Generalized Taylor and Generalized Calvo Price and Wage-Setting: Micro Evidence with Macro Implications

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Abstract

The Generalized Calvo and the Generalized Taylor model of price and wage-setting are, unlike the standard Calvo and Taylor counter-parts, 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.

JEL-Code: E31, E32, E52, J30.

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

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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 Erceg, Henderson and Levin (2000)(EHL): 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 automaticaly updated in response to inflation.[1] 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.[2] We take the cross-sectional distribution of completed spells and use this to calibrate a Generalized Taylor Economy (GTE) in which there are several sectors, each with a simple Taylor contract but with contract lengths differing across sectors[3]. Each of the two models we consider (GC and GTE) exactly reflects the full distribution of durations revealed by the micro-data. We also consider

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[1] In EHL, the indexation is to the unconditional mean inflation, while in SW and CEE it is to lagged inflation

[2] The GC approach has been adopted by Wolman (1999), Guerrieri (2006), Dixon (2009).

[3] References for the GT price setting model include Taylor (1993), Dixon and Kara (2005, 2010), Coenen et al. (2007).

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 GTE 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 function 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 distribution of both wages and price durations.* By contrast, previous research has used either only a few moments of these distributions or indirectly estimated distributions. Second we derive a model of wage-setting with GT and GC contracts, which builds on the EHL model. This extends the EHL framework to a more general and flexible structure of wage-rigidity than has been considered previously.

Our exercise is to a large extent an analytical one: 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 pricing. Our main result is that using these alternative frameworks we can partly replicate the persistence of inflation 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. In contrast, we find that all three approaches lead to similar responses to a productivity shock.

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 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 Economy* (GTE)

In the *Generalized Taylor Economy* (GTE) there are N sectors, $i = 1, ..., N$. 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 (or wage). If we think of the economy as a continuum of firms, we can describe the *GTE* 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 $\boldsymbol{\alpha} = (\alpha_1, ..., \alpha_F)$ 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 *GTE* 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 *GTE* has been developed in Taylor (1993), Carvalho (1995), Dixon and Kara (2005, 2006, 2010), Coenen et al (2007) and Kara (2010). The *GTE* 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 :

$$p_t = \sum_{i=1}^{F} \alpha_i p_{it} \tag{1}$$

In each sector i, a proportion i^{-1} of the α_i firms reset their price at each date. Assuming imperfect competition and 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 :

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

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 macreconomic model we use.

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

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

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

$$\bar{h} = \sum_{i=1}^{F} \frac{\alpha_i}{i} \tag{4}$$

2.2 The *Generalized Calvo Economy* (GCE)

In the *Generalized Calvo Economy (GCE)*, 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 $i = 1...F-1$. 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 GCE 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 is[4]:

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

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

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[4] Note 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.

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 GCE and GCT 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 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. 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 $W_t(h)$

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

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

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

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 households[5]. Employment is assumed to be demand determined: hence the households marginal rate of substitution at time t is:

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

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[5] See Ascari (2000) for the details.

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

$$W^*(h)_t = P_t.MRS(h)_t \tag{10}$$

$W^*(h)_t$ 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 GTE.

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

$$\begin{aligned} mrs(h)_t &= \sigma_L n(h)_t + \frac{\sigma_c}{1-b}\left(c_t - b.c_{t-1}\right) && (11)\\ n(h)_t &= \lambda_w \left(w_t - w(h)_t\right) + n_t && (12)\\ w^*(h) &= p_t + mrs_t && (13) \end{aligned}$$

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^w_{it} will fulfill $w(h)_{t+k} = x_{it}$ for $k = 0, ..., i-1$. The optimal reset wage is obtained by maximizing the intertemporal utility function subject to this structure of wage stickiness, and a standard budget constraint. In log-linear form the optimal reset wage is given by:

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

That is, x^w_{it} 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:

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

Therefore we can construct a wage setting GTE. 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:

$$\begin{aligned} w_t &= \sum_{i=1}^{F_w} \alpha_{iw} w_{it} && (16) \\ w_{it} &= \frac{1}{i} \sum_{k=0}^{i-1} x_{it-k}^{w} && (17) \end{aligned}$$

These equations can then be combined with the price-setting GTE 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 GCE.

