, is significantly higher in the KP-EU. σ_l also increases from 1.39 in the SW-EU to 2.25 in the KP-EU. The implication for wage rigidities is, however, different for the EU than for the US. Wages become more flexible in the model with intermediate materials. ζ_w decreases from 0.82 in the SW-EU to 0.52 in the KP-EU. In contrast, wages became more sticky in the model with intermediate materials for the US. Finally, the share of intermediate sector labour and capital in total labour and capital is estimated at 0.63.

5 Price Stickiness and the Phillips Curve

Prices in the KP-US are less rigid. The Calvo parameter for prices in the finished goods sector, ζ_p, is estimated at 0.62. An estimate of 0.62 suggests an average age of price contracts of 3.13 quarters. This degree of price rigidity is in line with the micro-evidence provided by Klenow and Malin (2011). Prices in the intermediate materials sector are also more flexible than in the finished goods producing sector. The average age of the price contract in the intermediate materials sector is only 1.88 quarters. However, with ζ_p of 0.86, the degree of price rigidity in the SW-US model is significantly larger than that suggested by the micro-data on prices. The posterior mean of 0.86 for ζ_p implies an average age of the price contract of 7.14 quarters.

Including intermediate materials in models for the EU also has similar implications. The model with intermediate materials requires a relatively smaller estimate for the Calvo parameter in order to match observed inflation dynamics. The posterior mean for ζ_p is 0.59 in the KP-EU suggesting an average age of price contract of 2 quarters. The average age of the price contract in the intermediate materials sector is almost similar to the finished goods sector. Both the estimates are in line with the micro-evidence provided by Klenow and Malin (2011). In contrast, the posterior mean for ζ_p in the SW-EU is 0.84. This implies an average age of the price contract of 6.25 quarters.

Posterior estimates for structural parameters imply that the NKPC is significantly steeper in the model with intermediate materials. The slope of the finished goods sector NKPC (i.e. κ^s) is 0.10 in the KP-US whereas it is only 0.004 in the SW-US. Similarly, estimation results for the EU suggest that the slope of the finished sector NKPC is 0.07 in the KP-EU. The estimate for κ^s is 0.003 in the SW-EU. The estimation results in this paper, therefore, do not support a flattening of the NKPC after the Great Recession as suggested by models without intermediate materials.

5.1 Role of Price Mark-up and Intermediate Input-Price Shocks

This section explains the mechanism which leads to a smaller degree of price rigidities and, therefore, a relatively steeper NKPC in the model with intermediate materials. Since inflation in both models, with and without intermediate materials, depends on current and expected marginal costs, it is instructive to compare the behaviour of marginal costs in the two models. Figure 1 and figure 2 compare the marginal cost of the US and the EU, respectively, with and without intermediate materials.

The figures show that the behaviour of marginal costs in the two models differs significantly. In most of the period since the 1990s, marginal costs in the model without intermediate materials are significantly lower than in the model with intermediate materials. The difference is significantly more pronounced for the US during the Great Recession period. The SW-US model suggests that there is a substantial fall in marginal costs. On the other hand, reflecting the increase in intermediate materials prices, the marginal cost in the KP-US remains almost stable throughout the period. Figure 3 and figure 4 highlight the increases in real intermediate prices and in real energy prices for the two economies during most of the 2000s.

