
DOCUMENT
DE TRAVAIL
N° 324

**GENERALIZED TAYLOR AND GENERALIZED
CALVO PRICE AND WAGE-SETTING: MICRO
EVIDENCE WITH MACRO IMPLICATIONS**

Huw Dixon and Hervé Le Bihan

March 2011



**GENERALIZED TAYLOR AND GENERALIZED
CALVO PRICE AND WAGE-SETTING: MICRO
EVIDENCE WITH MACRO IMPLICATIONS**

Huw Dixon and Hervé Le Bihan

March 2011

Les Documents de travail reflètent les idées personnelles de leurs auteurs et n'expriment pas nécessairement la position de la Banque de France. Ce document est disponible sur le site internet de la Banque de France « www.banque-france.fr ».

Working Papers reflect the opinions of the authors and do not necessarily express the views of the Banque de France. This document is available on the Banque de France Website "www.banque-france.fr".

Generalized Taylor and Generalized Calvo price and wage-setting: micro evidence with macro implications¹

Huw Dixon² and Hervé Le Bihan³

¹The authors thank Fabio Canova, Greg De Walque, Julien Matheron, and Argia Sbordone for helpful remarks. They are grateful to Michel Juillard for help in simulating the GT model with the Dynare code. The views expressed in this paper may not necessarily be those of the Banque de France. Huw Dixon thanks the Fondation Banque de France for funding his participation in this research.

²dixonh@cardiff.ac.uk, Cardiff Business School, Colum Drive, Cardiff CF10 3EU, UK.

³herve.lebihan@banque-france.fr. Banque de France, Direction des Etudes Microéconomiques et Structurelles, Service des Analyses Microéconomiques (SAMIC), 31 rue Croix des Petits Champs, 75001 Paris, France.

Abstract

The Generalized Calvo and the Generalized Taylor model of price and wage-setting are, unlike the standard Calvo and Taylor counterparts, exactly consistent with the distribution of durations observed in the data. Using price and wage micro-data from a major euro-area economy (France), we develop calibrated versions of these models. We assess the consequences for monetary policy transmission by embedding these calibrated models in a standard DSGE model. The Generalized Taylor model is found to help rationalizing the hump-shaped response of inflation, without resorting to the counterfactual assumption of systematic wage and price indexation.

Keywords: Contract length, steady state, hazard rate, Calvo, Taylor, wage-setting, price-setting.

JEL Classification: E31, E32, E52, J30

Résumé

Les modèles de fixation des prix et salaires de type «Calvo généralisé» et «Taylor généralisé» ont, contrairement aux modèles de Calvo et de Taylor standard, la propriété de rendre compte exactement des distributions des durées de fixité des prix et salaires observées au niveau microéconomique. En utilisant les données de prix et des salaires d'une grande économie de la zone euro (la France), nous développons des versions calibrées de ces modèles. Nous en évaluons les conséquences pour la transmission de la politique monétaire en intégrant ces modèles calibrés au sein d'un modèle DSGE standard de la zone euro. On obtient que le modèle de «Taylor généralisé» prédit une réponse graduelle et en forme de « cloche » de l'inflation à la suite d'un choc de politique monétaire. Cette spécification permet donc de rationaliser un fait stylisé empirique de la macroéconomie monétaire, en se dispensant de l'hypothèse contrefactuelle, souvent retenue de façon ad-hoc dans les modèles DSGE, d'indexation systématique des salaires et des prix.

Mots-clés: Fixation des prix et salaires, durée des contrats de salaires et de épisodes de prix, fonction de hasard, modèle de Calvo, modèle de Taylor.

Classification JEL: E31, E32, E52, J30

1 Introduction

Christiano, Eichenbaum and Evans (2004) (hereafter *CEE*) and Smets and Wouters (2003) (*SW*) have developed Dynamic Stochastic General Equilibrium models of the US and euro area economies that have become standard tools for monetary policy analysis. These models have been designed to reflect the empirical properties of the US and euro area data in a way that is consistent with New Keynesian theory. In particular these models have been shown to replicate the impulse-response functions of output and inflation to a monetary policy shock. Central to these models is the Calvo model of price and wage setting with indexation developed by Yun (1996) for prices and by Erceg, Henderson and Levin (2000) (*EHL*) for prices and wages: firms (unions) have a constant probability to be able to optimally reset prices (wages); when firms (unions) do not optimally reset prices (wages), the nominal price (wage) is automatically updated in response to inflation.⁴ This approach is however inconsistent with the micro-data along two dimensions. First, it assumes that the probability of price reoptimization is constant over time. Second, it implies that nominal wages and prices adjust every period, which is counterfactual as noted e.g. by Cogley and Sbordone (2008) and Dixon and Kara (2010).

The purpose of this paper is to take seriously the recent micro-data evidence on wages and prices and apply it directly to alternative wage and pricing models. Our main point of departure is the aggregate *distribution* of durations of price and wage spells. In steady-state, this can be represented in three different ways: the Hazard profile, the distribution of durations, and the cross-sectional distribution (see Dixon 2009 for a detailed explanation). We take the Hazard profile and use this to calibrate a Generalized Calvo (*GC*) model with duration-dependent reset probabilities.⁵ We take the cross-sectional distribution of completed spells and use this to calibrate a Generalized Taylor (*GT*) Economy in which there are several sectors, each with a simple Taylor contract but with contract lengths differing across sectors⁶. Each of the two models we consider (*GC* and *GT*) exactly reflects the

⁴In Yun (1996) and EHL, the indexation is to the unconditional mean inflation, while CEE assume full indexation to lagged inflation and SW assume partial indexation to lagged inflation.

⁵The *GC* approach has been adopted by Wolman (1999), Guerrieri (2006), Dixon (2009).

⁶References for the *GT* price setting model include Taylor (1993), Dixon and Kara

full distribution of durations revealed by the micro-data. We also consider the simple Calvo model with the reset probability calibrated by the average proportion of wages or prices changing in the data.

In order to carry out a quantitative experiment, we use original micro data on wages and prices in France. Whilst the data on prices has been well studied for a range of countries (Dhyne et al. 2006, Klenow and Malin, 2010), relevant wage data are harder to find. We are here able to use a unique, quarterly data set on wages from France (Heckel, Le Bihan, Montornes, 2008). Our approach is then to substitute the standard Calvo scheme with one based on the micro-data using the *GC* and *GT* pricing models and investigate how far these approaches work when set in the *SW* model of the euro area economy. While we use data for one country of the euro area (France), we would argue they are a relevant proxy for the whole euro area, for which similar hazard functions are not available. Comparative evidence for prices does indeed suggest that there is a large degree of similarity across the larger euro area economies (Dhyne et al. 2006). Finally, we are able to study macro dynamics, in particular the response to a monetary policy shock.

With respect to previous research that has used *GC* or *GT* models (e.g. Wolman 1999, Coenen et al. 2007, Dixon and Kara 2010, Kara 2010), our specific contribution is twofold. First, *we use direct evidence on the actual microeconomic distribution of both wages and price durations*. By contrast, previous research has used either only a few moments of the distribution of prices or indirectly estimated distributions from macro data. Second, *we derive a model of wage-setting with *GT* and *GC* contracts which is consistent with any distribution of durations*. This model extends the EHL framework which is based on the Calvo model and hence restricted to the Calvo distribution of durations.

Our main result is to show how the *GT* can replace indexation. The *SW* and *CEE* models and their clones rely on indexation to generate some of the features that make the models congruent with the macro-data: in particular, the degree of persistence in output and inflation in response to monetary shocks and the "hump shape" found in the macro-data. Since indexation is largely at odds with the micro-data, we want to see how far we can go keeping the *SW/CEE* framework but replacing indexation with a more rigorously micro-data based approach to price and wage setting. We show that using these alternative frameworks we can partly replicate the persistence of infla-

(2010, 2011), Coenen et al. (2007).

tion and output following shocks without relying on indexation. In particular the Generalized Taylor model is shown to be able to produce a hump-shaped response of inflation and output to monetary policy shocks, which does not happen with the Calvo based approaches. Indeed, if we calibrate the original *SW* model with indexation using the French microdata, we find that the model behaves in a quite similar way to the *GT*. Furthermore, we find that the hump shape in the *GT* is primarily driven by the pricing part: the long fat tail of the pricing distribution generates the hump. Introducing the *GT* to prices only can generate a hump, whilst in wages only it does not. The distribution of wages has very thin tail after 4 quarters.

The structure of the paper is as follows. Section 2 develops *GT* and *GC* models of price and wage setting. Section 3 presents our micro data on price and wages and uses the distribution of durations to calibrate these models. Section 4 embeds these calibrated *GC* and *GT* price and wage-setting schemes into the Smets and Wouters (2003) model of the euro area economy, and studies the implications for the monetary policy transmission mechanism. Section 5 concludes.