In the case of the GCE, we have the wage-survival function and related hazard rates: $S_w(i)$ and $h_w(i)$ $i = 1, ..., F_w$ 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:

$$\begin{aligned} x_t^w &= \frac{1}{\sum_{i=1}^{F} S_w(i)\beta^{i-1}} \sum_{i=1}^{F_w} S_w(i)\beta^{i-1} E_t w_{t+i-1}^{*} && (18) \\ &= \frac{1}{(1+\sigma_L \lambda_w)\sum_{i=1}^{F_w} S_w(i)\beta^{i-1}} \sum_{i=1}^{F_w} \beta^{i-1} E_t (p_{t+i-1} && (19) \\ &\qquad +\sigma_L \left(\lambda_w w_{t+i-1} + n_{t+i-1}\right) + \frac{\sigma_c}{1-h}\left(c_{t+i-1} - b.c_{t+i-2}\right)) \end{aligned}$$

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

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

Again, this wage-setting GCE can be combined with price-rigidity. Note that we can treat the Calvo model as a special case of the GCE. We can use the average proportion of wages reset each quarter as our calibration of the Calvo reset probability: the resulting GCE is a constant hazard model $h_w(i) = \bar{h}_w$ for $i = 1...F_w$. 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 $\bar{h}_w = 0.38$. 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[6], 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 $NKPC$.

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.

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[6] See SW equation (33) page 1138.

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....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 weigths, 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 the quarterly frequency of $\bar{h} = 0.53$.

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.[7] 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.

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[7] The maximum duration in the dataset is 104 months, but this concern a negligible fraction of price spells. The model simulations 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.

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 ($\bar{h}_w = 0.38$), while the weighted average duration of spells is 2.0 quarters. Less than 0.1 percent of wage spell last more than 16 quarters.[8]

3.2 Hazard function estimates

From the weighted distribution of price and wage durations, we compute survival function and hazard functions using the non-parametric Kaplan-Meier estimator. The estimates of the hazard function, the parameters h_i of sec-

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[8] In 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.

tion 2.2, are presented in Figure 1.[9] 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 where 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 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 at 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

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[9] Due 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 $F = 95$ (IS this correctXXX). Details available from the authors.

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 increases[10]. 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 (as in Mankiw and Reis, 2002). 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

4 Implications for monetary policy transmission.

In this section, we use the distribution of the price and wage data to calibrate the *GT* and *GC* models developed in section 2. We then embed these model in two alternative macroeconomic models to investigate the implications of *GC* and *GT* behavior for inflation and output persistence following a monetary policy shock.

4.1 A simple quantity theory model with price or wage-setting.

We will first examine the *GC* and *GTE* models of prices in a quantity theory model with labour as the only input of production. This model has the great advantage of being very simple, because almost all its dynamic properties are generated by the pricing models alone. DSGE models like the *SW* model in

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

contrast are quite complicated with dynamic properties emerging from the interaction of pricing with many other features of the model. The model we present is in its log-linearised version (see Ascari 2003, Dixon and Kara 2005 for the derivation from microeconomic foundation).

To model the demand side, we use the Quantity Theory[11]:

$$y_t = m_t - p_t$$

where (p_t, y_t) are aggregate price and output and m_t the money supply. We model the monetary growth process as an autoregressive process of order one $AR(1)$:

$$\begin{aligned} m_t &= m_{t-1} + \varepsilon_t \\ \varepsilon_t &= \nu \varepsilon_{t-1} + \xi_t \end{aligned}$$

where ξ_t is a white noise error term (effectively a monetary growth shock). Following CEE we set $\nu = 0.5$.

The optimal flexible price p_t^* at period t in all sectors is given by:

$$p_t^* = p_t + \gamma y_t \tag{21}$$

The key parameter γ captures the sensitivity of the flexible price to output[12]. As discussed in Dixon and Kara (2010), there are a range of calibrated and estimated values for γ: for illustrative purposes, we use the "moderate" case of $\gamma = 0.1$ as in Mankiw and Reis (2002). As discussed in Ascari (2003) and Edge (2002), the value of γ can be interpreted as resulting from either wage or price-setting. We therefore report the results using both the French wage and price data.

Knowing (21) we can use the GTE price-setting equations and price formulae $(2), (3), (4)$ .to derive actual price-setting. We can do the same for the GC price-setting equations $(5), (6), (7)$. To calibrate the model parameters α_{iw} and $h_i,$ we use the micro data estimates presented above in section 3. In the case of the Calvo model, we simply take the GC and have a constant hazard $\bar{h}$ taken from the data. We now take this simple quantity theory (QT)

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[11] In the case of $\nu = 0$ below, the quantity theory can be seen as resulting from an Euler equation (see Ascari 2003).

[12] This can be due to increasing marginal cost and/or an upward sloping supply curve for labour. See for example Walsh (2003, chapter 5) and Woodford (2003, chapter 3).

framework and subject it to a pure one-off monetary growth shock $\xi_t > 0$, which dies away rapidly with $\nu = 0.5$. The cumulative effect of the shock in the limit is twice the initial shock. The model, as well as that of next section, is solved and simulations are performed using the DYNARE toolbox (Juillard, 1996). In Figure 3, we depict the impulse response functions for output and inflation.

Insert FIGURE 3

There are two main observations to be made. First, in the inflation IRF, there is no hump shape in either the Calvo or the GCE model, but there is a hump shape with the GTE. This result confirms, in a set-up that uses data on actual distributions of price durations, the finding of Dixon and Kara (2010). Second, both the GTE and the GCE predict a more persistent inflation and output response than the simple Calvo model.