The reason for the differences in the models' predictions of marginal cost and,

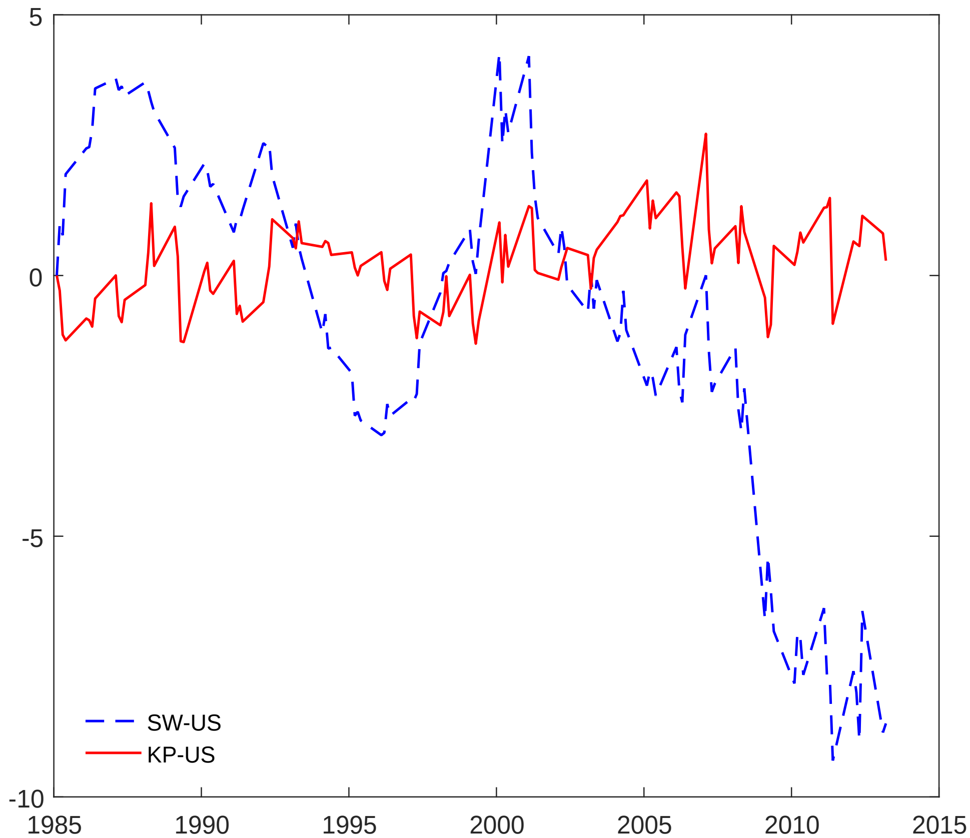

Figure 1: **US: Marginal Costs with and without Intermediate Sector**
The dashed line is the smoothed marginal cost, $E[mc_t|Y_{1:T_{full}}]$, from the model without intermediate materials (SW-US). The solid line is the smoothed marginal cost from the model with intermediate materials (SW-USinter).

therefore, price rigidities is that even though price mark-up shocks are sometimes interpreted as reflecting exogenous changes in energy and, likewise, intermediate input prices, these two shocks can have very different implications for marginal cost. While a positive price mark-up shock leads to a decrease in marginal cost, a positive intermediate input shock increases marginal cost. To see this, let us first explain the

