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

Huw Dixon[†] and Hervé Le Bihan[‡]

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Abstract

The Generalized Calvo and the Generalized Taylor models 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 and persistent response of inflation, without resorting to the counterfactual assumption of systematic wage and price indexation.

JEL: E31, E32, E52, J30.

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

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Christiano, Eichenbaum and Evans (2005) (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.[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 at the firm level. 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 (see Dixon 2009 for a detailed explanation): the Hazard profile, the distribution of durations, and the cross-sectional distribution of durations or distribution across firms (DAF). 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 (GT) Economy 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 GT) exactly reflects the full distribution of du-

[1] In 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.

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

rations 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.[4]

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 (Le Bihan, Montornès, and Heckel, *forthcoming*). 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 an exponential distribution for 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

[4] We do not consider the basic Taylor model here since it counterfactually predicts a degenerate distribution of durations.

micro-data based approach to price and wage setting. We show 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. 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*.[5] 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 structure of the paper is as follows. Section 1 develops *GT* and *GC* models of price and wage setting. Section 2 presents our micro data on price and wages and uses the distribution of durations to calibrate these models. Section 3 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 4 concludes.

1 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 contract 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

[5] Likewise, if we calibrate the *GT* using the original *SW* price and wage-setting parameters we find the same similarity.

is easily related to the Generalized Taylor model, where there are many sectors within which there is a simple Taylor staggered contract which differ in length 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.

1.1 *Generalized Taylor* (GT) *Economy*

In the *Generalized Taylor* (GT) *Economy* there are F sectors, $i = 1, ..., F$. 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 $\boldsymbol{\alpha} = (\alpha_1, ..., \alpha_F)$ 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), Dixon and Kara (2010, 2011), 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 :

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

In each sector i, a proportion i^{-1} of the α_i firms reset their price at each date. Assuming imperfect competition and 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 in sector i, 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 macroeconomic model we use. Note that since there is one reset-price per sector, it is possible to introduce a sector specific flex price p^*_{it} into (2) which might reflect sector specific shocks. Since we are interested in the aggregate response to monetary policy, we ignore such effects.

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 i^{-1} of sector i which is of size α_i:

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

1.2 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 $i = 1, ..., F-1$. 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 is:[6]

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

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.

1.3 The Labour market and Wage-setting.

We can apply *GC* and *GT* models to wage data in order to calibrate wage-setting. If we had 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

[6] 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.

or price rigidity lead to reduced-form dynamics that are 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, that allow for a general distribution of durations, rather than the specific Calvo distribution found in EHL. As in EHL, we take the craft-union model first employed in the macroeconomic setting by Blanchard and Kiyotaki (1987). There is a unit interval of monopolistic household "unions" $h \in [0,1]$ each with a unique type of labour. Aggregate labour L_t is constituted by combining each household's labour $L_t(h)$ according to a CES aggregator for labour inputs:

$$L_t = \left[\int_0^1 L_t(h)^{\frac{\lambda_w - 1}{\lambda_w}} dh \right]^{\frac{\lambda_w}{\lambda_w - 1}} \tag{8}$$

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

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

with the corresponding conditional labour demand:

$$L_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\lambda_w} L_t \tag{9}$$

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.[7] The union-household sets its nominal wage $W(h)_t$ and employment is assumed to be demand determined from (9), resulting in the households marginal rate of substitution at time t:

$$MRS(h)_t = -\frac{U_l(C_t - bC_{t-1}, 1 - L(h)_t)}{U_C(C_t - bC_{t-1}, 1 - L(h)_t)} = \frac{(C_t - bC_{t-1})^{\sigma_c}}{(1 - L_t(h))^{\sigma_L}} \tag{10}$$

We can define the "shadow nominal wage" as:

$$W^*(h)_t = P_t.MRS(h)_t \tag{11}$$

$W^*(h)_t$ 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 $W(h)_t$ and its current and past consumption according to (10).

Following SW, we have assumed that all firms employ the same mix of labour represented by the aggregator (8). Whilst this is convenient, it would also possible to model the labour market with firm or sector-specific labour. In the case of sector-specific labour, we would have a different aggregator for each sector and a corresponding sectoral wage and labour demand analogous to (9). In the case of firm specific labour, firms would employ labour directly and pay a firm specific wage. We refer to De Walque, Smets and Wouters (2006) and Camber and Millard (2010) for similar models with these features.[8]

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

[8] There is also the dimension of the assumption made about the labour market. In the SW framework it is assumed that wage-setters are monopolistic suppliers. Camber and Millard (2010) also consider the introduction of Nash bargaining into the labour market as in Gertler et al (2008, 2009).