The intuition behind the hump is that in the GTE, firms that are resetting their price are less forward looking *on average* in their pricing decision than in Calvo. That is 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 GCE 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 GCE firms raise their prices most on impact.

The GC and GTE are more persistent for both inflation and output than Calvo. The intuition here 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 (2005), that the presence of long-contracts has a disproportionate effect on the behavior of aggregate output and inflation due to the strategic complementarity of prices[13].

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

4.1.1 Wage rigidity in the QT model.

We can do the same exercise calibrating the Calvo, GC and GT models with the wage data. We should note however that the wage data does not have a long fat tail: indeed after 4 quarters, the proportion of long-spells is lower in the data than in the Calvo distribution. We would therefore expect to see the Calvo model as no less persistent than the GTE or GC.

In Figure 4, we depict the impulse responses for all three models using the wage data.

Insert FIGURE 4

As we see, the inflation and output IRFs for the Calvo and GC are very similar (and indeed both very different from the GTE case). There is an inflation hump for the GTE, with an impact effect on wage inflation being less than in the other two cases: but from the second quarter onwards the effect on wage inflation is larger. This is mirrored in the output IRF: there is initially a greater effect on output under the GTE, but after the third quarter there is less.

If we consider the simple QT framework, we can see that the nature of the empirical distribution matters. We have taken two distributions from the micro-data for the same economy: that of wages and prices. Whilst there are some qualitative similarities, the exact shape of the distribution matters. In particular if we take the GC and the GT, they may give rise to similar IRFs for output (in the case of price-data) or not (wage-data). This suggests that the micro-evidence is needed to evaluate the respective merits of the models.

4.2 A DSGE model: Smets and Wouters (2003)

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. The SW model is much more complicated than the simple QT model we have just used. There are many sources of dynamics other than prices and wages: capital adjustment (and capital utilization), 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. Hence the effect of pricing dynamics is not isolated as in the simple QT framework of the previous section.

4.2.1 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

$$mc_t = (1-\alpha)w_t + \alpha r_t^k - \varepsilon_t^a \tag{22}$$

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

$$p_t^* = mc_t \tag{23}$$

We can then use (23) to directly implement the GTE price equations $(1), (2), (3,)$ and also the wage equations $(11), (12), (13), (15), (16), (17)$.

Similarly, we can use (23) 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 and equal to $\bar{h}$ for prices and $\bar{h}^w$ for wages[14].

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).

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[14] 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.

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

Figure 5 reports the IRF for inflation and output in the SW model with GT and GC contracts following a monetary shock. We see that in this far more complex model, we get pretty much the same conclusions as in the simple QT model. First, inflation and output are more persistent for the GTE and GCE than with the Calvo set-up. Second, there is a hump-shaped response of inflation for the GTE, whilst the GC and Calvo have initial peak impact.

Insert FIGURE 5

The timing of the inflation peak is earlier than in the original SW model: with the GTE it is 3 quarters, whilst in SW it is 5 quarters. It is however not surprising that the model is not able to reach the same degree of persistence as the original model. First, we are not re-estimating the model, and use 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 GTE or GCE assumption on euro area data would probably come closer to fitting the actual response of inflation to monetary policy shock. 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. Overall, the fact that we get a hump with the GTE 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.

4.2.3 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 GTE 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 GTE economy, the same mecanism 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 tends to go back to its initial level, the required increase in price is smaller. As a result, the impact effect for both type of models is relatively close.

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 standard DGSE models used today. 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 these ways of looking at the micro-data, we can think of price and wage-setting models that are directly consistent with the micro-data: the Generalized Calvo and Generalized Taylor models of pricing. 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 Generalized 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.

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 an initial 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. Second, we could undertake an optimal policy exercise within this framework. Kara (2010) has conducted a comparison of optimal policy with a GTE in the simple quantity theory setting: he finds that the optimal policy with a GTE 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.

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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 $k = 0...(i-1)$:

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

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:

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

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

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

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 $\beta = \left(1 - \tau + \bar{r}^k\right)^{-1}$.