2 Price and Wage -setting in *GT* and *GC* economies

Standard time-dependent models of price rigidity have restrictive implications for the distribution of durations. The standard Taylor model predicts that all durations are identical. The standard Calvo (constant hazard) model predicts that durations are distributed according to the exponential distribution. In this paper, we consider the Generalized Taylor and Generalized Calvo set-ups which allow the distribution of durations implied by the pricing model to be exactly the same as the distribution found in the actual micro-data. The distribution of durations can be characterized in various ways. As shown in Dixon (2009), in steady-state there are a set of identities that link the Hazard function and the cross-sectional distribution of completed contracts lengths. These are just different ways of looking at the same data. However, the Hazard function relates naturally to the Generalized Calvo model where the hazard rates are mapped on to duration dependent price-reset probabilities. The cross-section of completed price-spell lengths is easily related to the Generalized Taylor model, where there are many sectors, and within each sector there is a simple Taylor staggered contract which differ across sectors.

We will first outline the Generalized Taylor and Generalized Calvo economies in terms of price-setting behavior. We will then see how this applies to wage-setting.

2.1 *Generalized Taylor (GT) Economy*

In the *Generalized Taylor (GT) Economy* there are N sectors, $i = 1, \dots, N$. In sector i there are i -period contracts: each period a cohort of i^{-1} of the firms in the sector sets a new price. If we think of the economy as a continuum of firms, we can describe the *GT* economy as a vector of sector shares: α_i is the proportion of firms that have price-spells of length i . If the longest observed price-spell is F , then we have $\sum_{i=1}^F \alpha_i = 1$ and $\boldsymbol{\alpha} = (\alpha_1, \dots, \alpha_F)$ is the F -vector of shares. We can think of the "sectors" as "duration sectors", defined by the length of price-spells. The essence of the Taylor model is that when they set the price, the firm knows exactly how long its price is going to last. The simple Taylor economy is a special case where there is only one length of price-spell (e.g. $\alpha_2 = 1$ is a simple Taylor "2 quarter" economy). The *GT* model is based on the cross-sectional distribution of completed spell lengths: hence it can also be called the distribution across firms (*DAF*) in this context. The *GT* model has been developed in Taylor (1993), Carvalho (1995), Dixon and Kara (2005, 2006, 2010), Coenen et al (2007) and Kara (2010). The *GT* model can represent any steady-state distribution of durations: hence it can be chosen to exactly reflect the distribution found in the micro-data.

The log-linearised equation for the aggregate price p_t is a weighted average of the sectoral prices p_{it} , where the weights are α_i :

$$p_t = \sum_{i=1}^F \alpha_i p_{it} \quad (1)$$

In each sector i , a proportion i^{-1} of the α_i firms reset their price at each date. Assuming imperfect competition and a standard demand curve, the optimal reset price in sector i , x_{it} is given by the first-order condition of an intertemporal profit-maximisation program under the constraint implied by price rigidity. The log-linearised equation for the reset price, as in the standard Taylor set-up, is then given by :

$$x_{it} = \left(\frac{1}{\sum_{k=0}^{i-1} \beta^k} \right) \sum_{k=0}^{i-1} \beta^k E_t p_{t+k}^* \quad (2)$$

where β is a discount factor, E_t is the expectation operator conditional on information available at date t , and p_{t+k}^* is the optimal flex price at time $t+k$. The reset price is thus an average over the optimal flex prices for the duration of the contract (or price-spell). The formula for the optimal flex price will depend on the model: clearly, it is a markup on marginal cost. We will specify the exact log-linearised equation for the optimal flex-price when we specify the precise macroeconomic model we use.

The sectoral price is simply the average over the i cohorts in the sector:

$$p_{it} = \frac{1}{i} \sum_{k=0}^{i-1} x_{it-k} \quad (3)$$

In each period, a proportion \bar{h} of firms reset their prices in this economy: proportion i^{-1} of sector i which is of size α_i :

$$\bar{h} = \sum_{i=1}^F \frac{\alpha_i}{i} \quad (4)$$

2.2 The *Generalized Calvo (GC) Economy*

In the *Generalized Calvo (GC) Economy*, initially developed by Wolman (1999), firms have a common set of duration-dependent reset probabilities: the probability of resetting price i periods after you last reset the price is given by h_i . This is a time-dependent model, and the profile of reset probabilities is $\mathbf{h} = \{h_i\}_{i=1}^F$. Clearly, if F is the longest price-spell we have $h_F = 1$ and $h_i \in [0, 1)$ for $i = 1 \dots F-1$. Again, the duration data can be represented by the hazard function. Estimated hazard function can then be used to calibrate \mathbf{h} . Since any distribution of durations can be represented by the appropriate hazard function, we can choose the *GC* model parameters to exactly fit micro-data.

In economic terms, the difference between the Calvo approach and the Taylor approach is that when the firm sets its price, it does not know how long its price is going to last. Rather, it has a *survivor function* $S(i)$ which gives the probability that its price will last at up to i periods. The survivor

function in discrete time is⁷:

$$\begin{aligned} S(1) &= 1 \\ S(i) &= \prod_{j=1}^{i-1} (1 - h_j) \quad i = 2, \dots, F \end{aligned} \tag{5}$$

Thus, when they set the price in period t , the firms know that they will last one period with certainty, at least 2 periods with probability $S(2)$ and so on. The Calvo model is a special case where the hazard is constant $h_i = \bar{h}$, $S(i) = (1 - \bar{h})^{i-1}$ and $F = \infty$. Of course, in any actual data set, F is finite. In the applications which follow we set $F = 20$ quarters, close to the maximum duration observed in price micro data.

In the *GC* model the reset price is common across all firms that reset their price. The optimal reset price, in the same monopolistic competition set-up as mentioned above, is given in log-linearised form by:

$$x_t = \frac{1}{\sum_{i=1}^F S(i)\beta^{i-1}} \sum_{i=1}^F S(i)\beta^{i-1} E_t p_{t+i-1}^* \tag{6}$$

The evolution of the aggregate price-level is given by:

$$p_t = \sum_{i=1}^F S(i)x_{t-i+1} \tag{7}$$

That is, the current price level is constituted by the surviving reset prices of the present and last F periods.

2.3 Wage-setting.

We can apply *GC* and *GT* models to wage data in order to calibrate wage-setting. If we have a model with flexible prices, simply using the same equations as the price-setting model would probably be a relevant shortcut. Indeed as was shown in Ascari (2003) and Edge (2002), models of either wage or price rigidity lead to reduced-form dynamics that is largely similar for

⁷Note that the discrete time survivor function effectively assumes that all "failures" occur at the end of the period (or the start of the next period): this corresponds to the pricing models where the price is set for a whole period and can only change at the transition from one period to the next.

reasonable parameter values. So, calibrating the models of sections 2.1 and 2.2 with the distributions implied by the wage data would presumably be a relevant strategy.

However, we also wish to provide a model that combines *both* wage and price rigidity as in the models of Erceg et al. (2000), Christiano et al. (2005), Smets and Wouters (2003). Clearly, the description of pricing decisions described above will continue to hold. What we need to add are the specific equations for marginal cost with sticky wages, that allow for a general distribution of durations, rather than the specific Calvo distribution as in *EHL*. As in *EHL*, we take the craft-union model first employed in the macroeconomic setting by Blanchard and Kiyotaki (1987). In this case, there is a *CES* aggregator for labour inputs with a specific elasticity λ_w . There is a unit interval of households $h \in [0, 1]$ each with a unique type of labour. Aggregate labour L_t is constituted of by combining each household's labour $L_t(h)$ according to:

$$L_t = \left[\int_0^1 L_t(h)^{\frac{\lambda_w-1}{\lambda_w}} dh \right]^{\frac{\lambda_w}{\lambda_w-1}}$$

The corresponding aggregate unit wage-cost index is derived from individual household wages $W_t(h)$

$$W_t = \left[\int_0^1 W_t(h)^{1-\lambda_w} dh \right]^{\frac{1}{1-\lambda_w}}$$

where λ_w is the elasticity of the corresponding conditional labour demand:

$$L_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\lambda_w} L_t \quad (8)$$

We assume that the household preferences are described by the following utility function that features habit formation

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t - H_t, 1 - L_t(h))$$

where $H_t = bC_{t-1}$, b is a parameter describing habit formation, assumed to be external, and $L_t(h)$ is hours worked by household h . We specify the functional form for U as:

$$U(C_t - H_t, 1 - L(h)_t) = \frac{1}{1 - \sigma_c} (C_t - H_t)^{1 - \sigma_c} + \frac{1}{1 - \sigma_L} (1 - L_t(h))^{1 - \sigma_L}$$

where σ_c is the inverse of intertemporal elasticity of substitution, and σ_L is the inverse of the elasticity of hours worked to the real wage rate.

We assume full-insurance so that the level of consumption will be equal across households⁸. Employment is assumed to be demand determined: hence the households marginal rate of substitution at time t is:

$$MRS(h)_t = - \frac{U_l(C_t - bC_{t-1}, 1 - L(h)_t)}{U_C(C_t - bC_{t-1}, 1 - L(h)_t)} = \frac{(C_t - bC_{t-1})^{\sigma_c}}{(1 - L_t(h))^{\sigma_L}} \quad (9)$$

The union-household sets its nominal wage $W(h)_t$. We can define the "shadow nominal wage" as:

$$W^*(h)_t = P_t.MRS(h)_t \quad (10)$$

$W^*(h)_t$ is nominal wage which would equate the real wage with the marginal rate of substitution for household h given the labour which is demanded of it at its current nominal wage $W(h)_t$ (from 8), and its current and past consumption according to (9).