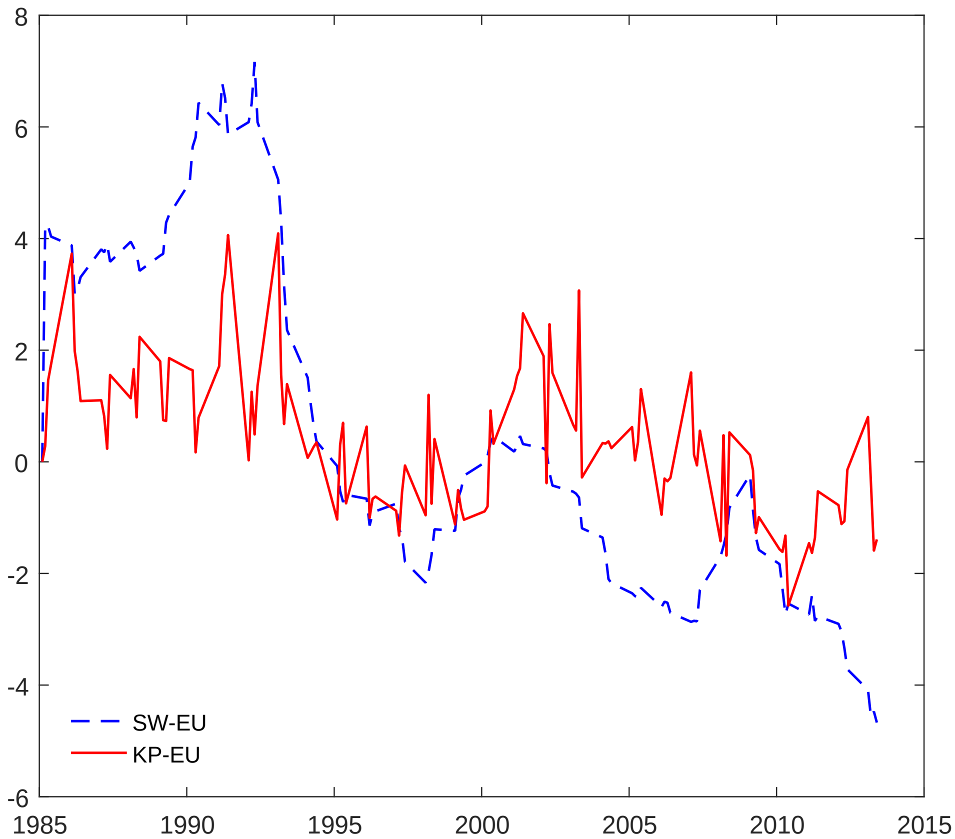

Figure 2: **EU: Marginal Costs with and without Intermediate Sector**
The dashed line is the smoothed marginal cost, $E[mc_t|Y_{1:T_{full}}]$*, from the model without intermediate materials (SW-EU). The solid line is the smoothed marginal cost from the model with intermediate materials (SW-EUinter).*

effects of price mark-up shocks on marginal costs in the model without intermediate materials. When there is an increase in price mark-ups, since prices are sticky, marginal cost must fall. Firms achieve this by lowering their output. Decreased output leads to a fall in the prices of other factor inputs thus leading to a fall in marginal cost. Since the mark-up shock adjusts persistently in the SW, there is