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:

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

Shocks follow autoregressive processes:

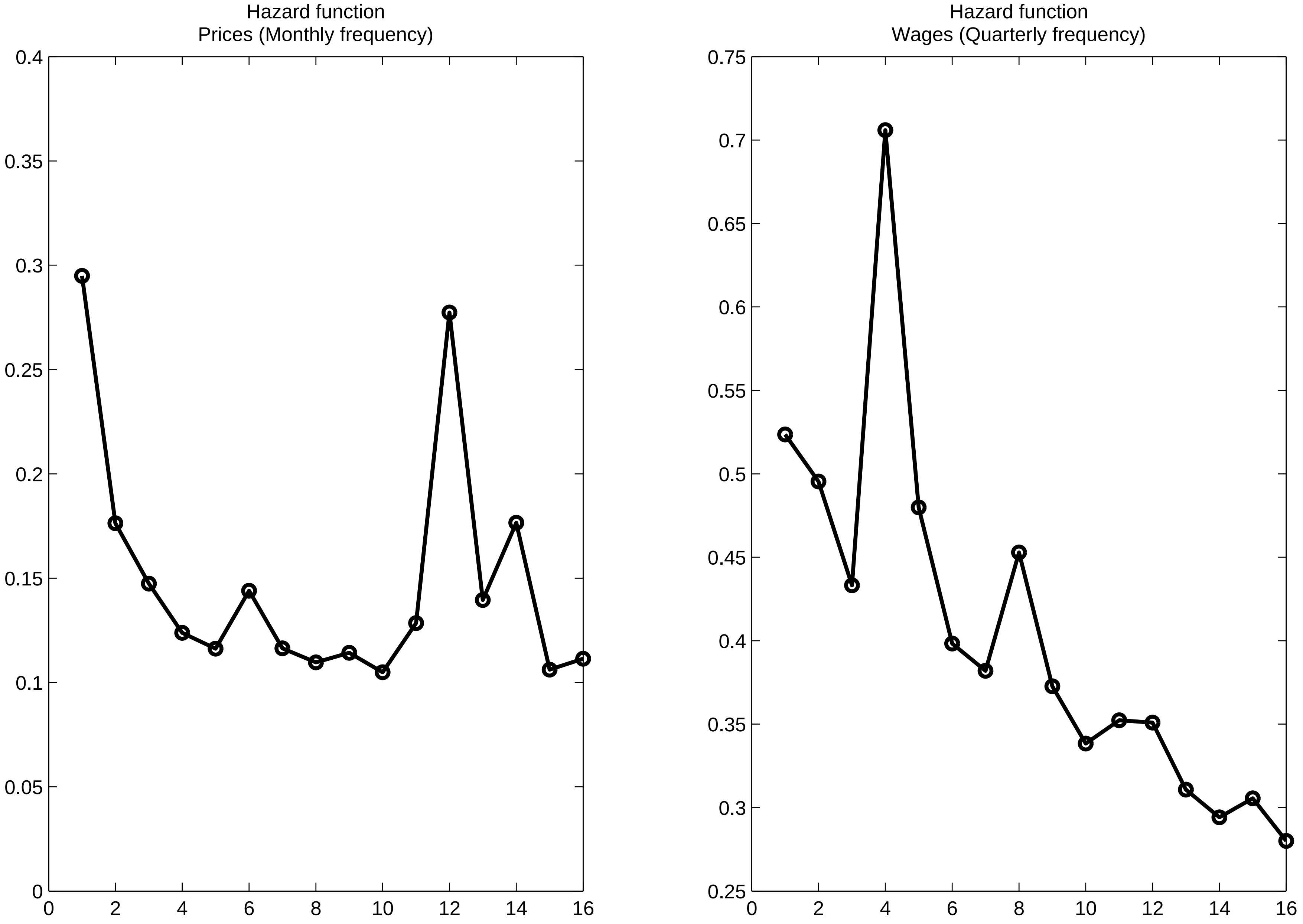
$$\begin{aligned}\varepsilon_t^a &= \rho_a \varepsilon_{t-1}^a + \eta_t^a \\ \varepsilon_t^b &= \rho_b \varepsilon_{t-1}^b + \eta_t^b \\ \varepsilon_t^I &= \rho_I \varepsilon_{t-1}^I + \eta_t^I \\ \varepsilon_t^Q &= \rho_Q \varepsilon_{t-1}^Q + \eta_t^Q \\ \varepsilon_t^g &= \rho_g \varepsilon_{t-1}^g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

Note in the paper we focus on the effects of two shocks: the 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