2.3.1 Wage-setting *GT* model.

Log-linearising these equations (9),(8),(10) we have:

$$mrs(h)_t = \sigma_L n(h)_t + \frac{\sigma_c}{1 - b} (c_t - b.c_{t-1}) \quad (11)$$

$$n(h)_t = \lambda_w (w_t - w(h)_t) + n_t \quad (12)$$

$$w^*(h) = p_t + mrs_t \quad (13)$$

where lowercase letter are log-deviation and $n(h)_t$ is the log-deviation of $L_t(h)$. If the household-union knows the length of its contract to be i periods, the (nominal) reset wage x_{it}^w will fulfill $w(h)_{t+k} = x_{it}^w$ for $k = 0, \dots, i - 1$. The optimal reset wage is obtained by maximizing the intertemporal utility

⁸See Ascari (2000) for the details.

function subject to this structure of wage stickiness, and a standard budget constraint. In log-linear form the optimal reset wage is given by:

$$x_{it}^w = \left(\frac{1}{\sum_{k=0}^{i-1} \beta^k} \right) \sum_{k=0}^{i-1} \beta^k E_t w_{t+k}^* \quad (14)$$

That is, x_{it}^w is a weighted average of the discounted nominal shadow wages w_{t+k}^* .

As shown in the appendix, using equations (11),(12),(13) it is straightforward to derive the reset wage equation:

$$x_{it}^w = \frac{1}{(1 + \sigma_L \lambda_w) \sum_{k=0}^{i-1} \beta^k} \sum_{k=0}^{i-1} \beta^k E_t \left(p_{t+k} + \sigma_L (\lambda_w w_{t+k} + n_{t+k}) + \frac{\sigma_c}{1-h} (c_{t+k} - b \cdot c_{t+k-1}) \right) \quad (15)$$

Therefore we can construct a wage setting *GT* model. The aggregate wage is related to the sectoral wages w_{it} , where the weights α_{iw} come from the cross-sectional distribution across firms in the data. The sectoral wages w_{it} are simply an average across past reset wages in that sector:

$$w_t = \sum_{i=1}^{F_w} \alpha_{iw} w_{it} \quad (16)$$

$$w_{it} = \frac{1}{i} \sum_{k=0}^{i-1} x_{it-k}^w \quad (17)$$

These equations can then be combined with the price-setting *GT* equations to simulate an economy with *GT* nominal rigidity in both price and wage setting. Clearly, the wage-setting decision will depend directly on the level of the aggregate variables (L_t, C_t) and indirectly on the rest of the variables in the model.

2.3.2 Wage-setting *GC* model.

In the case of the *GC* model, we have the wage-survival function and related hazard rates: $S_w(i)$ and $h_w(i)$ $i = 1, \dots, F_w$ derived from the data on wages. The optimal reset wage is the same for all firms, and is given by the log-

linearized first order condition:

$$x_t^w = \frac{1}{\sum_{i=1}^{F_w} S_w(i)\beta^{i-1}} \sum_{i=1}^{F_w} S_w(i)\beta^{i-1} E_t w_{t+i-1}^* \quad (18)$$

$$= \frac{1}{(1 + \sigma_L \lambda_w) \sum_{i=1}^{F_w} S_w(i)\beta^{i-1}} \sum_{i=1}^{F_w} S_w(i)\beta^{i-1} E_t (p_{t+i-1} + \sigma_L (\lambda_w w_{t+i-1} + n_{t+i-1}) + \frac{\sigma_c}{1-h} (c_{t+i-1} - b.c_{t+i-2})) \quad (19)$$

The aggregate wage is an average of past reset wages, weighted by survival probabilities:

$$w_t = \sum_{i=1}^{F_w} S_w(i) x_{t-i+1}^w \quad (20)$$

Again, this wage-setting *GC* model can be combined with price-rigidity. Note that we can treat the Calvo model as a special case of the *GC* model. We can use the average proportion of wages reset each quarter as our calibration of the Calvo reset probability: the resulting *GC* is a constant hazard model $h_w(i) = \bar{h}_w$ for $i = 1 \dots F_w$. In practice, we truncate the wage setting to a maximum duration of 20 quarters, rather than having the infinite horizon assumed by the theoretical Calvo model. The truncation at $F_w = 20$ has almost no quantitative impact on the conclusions derived from the model given that in our data and in the calibration we consider survival is negligible after 20 quarter. For instance calibrating \bar{h}_w with the empirical frequency of wage change yields $S_w(20) = (1 - 0.38)^{19}$. Removing the infinite time horizon may in any case be seen an improvement on the Calvo model.

Note that in the case of the constant hazard, equation, combining (19) and (20) yields the "new Keynesian Phillips curve" formulation found in *SW*⁹, which writes the wage-setting equation in terms of price inflation, wage inflation and the sum of current and future deviations of the real wage from the *MRS* between consumption and leisure. Equation (19) is probably more intuitive and easy to understand than the NKPC-like formulation. Note also we have log-linearized the model around a zero inflation rate steady-state (as is the case in the NKPC formulations of *CEE* and *SW*) which means that the wage and price levels are stationary: if there was non-zero inflation in steady-state, this would not be the case. However, as Ascari (2004) demonstrates, this also invalidates traditional formulations of the *NKPC*.

⁹See *SW* equation (33) page 1138.

3 The hazard function of price and wage changes: micro evidence

This section describes the micro data we use to characterize the distribution of wages and prices, and report some important statistics about this distribution. We confine ourselves to a brief description, since a more complete description and details can be found in earlier papers.

3.1 Data

The dataset used in the case of prices is composed of the consumer price quotes collected by the INSEE, the French Statistical Institute, to build the CPI (Consumer Price Index). A detailed investigation of this dataset is presented in Baudry et al. (2007). The sample contains around 13 million price observations collected monthly over the 9 year period 1994:7 to 2003:2. Data are available for a range of goods that cover 65% of the French CPI data. These data are collected for several hundreds of elementary products, at different outlets and at different months. An individual observation is a price quote P_{jkt} for product j at outlet k at time t ($t=1\dots 104$). The resulting dataset is a panel with about 125,000 price quotes each of the 104 months. The panel is unbalanced since the range of products and the outlets are changed over time for reasons to do with constructing the CPI. The dataset also includes CPI weights, which we use to compute aggregate statistics. From the panel of prices, we can compute the frequency of price changes, i.e. the average proportion of prices that do change a given month. On our sample this weighted average frequency is equal to 19%: this statistic is the empirical counterpart of the Calvo parameter in discrete time. This is a *monthly* statistic: it corresponds to a quarterly frequency of $\bar{f}_p = 0.53$.

Consistently with the concepts introduced in section 2, we can organize this data into price spells. These are a sequence of price-quotes at the same outlet for which the price quoted is the same. There are 2,372,000 price spells in the panel. The weighted average duration of price spells is 7.2 months.¹⁰ The maximum duration in the dataset is 104 months, but this concerns a

¹⁰Thus 2.4 quarters. The reciprocal of this average duration, i.e. 0.417, differs from the quarterly frequency of prices changes due to the weighting of the data (interacting with heterogeneity in duration across products) and to censoring of the data, as discussed in Baudry et al. (2007).

negligible fraction of price spells. In the model-based analysis that follow use a truncation of the hazard function at $F = 20$ quarters. This has no material empirical consequence since less than 0.03 percent of price spells last more than 60 months. There are several data issues, which are discussed in Baudry et al. (2007). Not least is the issue of censored data: we can have left truncated data, where the beginning of the price spell is not observed. We have right truncated data, where we do not observe the end of the spell. We also observe spells which are both right and left truncated: we know neither the beginning or the end. Truncation results either from the turn-over of products in stores, and from changes in the sample decided by the statistical institute. The majority of price spells are uncensored: 57%. There are a lot of left truncated spells: 27%. The rest are either right truncated or truncated at both ends. In our empirical analysis below we will focus on the distribution of spells that are non-left-censored (and disregard other spells). We include right-truncated spells (i.e. price trajectories that are terminated before the actual end of sample) because we interpret them as completed spells: for example we regard product substitution in a store as actually ending a price spell. There are of course different ways of interpreting truncation. However, we have carried out our analysis using alternative treatments of censoring and our results were robust.

To characterize the distribution of wage durations, we here rely on a survey of firms conducted by the French Ministry of Labour, the ACEMO survey. The ACEMO is unique, owing to its quarterly frequency. Indeed, while CPI data are collected at the monthly frequency in a very standardized fashion for many countries, data on wages at a higher frequency than annual are scarce. The ACEMO dataset is analyzed in Heckel, Le Bihan and Montornes (2008). The ACEMO survey covers establishments with at least ten employees in the non-farm market sector. Data are collected at the end of every quarter from a sample of about 38,000 establishments. The available files span the period from the fourth quarter of 1998 to the fourth quarter of 2005. The ACEMO survey collects the level of the monthly base wage, inclusive of employee social security contributions. The data excludes bonuses, allowances, and other forms of compensations. The survey collects the wage level of representative employees, for four categories of positions within the firm: manual workers, clerical workers, intermediate occupations, managers. Each firm has to report the wages level of up to 12 employees, representative of the four above mentioned occupations (1 to 3 occupations in each category). Measurement error is a crucial concern when analyzing

wage data. Here, this concern is attenuated because we have answers by firm to a compulsory survey, rather than self-reported household answers as in many studies. Furthermore the statistical agency performs some quality checks. The data set contains some information which allows us to make sure that the individuals are actually the same from one quarter to another.