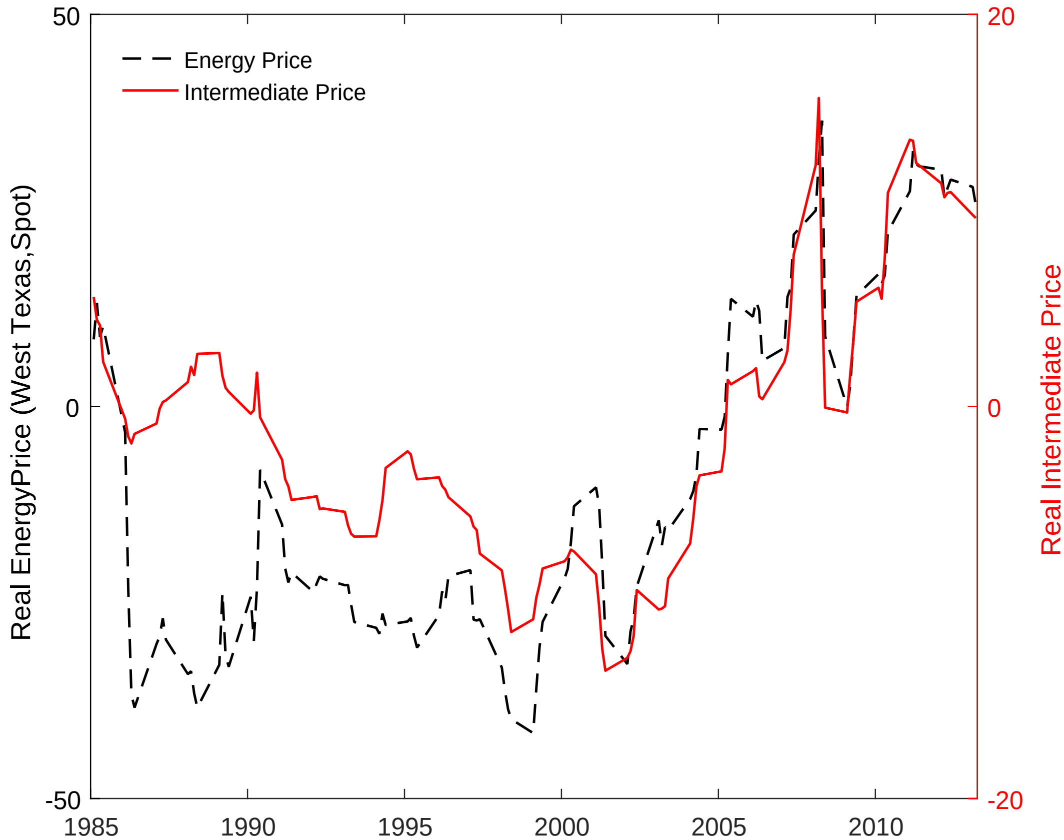

Figure 3: **US: Evolution of Actual Real Energy and Intermediate Prices**
The dashed line is the log of deflated Energy Prices. The solid line is the log of deflated intermediate prices. Both data series are seasonally adjusted and are obtained from the St. Louis FED database. I deflate the two series using the GDP deflator. The intermediate price series is the Producer Price Index by Commodity Intermediate Materials: Supplies & Components (PPIITM). The energy price series is the Producer Price Index: Finished Energy Goods (PPIFEG).

a persistent decline in marginal cost. Turning to the effect of input-price shock on marginal cost, the effect of such a shock is easy to understand. Intermediate materials are an additional component in marginal cost. Therefore, a positive shock