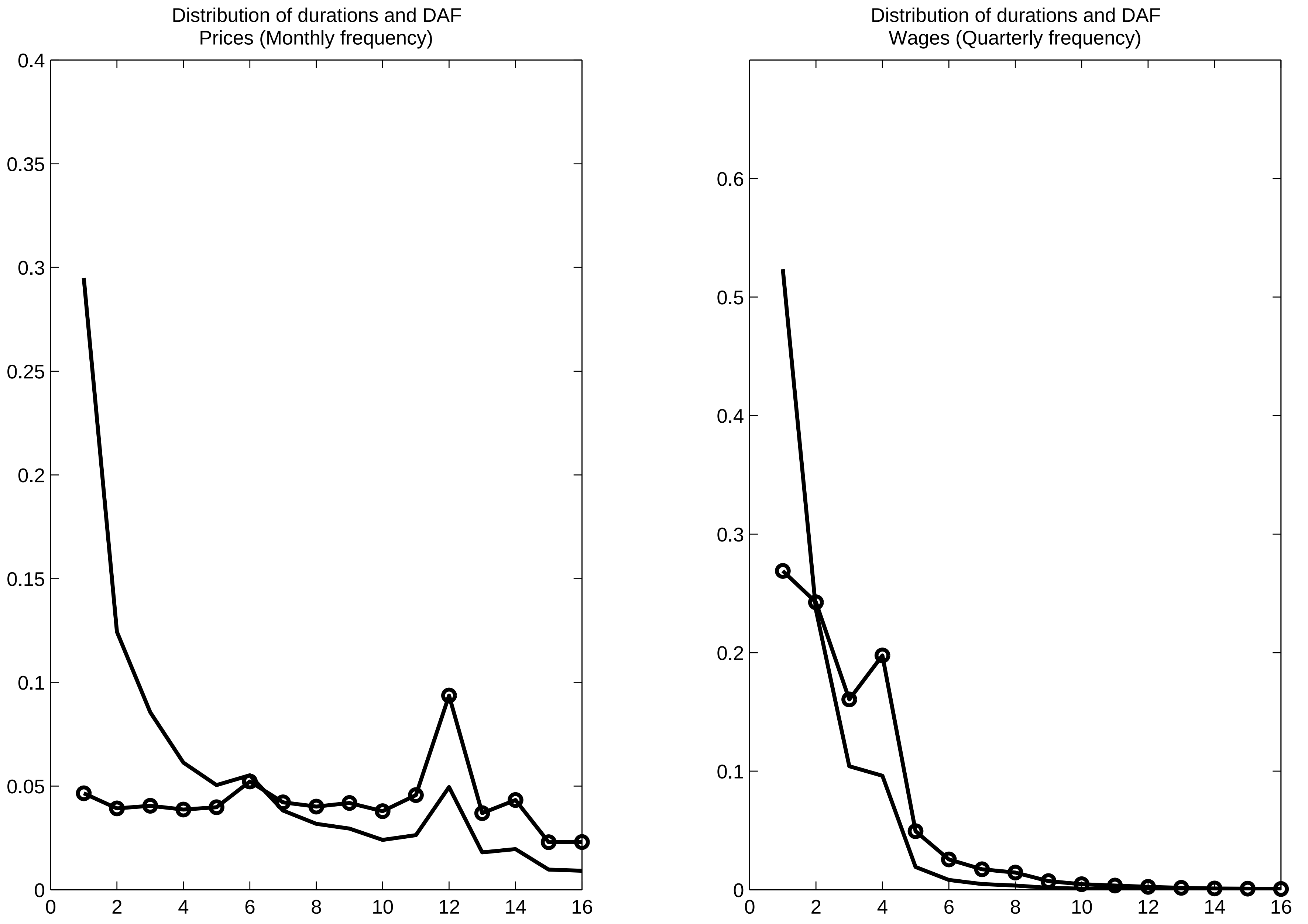
Figure 1



Hazard function
Prices (Monthly frequency)

Hazard function
Wages (Quarterly frequency)