The final dataset contains around 3.7 million wage records and around 1.8 million wage spells. To produce aggregate statistics, data are weighted using the weight of firms and sectors in overall employment. The average frequency of wage change is 38% per quarter ($\bar{f}_w = 0.38$), while the weighted average duration of spells is 2.0 quarters.¹¹ Less than 0.1 percent of wage spell last more than 16 quarters.¹²

3.2 Hazard function estimates

From the weighted distribution of price and wage durations, we compute survival and hazard functions using the non-parametric Kaplan-Meier estimator. The estimates of the hazard function, the parameters h_i of section 2.2, are presented in Figure 1.¹³ Importantly, note that the hazard function for prices relates to monthly data while that for wages relates quarterly data, consistent with the original frequency of the data. When proceeding to model-based analysis below, information on price spells will be converted to the quarterly frequency. As discussed above, these hazard functions were obtained by discarding left-censored spell and treating right-censored spells as a price or wage changes, but our results are robust to other assumptions on censoring.

Insert FIGURE 1

The hazard function for prices is typical of that observed in recent research with micro price data (see Dhyne et al., 2006, Klenow and Malin, 2010). It tends to be decreasing over the first months. This, to some extent, reflects heterogeneity across sectors in the baseline level of price rigidity (see Alvarez

¹¹As for as for the price distribution, the inverse of the average duration, here 0.5, differs from the frequency of wage change, due to weighting and censoring of the data

¹²In the model simulations we use a truncation of the hazard function at a maximum duration of $F^w = 20$ quarters. Virtually no information is thus lost.

¹³Due to the huge number of observations, confidence intervals are very narrow, thus are not reported. The figure contains the estimates for the first 16 months, although we estimated the hazard function for $F = 95$. Details available from the authors.

et al., 2005, Fougère et al, 2007 for a discussion and empirical investigations). There is a massive spike at duration 12 months, indicating that a lot of retailers change their prices after exactly 1 year. The hazard function of wage is flatter than prices, but clear spikes are seen at duration 4 and 8 quarters. Overall, the bottomline for both price and wage is that hazard functions are neither flat (as the simple Calvo model would predict), nor degenerate spikes at a given duration (as in the Taylor model), but have a more general shape that mixes patterns of these two cases. We view these observed patterns as a motivation for using Generalized Taylor and Generalized Contracts to reflect the estimated distributions.

The two panels of Figure 2 present the distribution of durations, as well as the Distribution across Firms (i.e. the parameters α_i and α_{iw} defined in sections 2.1. and 2.3.1), for prices and wages respectively. These figures convey the same information as the hazard function. They make more visible that at a given date, the cross-section of spells is dominated by firms that experience a one-year price or wage contract. For wages, one observes that there is a substantial mass of short durations, which explain why the average duration for wages is rather short. This observation does not completely conform with intuition and requires some qualifications. Following Heckel et al (2008), our interpretation is that this result reflects to a large extent cases where one single decision of wage increase (say a yearly general increase in a given firm) is spread out over the year and split up between two or (more) smaller wage increases¹⁴. Informal evidence suggest that a fraction of French firms actually follow such a policy of gradual implementation of wage increase. The prevalence of such a pattern is confirmed by the empirical analysis of wage-agreement data by Avouyi-Dovi, Fougère and Gautier (2010). For a given duration of wages, these types of cases create more inertia than the one predicted by sticky wage models, because some wage changes are based on past information. They are thus pre-determined and cannot respond to current shocks. While it is difficult to correct for the degree of such pre-determination in our dataset, we simply note that our duration measures, and thus our model-based analysis, may tend to underestimate the degree of wage rigidity, and presumably macroeconomic persistence.

Insert FIGURE 2

¹⁴In effect, this behaviour is similar to the Fischer-like contracts used in sticky-information models (Mankiw and Reis, 2002).

4 Macroeconomic implications in a euro area DSGE model

In this section, we use the Smets and Wouters (2003) model, a now standard model of the euro area widely used for monetary policy analysis. We write it down in its log-linearized form, which is for convenience reported in the appendix. In the *SW* model there are many sources of dynamics other than prices and wages: capital adjustment and capital utilization costs, consumer dynamics with habit formation, and a monetary policy reaction function. The behavior of the model is the outcome of the interaction of all of these processes together as it should be in a DSGE model. This contrasts to the earlier studies of *GT* models in Dixon and Kara (2011) where pricing was the main source of dynamics.

4.1 Embedding *GT* and *GC* set-up in Smets and Wouters

Our strategy is the following. We are going to alter the structure of both price and wage rigidity in the model. We first remove the price and wage inflation *NKPC's* from the *SW* model: that is equations (32-33) of the original article. The rest of the model is left as it is. We then replace these with the nominal price and wage equations we derived in section 2, and define price inflation as the difference in prices $\pi_t = p_t - p_{t-1}$ and wage inflation as $\pi_t^w = w_t - w_{t-1}$.

To describe the price-setting decision, we can define (nominal) marginal cost in terms of the rental on capital and nominal wages

$$mc_t = (1 - \alpha)w_t + \alpha r_t^k - \varepsilon_t^a \quad (21)$$

where r_t^k is the rental rate of capital and ε_t^a a productivity shock. Hence, in log-linear form we have the optimal flex-price equation

$$p_t^* = mc_t \quad (22)$$

We can then use (22) to directly implement the *GT* price equations (1), (2), (3), and also the wage equations (11), (12), (13), (15), (16), (17).

Similarly, we can use (22) to implement the *GC* price equations (6), (7) and wage equations (19), (20). To implement the Calvo model, we simply take the *GC* model and set the reset-probability constant, equal to \bar{h}_p for prices and \bar{h}_w for wages. We calibrated these parameter from the weighted

distributions of non-left-censored price and wage changes, using the formulas in Dixon (2009), and obtained $\bar{h}_p = 0.398$ and $\bar{h}^w = 0.514$.¹⁵ There is some approximation here, as we are truncating the Calvo distribution. However, the difference is quantitatively negligible: we ran the original code for the SW model (with the NKPC in terms of price and wage inflation) with zero-indexation and found no visible difference.

We underline that following our approach of starting from the micro-data evidence, we remove indexation (which is a strong mechanism for creating persistence) from the *SW* model. We can then see how the price and wage equations without indexation but reflecting the micro-data perform. We do not seek to re-estimate the *SW* model in this paper: our purpose is not to estimate a DSGE model of the Euro area. Rather, we want to illustrate how easy it is to introduce evidence from the micro-data into a complex DSGE model such as the widely used *SW* model. Hence we take the calibrated or estimated values for parameters directly from the *SW* paper. For those parameters that were estimated in *SW*, we retain the mode of the posterior distribution for each parameter (values are listed in the appendix).

4.2 Monetary policy shock under *GT* and *GC* price and wage contracts.

Figure 3 reports the IRF for inflation and output in the *SW* model with *GT* and *GC* contracts following a monetary shock. There are two main observations to be made. First, in the inflation IRF, there is no hump shape in either the Calvo or the *GC* model, but there is a hump shape with the *GT* model. This result confirms, in a set-up that uses data on actual distributions of price durations, the finding of Dixon and Kara (2010) which was in a much simpler model. Overall, the fact that we get a hump with the *GT* even in the complicated *SW* framework shows that this is a robust result. Conversely, the fact that the *GC* does not give us a hump is also shown to be robust. Second, both the *GT* and the *GC* models predict a more persistent inflation and output response than the simple Calvo model.

The intuition behind the hump is that in the *GT* model, firms that are re-setting their price are less forward looking *on average* in their pricing decision

¹⁵As expected, these numbers are close to the inverse average durations. We also implemented an alternative calibration approach, using the average frequencies of price and wages changes, \bar{f}_p and \bar{f}_w , and obtained similar results.

than in Calvo. This myopia arises because they know exactly how long their spell will last, and so can ignore what happens after the spell finishes (since they will be able to choose another price). For example, the firms with one period spells only look at what is happening in the current period. That means that they will raise their prices less than firms who have longer spells and so are more forward looking and anticipate future inflation that will occur during the spell and hence raise their price by more in anticipation of this. In the *GC* and Calvo framework, all firms that reset their prices have to look forward F periods, since there is a possibility that their price might last that long. This means that the Calvo and *GC* firms raise their prices most on impact. The same argument applies to wage-setting when we compare the *GT* with *GC* and Calvo.

The intuition behind the persistence of both the *GC* and *GT* is that the French price data has a fatter tail of long spells in the distribution of durations (and the cross-sectional DAF) than is present in the Calvo distribution. As shown in Dixon and Kara (2011), that the presence of long-contracts has a disproportionate effect on the behavior of aggregate output and inflation due to the strategic complementarity of prices¹⁶.