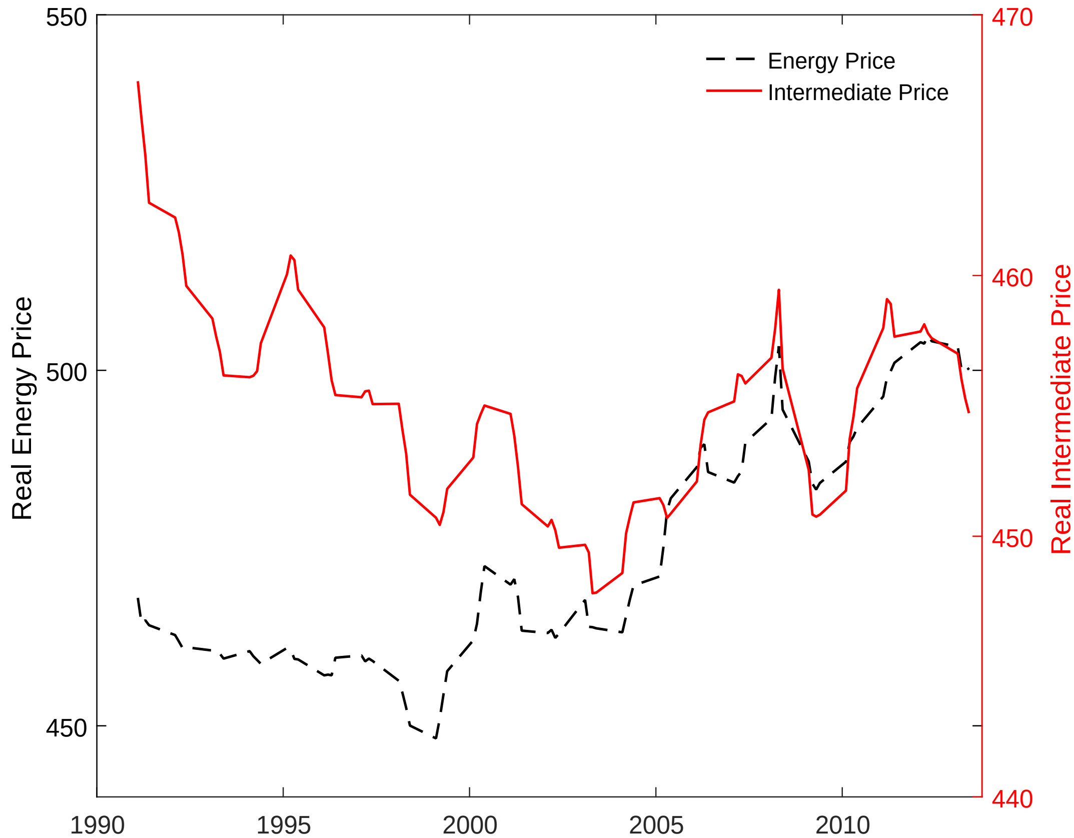

Figure 4: **EU: Evolution of Actual Real Energy and Intermediate Prices**
The dashed line is the log of deflated Energy Prices. The solid line is the log of deflated intermediate materials prices. Both data series are seasonally adjusted and are obtained from the Eurostat. I deflate the two series using the GDP deflator. The intermediate price series is: Euro area 18 (fixed composition) - Producer Price Index, domestic sales, MIG Intermediate Goods Industry.

to the intermediate prices leads to an increase in input prices and, consequently, an increase in marginal cost.

Figure 5 confirms these suggestions. There I plot the impulse response functions (IRF) for a positive input-price shock and those of a positive price mark-up shock for

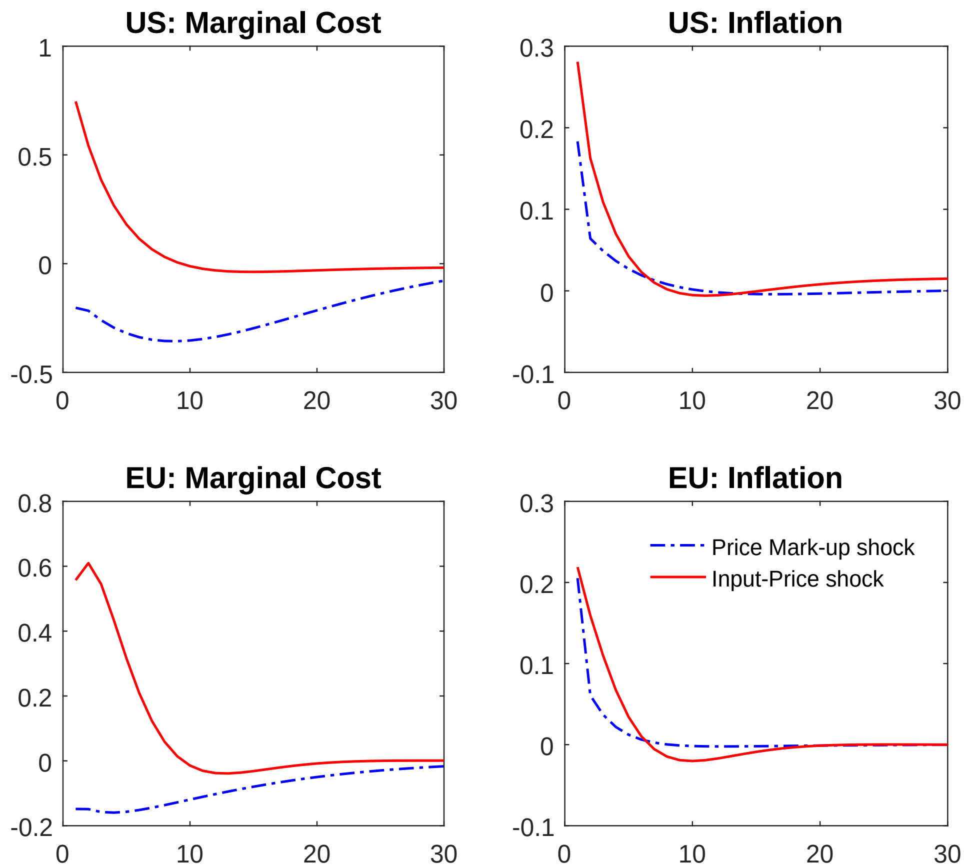

Figure 5: **IRFs to Price Mark-up and Intermediate Input-Price Shock**
Note: The dashed blue line is the IRF to the price mark-up shock in the model without intermediate materials. The solid red line is the IRF for the model with intermediate materials price. The top panel plots IRFs for the US whereas the bottom panel plots IRFs for the EU.

both the US and the EU. As is evident from the figure, the IRFs of inflation in the models with and without intermediate materials are very similar. Even though this is the case, the responses of the marginal cost in the two models are very different. In the model with intermediate materials, an immediate increase in the intermediate materials price increases both inflation and marginal cost. However, a price mark-up shock has opposite effects on inflation and marginal cost. In response to a positive price mark-up shock, marginal costs fall, while inflation increases.