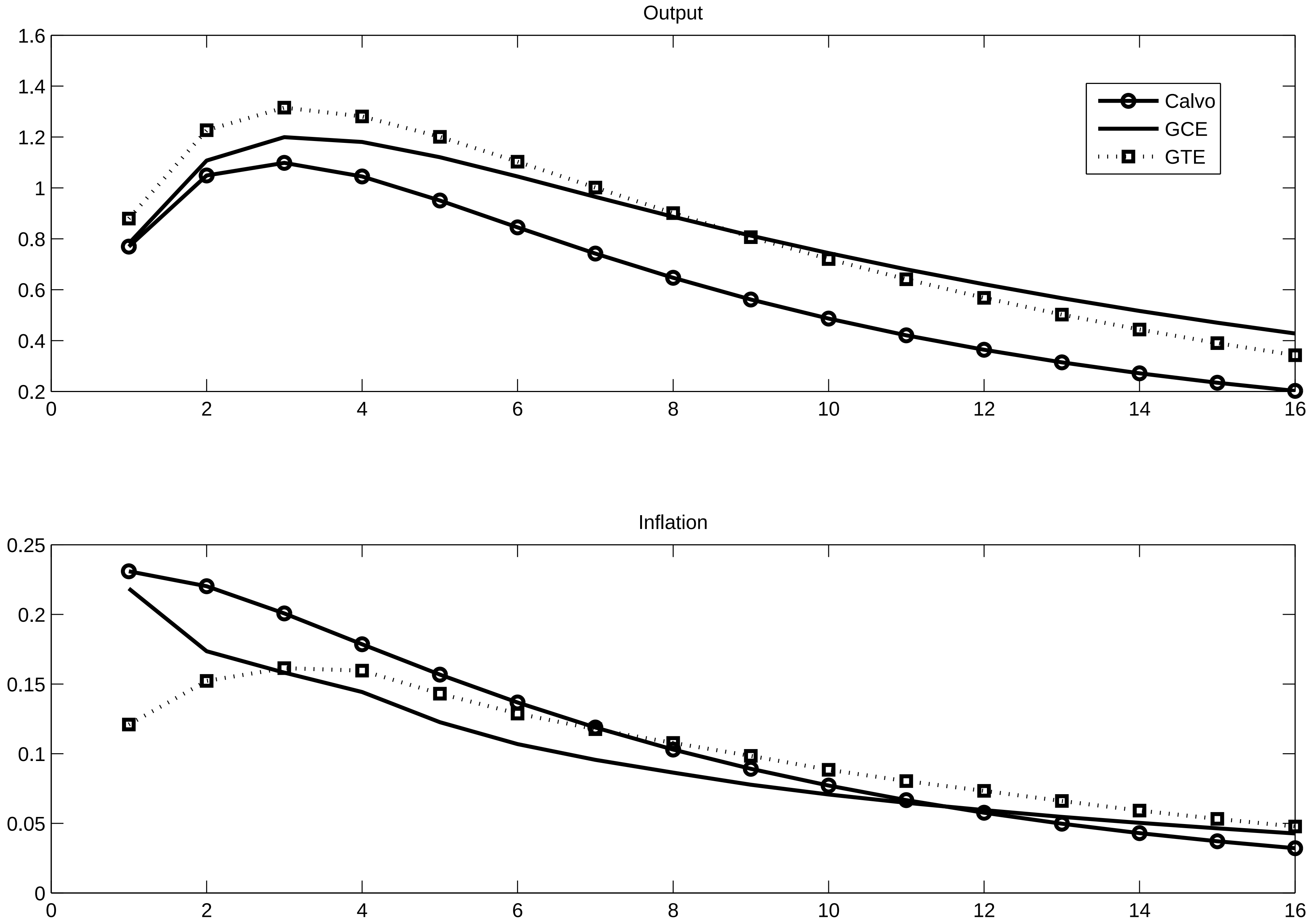
Figure 2



Distribution of durations and DAF
Prices (Monthly frequency)

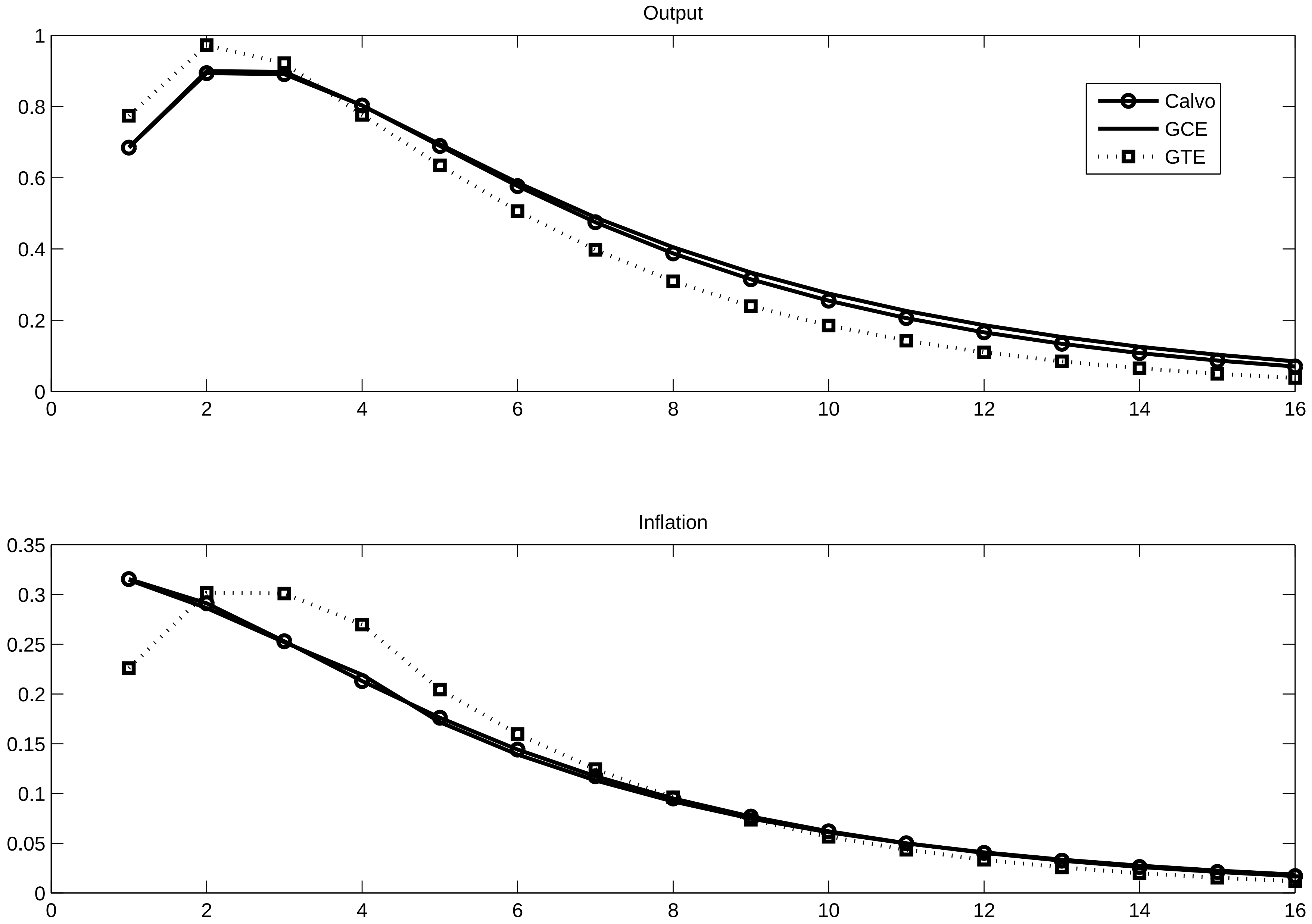
Distribution of durations and DAF
Wages (Quarterly frequency)