Insert FIGURE 3

4.3 The inflation hump: further investigation

We now ask to what extent the *GT* model matches the actual degree of inflation persistence following a monetary shock. Figure 4 compares the inflation impulse response in the original *SW* (the plain line) and in our modified *SW* model that features *GT* price and wage setting (the dotted line with squares). Adjustment is much less protracted in the *GT* model than in the original *SW*: the timing of the inflation peak is earlier with the *GT* (at 3 quarters), than in the original *SW* (at 5 quarters). It is arguably not surprising that our *GT* model is not able to reach the same degree of persistence as the original *SW* model. First, as noted by several authors (inter alia De Walque, Smets and Wouters, 2006) the estimated degree of price and wage rigidity in Smets and Wouters (2003) is very high : the probability of being able to reset price is estimated to be around 9.2 percent per quarter, and

¹⁶See also Carvalho (2006) in the context of sectoral heterogeneity using the Calvo approach.

for the wage is 26.3 percent per quarter¹⁷. While these numbers help replicate the macro persistence, they are much lower than those derived from the French microdata that underlie our *GT* model. Second, we have removed the indexation assumption both for wage and prices. One of the main roles of indexation is to generate a hump shaped response of inflation. Finally note we are using a set of auxiliary parameters that were estimated to fit the data under the Calvo-with-indexation assumption. Re-estimating the full model, with the *GT* or *GC* assumption on euro area data would probably come closer to fitting the actual response of inflation to monetary policy shock.

In an attempt to disentangle the relative importance of the various sources of differences, we have simulated the *SW* model replacing the price and wage rigidity parameters estimated by Smets and Wouters (2003) by the corresponding parameters derived from the hazard functions estimated from the microdata $\xi_p = 1 - \bar{h}_p = 0.602$ and $\xi_w = 1 - \bar{h}_w = 0.486$. The rest of the *SW* specification is maintained and other parameters, including indexation, are kept equal to those estimated by Smets and Wouters (2003). The resulting impulse response function is the dotted line with circles in Figure 4. This is quite close to the IRF of the *GT* model and peaks at the same time, that is three periods after the shock. *Thus, controlling for the overall degree of nominal rigidity, the GT model does nearly as well in terms of producing a hump and generating persistence, as a Calvo model with an indexation mechanism.* For comparison purposes we also include (the line with crosses) the IRF of the model with our micro price and wage rigidity parameters and indexation removed, i.e. the genuine Calvo model of the previous exercise. As already obtained the hump is absent in this model, which illustrates the key role of indexation in replicating the pattern of inflation response to a monetary policy shock in *SW*. Our assumption of a *GT* is an alternative model that is consistent with the microdata.

Insert FIGURE 4

A relevant question is whether the capacity of the *GT* to generate a hump, and some persistence, comes from the properties of the distribution of price durations, or the properties of the duration of wage durations. To investigate this further we simulated a version of the model in which the *GT*

¹⁷*SW* actually estimate a probability of non price-adjustment $\xi_p = 0.908$ and a probability of non wage-adjustment $\xi_w = 0.737$. For prices, this implies that when a firm resets its price the expected duration to when it can reset its price again is over 10 quarters.

scheme was implemented for prices only, leaving wages modelled by a Calvo-without-indexation scheme. We also simulated a model in which the *GT* scheme was implemented for wages only, leaving prices modelled by a Calvo-without-indexation scheme. The IRFs are presented in Figure 5, together with the IRF deriving from our wage and price *GT* version of the SW model. It appears that it is mainly the distribution of prices that account for the hump. The model with *GT* in wages and price produces an intermediate pattern of the IRF (the plain line), while the IRF for the *GT* wages-only model (the dashed line) has a larger impact effect and is monotonous.

The reason has not only to do with the relative myopia of firms in the *GT*, but is also that the distribution of prices has a much fatter tail than the distribution postulated by the Calvo model. Thus firms able to reset prices after the shock know they compete with other price-setters than may have their prices fixed for a very long period. This creates some strategic complementarity, which subdues price changes. When we change the distribution of prices to Calvo (compare the plain line with the dashed line), the absolute size of the impact effect increases substantially and the persistence diminishes. On the contrary the actual distribution of wages has a very thin tail: not many wages have a duration larger than 4 quarters. Thus, replacing the *GT* distribution for wages by a counterfactual Calvo assumption actually increases the persistence of the response of inflation (compare the dotted line with squares with from the plain line). Indeed, under the Calvo scheme a strategic complementarity between wage-setters in the shock period and wages setters in a remote future emerges.

Insert FIGURE 5

4.4 Technology shock

We also consider the case of a productivity shock and corresponding IRF in Figure 6. The shock is a persistent but non-permanent increase in total factor productivity. After the shock, there is an initial decline in marginal cost leading to a fall in prices and negative inflation for the first 5 quarters. This is followed by positive inflation as the shock dies away. Contrasting with a quantity theory model, but in accordance with the standard Smets and Wouters model, the long run impact on prices and wages is non-zero: the specific monetary policy rule employed results in a fall in the level of prices and wages, of about a third in absolute value of the maximum short-

run effect. The effect on output is everywhere positive, peaking at 7 quarters and very gradually dying away.

The differences between the alternative price-setting models depend on how they balance prices/inflation and output over this path. As in the case of a monetary shock, the impact effect on prices is smaller for the *GT* model than the models where firms/unions do not know the length of the price spell (*GC* and Calvo). However, all three models are quite similar in terms of the shape and position of the IRF, unlike the case of the monetary shock. This is due to the fact that the trajectory of the general price level is non-monotonic. In the *GT* economy, the same mechanism as for the monetary policy shock plays a role in explaining a dampened reaction of the price level. In the case of the Calvo and *GC* economies, all price-setters have to consider the likelihood of a long-price-spell. At a longer horizon however, due to the price level tending to go back to its initial level, the required decrease in price is smaller. As a result, the impact effect for both type of models is relatively close. By contrast, under a monetary policy shock, while the inflation rates goes back to its initial level, the price level is permanently affected to a larger extent than with a technology shock.

Insert FIGURE 6

5 Conclusion

In this paper, we have shown how we can take the micro-data on prices and wages seriously and introduce them directly into our analysis of macroeconomic policy using the current standard DGSE. Using the theoretical framework of Dixon (2009), we have shown how we can take the estimated hazard function as a representation of the distribution of price-spell durations in the data and use it to infer the cross-sectional distribution under the assumption of a steady-state. From this, we can have price and wage-setting models that are directly consistent with the micro-data: the Generalized Calvo and Generalized Taylor models which are consistent with any empirical distribution of durations. Also, for the first time to our knowledge, we show how we can do this not only for prices or wages on their own but for both wages and prices. We are able to use French original micro data to calibrate separately wage and price setting and combine them in a consistent DGSE approach.

Perhaps the most interesting result we find is that if we adopt the Gener-

alized Taylor approach in both the output and labour market, we are able to generate a hump-shaped response of inflation to a monetary shock. This is not so in the case of the generalized Calvo approach. This generalizes Dixon and Kara (2010) for an actual distribution of wage and price durations from the euro area in a realistic model. In the case of a productivity shock, we find that all three approaches lead to a quite similar response. We have found that when we calibrate the *SW* model with indexation to the French data, the *GT* and *SW* have a similar hump-shaped response of inflation. Furthermore, we find that this hump shape is primarily generated by the *GT* in prices rather than wages.

There are of course many ways to move on from this exercise. First, we might choose to re-estimate the *SW* model with the wage and price-setting models derived from the micro-data. The micro-data used here could provide either calibrated parameters of the pricing block or a prior distribution for euro area parameters in the context of a Bayesian estimation. However, since the *SW* and *CEE* models were developed with different pricing models, it might well be that we would want to change the structure of the models in some ways in addition to the pricing part. For instance introducing firm-specific-capital as in De Walque, Smets and Wouters (2006) may help matching the persistence of inflation together with micro data consistent estimates of price and wage rigidity. Combining *GT* models of prices with firm-specific capital would raise computational issues due to the number of cohorts for which the states variables have to be monitored. Second, relaxing the assumptions of zero steady-state inflation could be investigated. Ascari (2004) has shown that trend inflation creates some nuisances with the Calvo specification, although not with Taylor contracts. Whether these results extend to *GC* and *GT* models is an open issue. Third, we could undertake an optimal policy exercise within this framework. Kara (2010) has conducted a comparison of optimal policy with a *GT* model in the simple quantity theory setting: he finds that the optimal policy with a *GT* model is similar to that derived under Calvo pricing. It would be interesting to see how this carries over to the more complicated *SW* approach in this paper. These remain for future work.