The discrepancy between marginal cost and actual inflation in the SW-US model is larger in the 2000s. This is also the period during which energy prices and intermediate prices exhibit substantial increases. The SW-US model captures the effect of the increase in energy prices and the intermediate prices by allowing for large price mark-up shocks. However, for the reasons I have discussed, such large price mark-up shocks lead to substantial falls in marginal cost. A substantial fall in marginal cost requires a large degree of price rigidities in order to match stable inflation dynamics observed in the data. When prices are sticky, prices cannot adjust immediately in full proportion to the decrease in marginal cost. Therefore, the fall in inflation is muted. Thus, a large degree of price stickiness is crucial for the model without intermediate materials to explain inflation dynamics during the 2000s - a period of increasing intermediate materials prices.

The results for the EU are similar but less pronounced than the US. This is because firms in the EU experienced a relatively smaller increase in real intermediate materials prices (see figure 4).

6 Robustness

The estimation results in section 4 suggested that the posterior mean of α in the model with intermediate materials was significantly less for both the US and the EU.

To test if the results in this paper are robust to changes in the value of α, I calibrate α to equal 0.3 and re-esitmate the model for both the US and the EU. The results do not change. For the US, the posterior mean for ζ_p and ζ_p^m increases slighly to 0.66 and 0.50, respectively. For the EU, the posterior mean for ζ_p and ζ_p^m is 0.57 and 0.67, respectively. Introducing intermediate materials to the standard model also had important implications for the parameters governing the Taylor rule, productivity shock, monetary policy shock and inflation targeting shock. These differences across the model with and without intermediate materials are also robust to keeping α fixed at 0.3.

The parameter, μ, was calibrated to match the revenue share of intermediate inputs in gross output. Intermediate inputs include both intermediate materials and intermediate services. Since I use data on intermediate materials prices in estimations, it is likely that intermediate materials price data are not representative of intermediate services. In an alternate setting, I calibrate μ to match the revenue share of intermediate materials only (i.e. 20% of gross output). The results show that the degree of price stickiness required to simultaneously match model-implied marginal costs and observed inflation decreases further for both the US and the EU. The key differences between model parameters for the model with and without intermediate materials still hold.

Finally, I test the implication of including price indexation for the results in this paper. Results are robust. The degree of price stickiness in the finished goods sector is the same as before for both the US and the EU. However, the degree of price stickiness in the intermediate materials sector, ζ_m, decreases to 0.40 for the US and increases to 0.70 for the EU. Moreover, the posterior mean of the degree of price indexation is close to 0.10 for the finished goods sector, whereas it is around 0.40 for the intermediate sector. Likewise, including indexation in the model without intermediate materials does not lead to any significant difference in the posterior mean of ζ_p for both the US and the EU. The posterior mean of the degree of price indexation is close to 0.25 for both the regions. In terms of log data density, the specification without price indexation is strongly preferred by the data.

7 Conclusion

Standard New Keynesian models require a large degree of price stickiness to match the stable inflation dynamics observed since the 2000s. The required degree of price stickiness increases further when financial frictions and the zero lower bound are included in the model. However, micro-data on prices does not point towards any change in the duration of price contracts before and after the Great Recession. On the contrary, the average duration of price contracts has been decreasing since the 2000 for the US economy. This mis-match between the micro-data and the macro-estimates point towards an important source of misspecification in New Keynesian models.

This paper has attempted to address this shortcoming of New Keynesian models. I show that when intermediate materials prices affect firms' marginal costs, the model no longer requires a large degree of price stickiness to match observed inflation dynamics. This is because marginal cost in the model with intermediate materials is significantly different than in the standard model. The results show that marginal cost in the new model is relatively stable over the sample period. As a result, the new model does not require a large degree of price rigidities to match model-implied marginal costs and observed inflation.

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