Figure 3



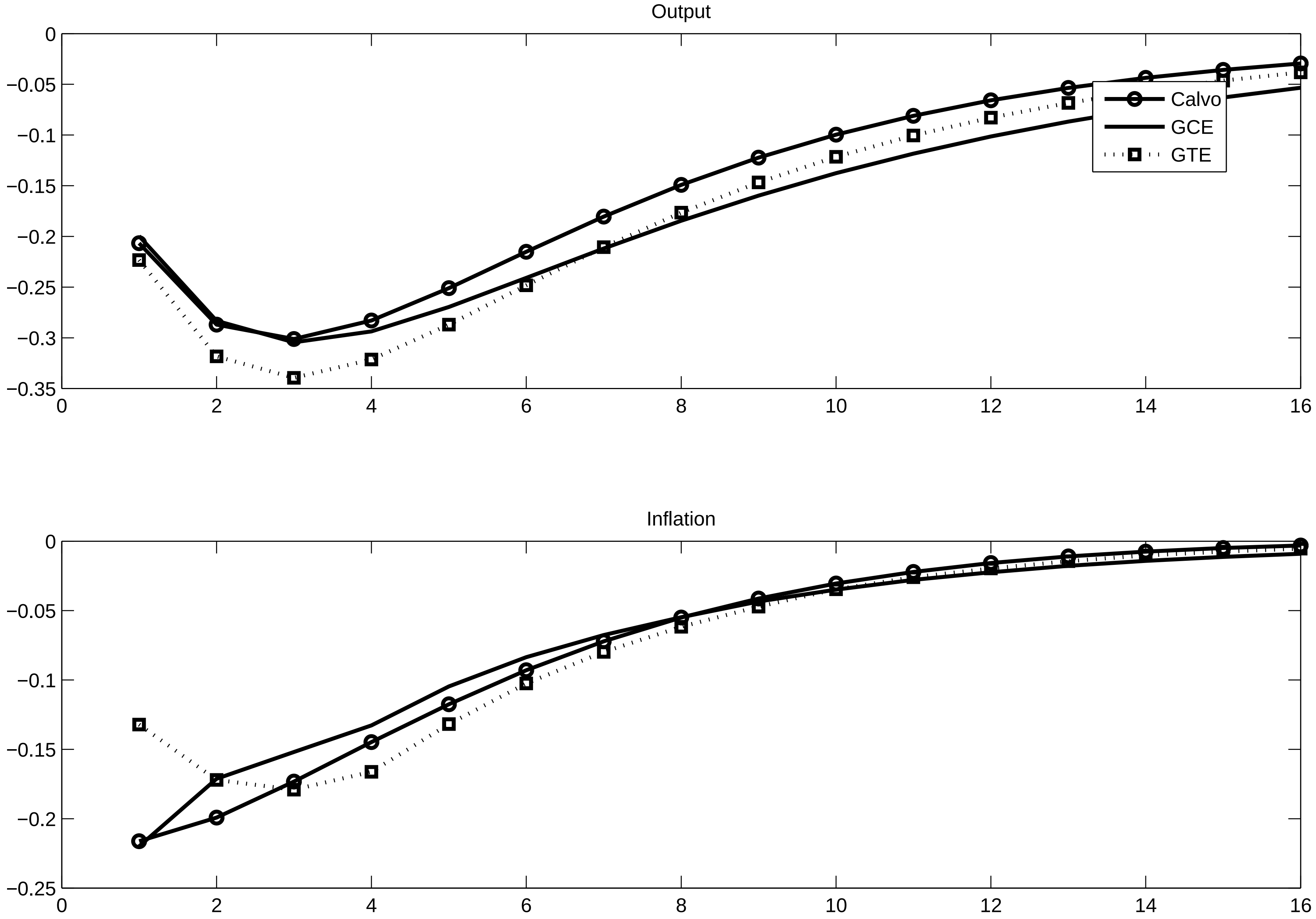
IRF of money growth shock in Quantity Theory model for GTE, GCE, Calvo price−setting