6 References

- Alvarez LJ, Burriel P, Hernando I (2005). Do decreasing hazard functions of price durations make any sense? *ECB working paper series*, No.461.
- Ascari G. (2000). Optimizing Agents, Staggered wages and the persistence in the real effects of monetary shocks, *Economic Journal*, 110, 664-686.
- Ascari G. (2003). Price and Wage Staggering: a Unifying framework, *Journal of Economic Surveys*, 17, 511-540.
- Ascari G (2004). Staggered prices and trend inflation: some nuisances, *Review of Economic Dynamics*, 7, 642-667.
- Avouyi-Dovi S., Fougère D, Gautier E (2010). Wage Rigidity, Collective Bargaining and the Minimum Wage: Evidence from French agreements data, Banque de France *Working Paper 287*
- Baudry L, Le Bihan H, Sevestre P and Tarrieu S (2007). What do thirteen million price records have to say about consumer price rigidity? *Oxford Bulletin of Economic Statistics*, 69, 139-183.
- Blanchard O. and Kiyotaki N. (1987). Monopolistic Competition and the Effects of Aggregate Demand, *American Economic Review* 77, 647-66
- Carvalho, C. (1995). Firms Heterogeneous, Sobreposicao de Contratos e Desinflacao, *Pesquisa e Planejamento Economico*, V. 25 n. 3, 479-496.
- Carvalho, C (2006). Heterogeneity in Price Stickiness and the Real Effects of Monetary Shocks, *Frontiers of Macroeconomics*: Vol. 2 : Iss. 1, Article 1.
- Christiano L., Eichenbaum M. et Evans C, (2005). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy, *Journal of Political Economy*, 113, 1-45
- Coenen G, Levin AT, Christoffel K (2007). Identifying the influences of nominal and real rigidities in aggregate price-setting behavior, *Journal of Monetary Economics*, 54, 2439-2466

- Cogley T. and Sbordone A. (2008). Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve. *American Economic Review*, 98(5).
- De Walque G., Smets F., Wouters R. (2006). Firm-Specific Production Factors in a DSGE Model with Taylor Price Setting, *International Journal of Central Banking*, vol. 2(3), 107-154.
- Dhyne, E., Alvarez, L., Le Bihan, H., Veronese, G., Dias, D., Hoffman, J., Jonker, Lünne-man, P., Rumlér, F. and Vilmunen, J. (2006). Price Changes in the Euro Area and the United States: Some Facts from Individual Consumer price Data, *Journal of Economic Perspectives*, 20, 171-192.
- Dixon H. (2009). A unified framework for understanding and comparing dynamic wage and price setting models, *Banque de France Working Paper* 259..
- Dixon, H and Kara, E (2006). How to Compare Taylor and Calvo Contracts: A Comment on Michael Kiley, *Journal of Money, Credit and Banking.*, 38, 1119-1126..
- Dixon H, Kara E (2010). Can we explain inflation persistence in a way that is consistent with the micro-evidence on nominal rigidity, *Journal of Money, Credit and Banking*, 42(1), 151-170.
- Dixon, H. and Kara, E (2011). Contract length heterogeneity and the persistence of monetary shocks in a dynamic generalized Taylor economy, *European Economic Review*, 55 (2011) 280–292
- Edge, R. (2002) The Equivalence of Wage and Price Staggering in Monetary Business Cycle Models. *Review of Economic Dynamics*, 5, 559–585.
- Erceg C, Henderson D and Levin A (2000) Optimal Monetary Policy with Staggered Wage and Price Contracts, *Journal of Monetary Economics*, 46, 281-313.
- Fougère D, Le Bihan H and Sevestre P(2007). Heterogeneity in price stickiness: a microeconomic investigation, *Journal of Business and Economics Statistics*, 25(3), 247-264.

- Guerrieri, L. (2006). The Inflation Persistence of Staggered Contracts, *Journal of Money, Credit and Banking*, 38(2), 483-494.
- Heckel T., Le Bihan H., Montornes J.(2008) Sticky wages: evidence from quarterly microeconomic data *ECB Working Paper* No. 893.
- Juillard M, (1996). Dynare : A Program for the Resolution and Simulation of Dynamic Models with Forward Variables Through the Use of a Relaxation Algorithm, *CEPREMAP Working Paper* 9602.
- Kara E (2010). Optimal Monetary Policy in the Generalized Taylor Economy (forthcoming, *Journal of Economic Dynamics and Control*).
- Klenow, P., and Malin B., (2010). Microeconomic Evidence on Price-Setting, forthcoming, *Handbook of Monetary Economics*, Elsevier.
- Mankiw N.G. and Reis R (2002). Sticky information versus sticky prices: a proposal to replace the new Keynesian Phillips curve, *Quarterly Journal of Economics*, 117(4), 1295-1328.
- Smets F and Wouters R, (2003). An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area, *Journal of the European Economic Association*,1, 1123-1175, 09
- Taylor, J B (1993), *Macroeconomic Policy in a World Economy*, Norton.
- Walsh C (2003) *Monetary Theory and Policy* (second edition), MIT Press.
- Wolman A (1999). Sticky prices, marginal cost and the behavior of inflation", *Federal reserve bank of Richmond quarterly*, 85, 29-47.
- Woodford M (2003) *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton.University Press.
- Yun, T (1996). Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles, *Journal of Monetary Economics*, 37(2), 345–70.

7 Appendix.

7.1 Deriving the reset wage in a GT economy.

Starting from (14), we first substitute for w_{t+k}^* using (13), and then substitute for $n(h)_{t+k}$ using (8) and noting that $w(h)_{t+k} = x_{it}$ for $k = 0 \dots (i-1)$:

$$\begin{aligned}
 x_{it} &= \frac{1}{\sum_{k=0}^{i-1} \beta^k} \sum_{k=0}^{i-1} \beta^k w_{t+k}^* \\
 &= \frac{1}{\sum_{k=0}^{i-1} \beta^k} \sum_{k=0}^{i-1} \beta^k E_t \left(p_{t+k} + \sigma_L n(h)_{t+k} + \frac{\sigma_c}{1-b} (c_{t+k} - b \cdot c_{t+k-1}) \right) \\
 &= \frac{1}{\sum_{k=0}^{i-1} \beta^k} \sum_{k=0}^{i-1} \beta^k E_t \left(p_{t+k} + \sigma_L (\lambda_w (w_{t+k} - x_{it}) + n_{t+k}) + \frac{\sigma_c}{1-b} (c_{t+k} - b \cdot c_{t+k-1}) \right)
 \end{aligned}$$

Hence we can express the optimal reset wage in sector i as a function of the aggregate variables $\{p_{t+k}, w_{t+k}, n_{t+k}, c_{t+k}, c_{t+k-1}\}$ only:

$$x_{it} = \frac{1}{(1 + \sigma_L \lambda_w) \sum_{k=0}^{i-1} \beta^k} \sum_{k=0}^{i-1} \beta^k E_t \left(p_{t+k} + \sigma_L (\lambda_w w_{t+k} + n_{t+k}) + \frac{\sigma_c}{1-b} (c_{t+k} - b \cdot c_{t+k-1}) \right)$$

7.2 The log-linearized Smets-Wouters model and parameter values.

First, there is the consumption Euler equation with habit persistence:

$$c_t = \frac{b}{1-b} c_{t-1} + \frac{1}{1+b} c_{t+1} - \frac{1-b}{(1+b)\sigma_c} (r_t - E_t \pi_{t+1}) + \frac{1-b}{(1+b)\sigma_c} \varepsilon_t^b$$

Second there is the investment equation and related Tobin's q equation

$$\begin{aligned}
 \widehat{I}_t &= \frac{1}{1+\beta} \widehat{I}_{t-1} + \frac{\beta}{1+\beta} E_t \widehat{I}_{t+1} + \frac{\varphi}{1+\beta} q_t + \varepsilon_t^I \\
 q_t &= -(r_t - E_t \pi_{t+1}) + \frac{1-\tau}{1-\tau + \bar{r}^k} E_t q_{t+1} + \frac{\bar{r}^k}{1-\tau + \bar{r}^k} E_t r_{t+1}^k + \eta_t^Q
 \end{aligned}$$

where, \widehat{I}_t is investment in log-deviation, q_t is the shadow real price of capital, τ is the rate of depreciation, \bar{r}^k is the rental rate of capital. In addition, φ is

a parameter related to the cost of changing the pace of investment, and β fulfills $\beta = (1 - \tau + \bar{r}^k)^{-1}$.

Capital accumulation is given by

$$\widehat{K}_t = (1 - \tau)\widehat{K}_{t-1} + \tau\widehat{I}_{t-1}$$

Labour demand is given by

$$n_t \equiv \widehat{L}_t = -\widehat{w}_t + (1 + \psi)\widehat{r}_t^K + \widehat{K}_{t-1}$$

Good market equilibrium condition is given by

$$\begin{aligned}\widehat{Y}_t &= (1 - \tau k_y - g_y)\widehat{c}_t + \tau k_y \widehat{I}_t + g_y \widehat{\varepsilon}_t^g \\ &= \phi \widehat{\varepsilon}_t^a + \phi \alpha \widehat{K}_{t-1} + \phi \alpha \psi \widehat{r}_t^K + \phi(1 - \alpha)\widehat{L}_t\end{aligned}$$

The monetary policy reaction function is:

$$\begin{aligned}\widehat{i}_t &= \rho \widehat{i}_{t-1} + (1 - \rho)\{\bar{\pi}_t + r_\pi(\widehat{\pi}_{t-1} - \bar{\pi}_t) + r_Y(\widehat{Y}_t - \widehat{Y}_t^P)\} \\ &\quad + \{(r_{\Delta\pi}(\widehat{\pi}_t - \widehat{\pi}_{t-1}) + r_{\Delta Y}((\widehat{Y}_t - \widehat{Y}_t^P) - (\widehat{Y}_{t-1} - \widehat{Y}_{t-1}^P)))\} + \eta_t^R\end{aligned}$$

Shocks follow autoregressive processes:

$$\begin{aligned}\varepsilon_t^a &= \rho_a \varepsilon_{t-1}^a + \eta_t^a \\ \varepsilon_t^b &= \rho_b \varepsilon_{t-1}^b + \eta_t^b \\ \varepsilon_t^I &= \rho_I \varepsilon_{t-1}^I + \eta_t^I \\ \varepsilon_t^Q &= \rho_Q \varepsilon_{t-1}^Q + \eta_t^Q \\ \varepsilon_t^g &= \rho_g \varepsilon_{t-1}^g + \eta_t^g\end{aligned}$$

Note in the paper we focus on the effects of two shocks: the i.i.d. monetary policy shock η_t^R and the technology shock ε_t^a . The calibration of the parameters is given in Table A.1. below. It is based on the mode of the posterior estimates, as reported in Smets and Wouters (2003).

Table A.1		
Parameter	Value	Interpretation
β	0.99	Discount rate
τ	0.025	Depreciation rate
α	0.30	Capital share
λ_w	0.5	Mark-up wage
φ^{-1}	6.771	Inv. adj. cost
σ_c	1.353	Consumption utility elasticity
b	0.573	Habit formation
σ_L	2.400	Labor utility elasticity
ϕ	1.408	Fixed cost in production
ξ_e	0.599	Calvo employment
ψ	0.169	Capital util. adj. cost
		Reaction function coefficients
r_π	1.684	to inflation
$r_{\Delta\pi}$	0.140	to change in inflation
ρ	0.961	to lagged interest rate
r_y	0.099	to the output gap
$r_{\Delta y}$	0.159	to change in the output gap
ρ_a	0.823	persistence, productivity shock

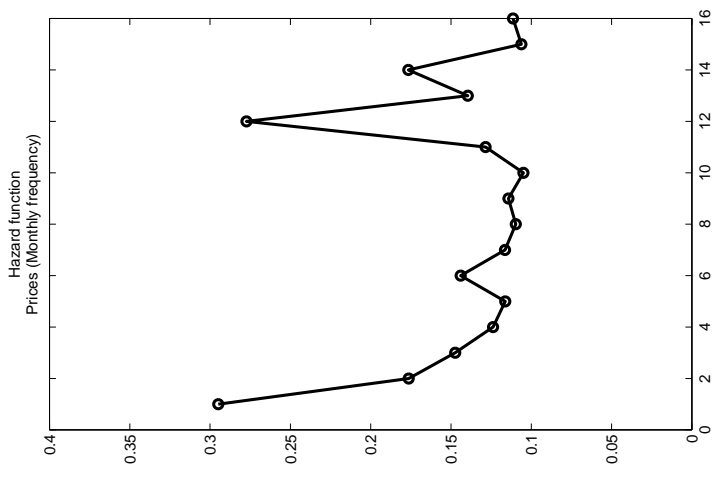
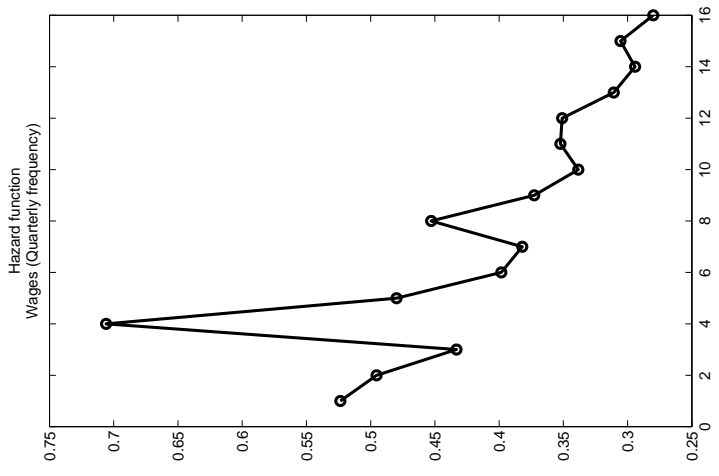