Figure 4



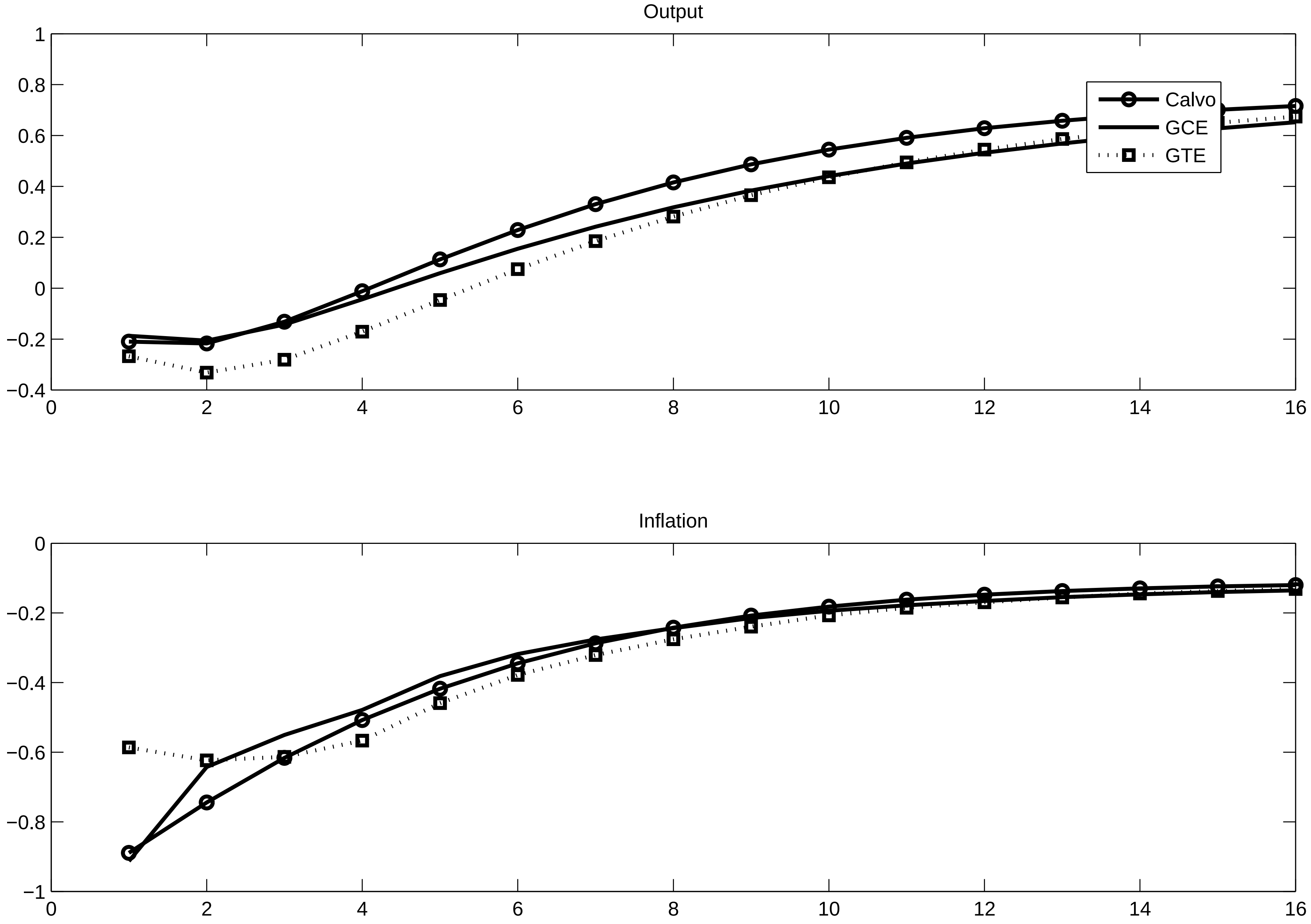
IRF of money growth shock in Quantity Theory model for GTE, GCE, Calvo scheme − Wage calibration

Figure 5



IRF for monetary policy shock in the Smets and Wouters model with GTE, GCE and Calvo price/wage setting

Figure 6



IRF for technology shock in Smets and Wouters model GTE, GCE, Calvo price/wage setting

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