Figure 1

Figure 2

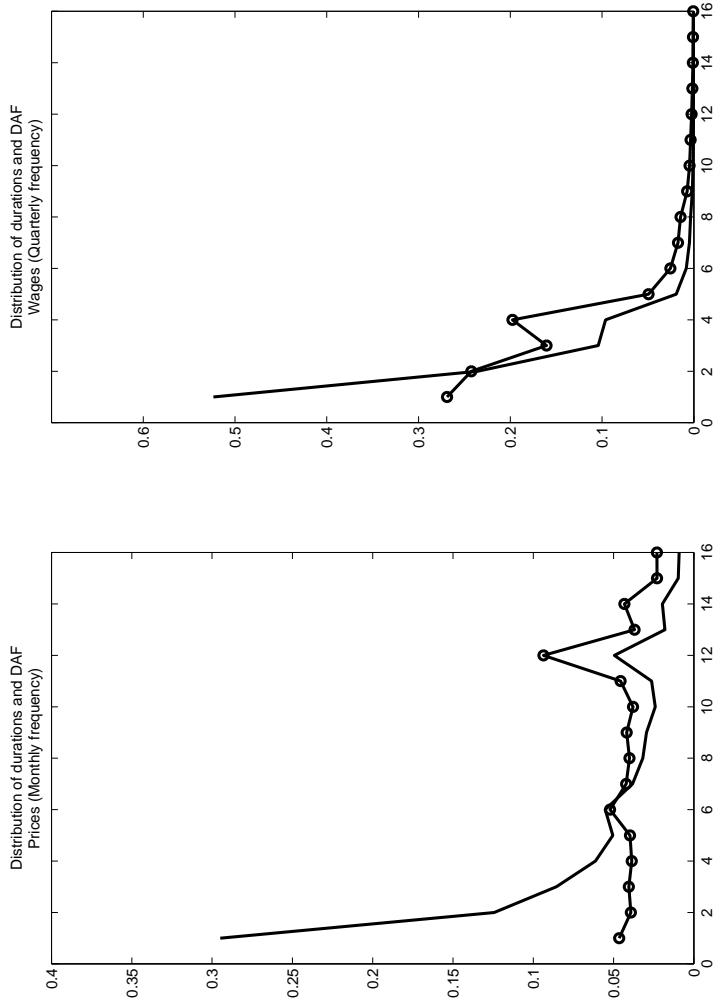


Figure 3

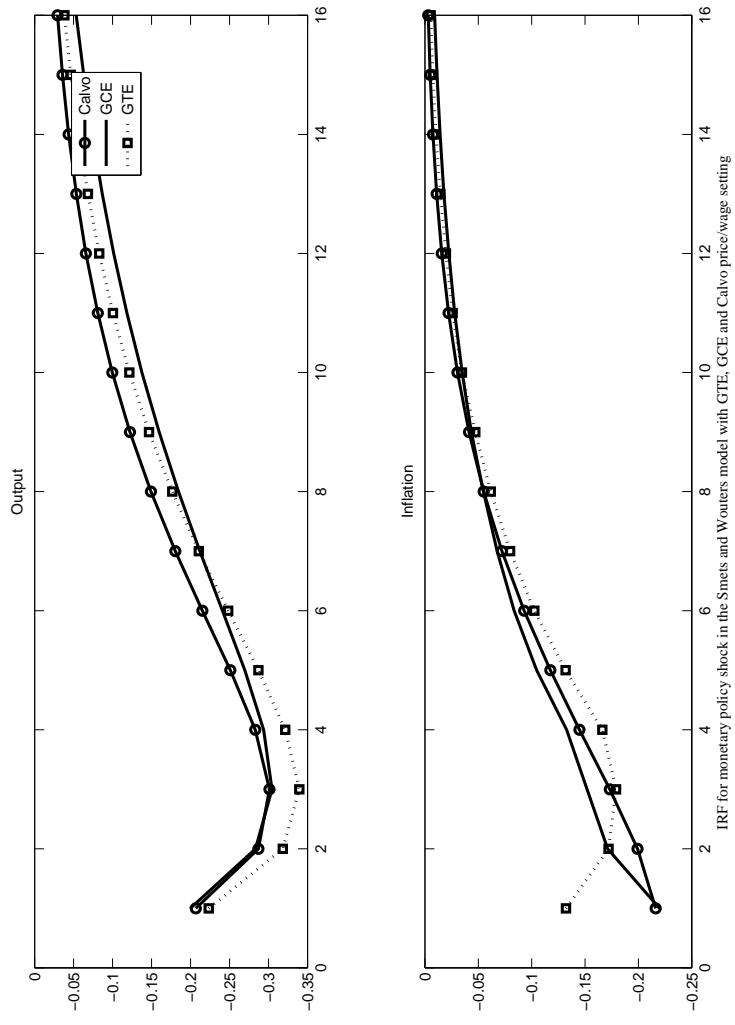


Figure 4

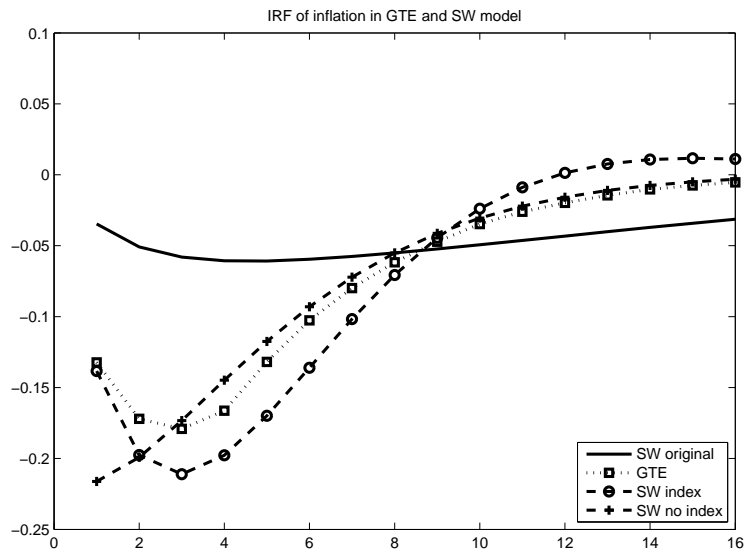


Figure 5

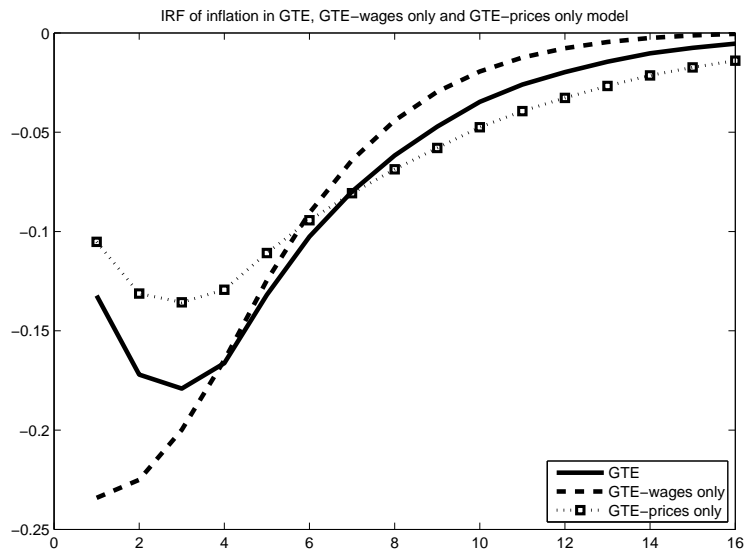
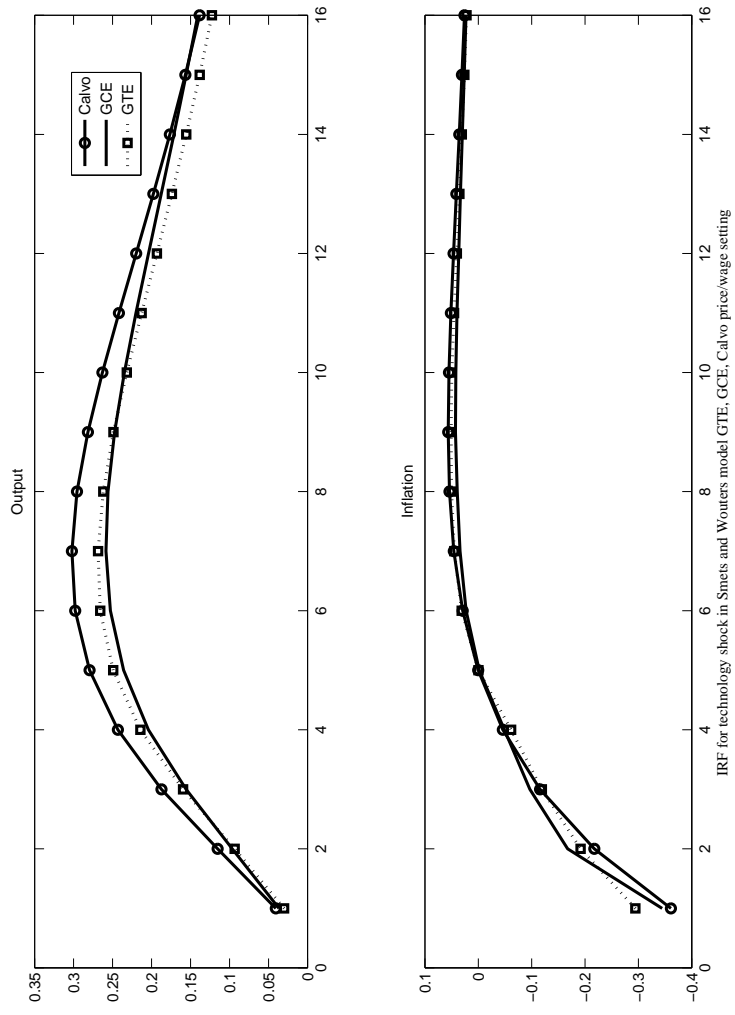


Figure 6



Documents de Travail

300. X. Ragot, "The Case for a Financial Approach to Money Demand," October 2010
301. E. Challe, F. Le Grand and X. Ragot, "Incomplete markets, liquidation risk, and the term structure of interest rates," October 2010
302. F. Le Grand and X. Ragot, "Prices and volumes of options: A simple theory of risk sharing when markets are incomplete," October 2010
303. D. Coulibaly and H. Kempf, "Does Inflation Targeting decrease Exchange Rate Pass-through in Emerging Countries?," November 2010
304. J. Matheron, « Défisiscalisation des heures supplémentaires : une perspective d'équilibre général », Décembre 2010
305. G. Horny and P. Sevestre, "Wage and price joint dynamics at the firm level: an empirical analysis," December 2010
306. J. Coffinet and S. Lin, "Stress testing banks' profitability: the case of French banks," December 2010
307. P. Andrade and H. Le Bihan, "Inattentive professional forecasters," December 2010
308. L. Clerc, H. Dellas and O. Loisel, "To be or not to be in monetary union: A synthesis," December 2010
309. G. Dufrénot and S. Malik, "The changing role of house price dynamics over the business cycle," December 2010
310. M. Crozet, I. Méjean et S. Zignago, "Plus grandes, plus fortes, plus loin...Les performances des firmes exportatrices françaises," Décembre 2010
311. J. Coffinet, A. Pop and M. Tiesset, "Predicting financial distress in a high-stress financial world: the role of option prices as bank risk metrics," Décembre 2010
312. J. Carluccio and T. Fally, "Global Sourcing under Imperfect Capital Markets," January 2011
313. P. Della Corte, L. Sarno and G. Sestieri, "The Predictive Information Content of External Imbalances for Exchange Rate Returns: How Much Is It Worth?," January 2011
314. S. Fei, "The confidence channel for the transmission of shocks," January 2011
315. G. Clette, S. Chang and M. Konte, "The decreasing returns on working time: An empirical analysis on panel country data," January 2011
316. J. Coffinet, V. Coudert, A. Pop and C. Povel, "Two-Way Interplays between Capital Buffers, Credit and Output: Evidence from French Banks," February 2011
317. G. Clette, N. Dromel, R. Lecat, and A-Ch. Paret, "Production factor returns: the role of factor utilisation," February 2011
318. S. Malik and M. K. Pitt, "Modelling Stochastic Volatility with Leverage and Jumps: A Simulated Maximum Likelihood Approach via Particle Filtering," February 2011
319. M. Bussière, E. Pérez-Barreiro, R. Straub and D. Taglioni, "Protectionist Responses to the Crisis: Global Trends and Implications," February 2011
320. S. Avouyi-Dovi and J-G. Sahuc, "On the welfare costs of misspecified monetary policy objectives," February 2011
321. F. Bec, O. Bouabdallah and L. Ferrara, "the possible shapes of recoveries in Markof-switching models," March 2011
322. R. Coulomb and F. Henriët, "Carbon price and optimal extraction of a polluting fossil fuel with restricted carbon capture," March 2011
323. P. Angelini, L. Clerc, V. Cúrdia, L. Gambacorta, A. Gerali, A. Locarno, R. Motto, W. Roeger, S. Van den Heuvel and J. Vlček, "BASEL III: Long-term impact on economic performance and fluctuations," March 2011
324. H. Dixon and H. Le Bihan, "Generalized Taylor and Generalized Calvo price and wage-setting: micro evidence with macro implications," March 2011

Pour accéder à la liste complète des Documents de Travail publiés par la Banque de France veuillez consulter le site :
http://www.banque-france.fr/fr/publications/documents_de_travail/documents_de_travail_11.htm

For a complete list of Working Papers published by the Banque de France, please visit the website:
http://www.banque-france.fr/fr/publications/documents_de_travail/documents_de_travail_11.htm

Pour tous commentaires ou demandes sur les Documents de Travail, contacter la bibliothèque de la Direction Générale des Études et des Relations Internationales à l'adresse suivante :

For any comment or enquiries on the Working Papers, contact the library of the Directorate General Economics and International Relations at the following address :

BANQUE DE FRANCE
49- 1404 Labolog
75049 Paris Cedex 01
tél : 0033 (0)1 42 97 77 24 ou 01 42 92 62 65 ou 48 90 ou 69 81
email : marie-christine.petit-djemad@banque-france.fr
jeannine.agoutin@banque-france.fr
michael.brassart@banque-france.fr
veronique.jan-antuoro@banque-france.fr
nathalie.bataille-salle@banque-france.fr