1.3.1 Wage-setting in the GT model.

Log-linearising equations (9),(10),(11) we have:

$$
\begin{aligned}
mrs(h)_t &= \sigma_L n(h)_t + \frac{\sigma_c}{1-b}\left(c_t - b.c_{t-1}\right), &(12)\\
n(h)_t &= \lambda_w \left(w_t - w(h)_t\right) + n_t, &(13)\\
w^*(h) &= p_t + mrs_t, &(14)
\end{aligned}
$$

where lowercase letter are log-deviations 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, then given the (nominal) reset wage x_{it}^w we have $w(h)_{t+k} = x_{it}^w$ for $k \leq (i-1)$. 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:

$$
x_{it}^w = \left(\frac{1}{\sum_{k=0}^{i-1}\beta^k}\right)\sum_{k=0}^{i-1}\beta^k E_t w_{t+k}^* \tag{15}
$$

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 (12),(13),(14) it is straightforward to derive the reset wage equation:

$$
\begin{aligned}
x_{it}^w = \; & \frac{1}{(1+\sigma_L\lambda_w)\sum_{k=0}^{i-1}\beta^k}\sum_{k=0}^{i-1}\beta^k (E_t p_{t+k} \\
& +\sigma_L\left(\lambda_w w_{t+k} + n_{t+k}\right) + \frac{\sigma_c}{1-h}\left(c_{t+k} - b.c_{t+k-1}\right)) \qquad (16)
\end{aligned}
$$

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

$$
\begin{aligned}
w_t &= \sum_{i=1}^{F_w}\alpha_{iw} w_{it} &(17)\\
w_{it} &= \frac{1}{i}\sum_{k=0}^{i-1} x_{it-k}^w &(18)
\end{aligned}
$$

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, P_t, W_t) and indirectly on the rest of the variables in the model.

1.3.2 Wage-setting in the GC model.

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

$$
\begin{aligned}
x_t^w &= \frac{1}{\sum_{i=1}^{F} S_w(i)\beta^{i-1}} \sum_{i=1}^{F_w} S_w(i)\beta^{i-1} E_t w_{t+i-1}^*, && (19)\\
&= \frac{1}{(1+\sigma_L \lambda_w) \sum_{i=1}^{F_w} S_w(i)\beta^{i-1}} \sum_{i=1}^{F_w} S_w(i)\beta^{i-1} E_t (p_{t+i-1} && (20)\\
&\qquad +\sigma_L \left(\lambda_w w_{t+i-1} + n_{t+i-1}\right) + \frac{\sigma_c}{1-h}\left(c_{t+i-1} - b.c_{t+i-2}\right)).
\end{aligned}
$$

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

$$
w_t = \sum_{i=1}^{F_w} S_w(i) x_{t-i+1}^w \tag{21}
$$

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 $i = 1...F_w$. 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, combining (20) and (21) 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 (20) 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 $NKPC$.

2 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 reports some important statistics about these distributions. We confine ourselves to a brief description, since a more complete description and details can be found in earlier papers.

2.1 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 ($t = 1, ..., 104$). 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.

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

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 $\overline{f}_p = 0.47$. This figure falls in the range of available evidence for OECD countries, with consumer prices in France being somewhat more rigid than in the US and less rigid than in the euro area on average (respective monthly frequencies are around 26% and 15%, see Dhyne et al., 2006, or Klenow and Malin, 2010).

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 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: data can be left truncated data, when the beginning of the price spell is not observed, or right truncated data, when we do not observe the end of the spell. Some spells in the dataset are both right and left truncated. 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 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. Another important issue is sales. Nakamura and Steinsson (2008) have emphasized

[10] Thus 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).

the importance of the treatment of sales in the assessment of price rigidity in the case of the US. We include all sales data in the present analysis. As documented in Baudry et al. (2007), discarding sales episodes only changes marginally the distribution of durations and the hazard function:[11] for instance, the weighted monthly frequency of price change decreases from 19% to 17%. This relatively limited effect (in contrast to the US) is due to sales being applied only to specific goods (mainly clothes) and French laws that limited sales to certain periods of the year.

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 Le Bihan et al. (*forthcoming*). 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

[11] See Tables 8 and 9 in Baudry et al. (2007). There is actually a flag in the data that identifies sale prices, which is documented directly by the field agent recording prices rather than constructed using a statistical filter.

frequency of wage change is 38% per quarter ($\overline{f}_w = 0.38$), while the weighted average duration of spells is 2.0 quarters.[12] Less than 0.1 percent of wage spells last more than 16 quarters.[13]

2.2 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.[14] 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:Hazard Functions for French Prices and Wages.

The hazard function for prices is typical of that observed in recent research with micro price data for various countries (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

[12] 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

[13] 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.

[14] 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 monthly hazard function for $F = 95$. Details available from the authors.

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 Calvo to reflect the estimated distributions.

The two panels of Figure 2 present the distribution of durations, as well as the cross-sectional distribution across firms and unions (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 (unions) 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 increases.[15] 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: The Distribution of durations and DAF for French prices and wages.

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

3 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 (2010) where pricing was the main source of dynamics.

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

Our strategy is the following. We 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 *GT* price equations $(1), (2), (3)$, and also the wage equations $(12), (13), (14), (16), (17), (18)$ [16].

Similarly, we can use (23) to implement the *GC* price equations $(6), (7)$ and wage equations $(20), (21)$. To implement the Calvo model, we simply

[16] In the case of the GTE, we could have added sector specific shocks to marginal cost (21) or a markup shock to (22) resulting in sector specific p_{it}^*: however, following SW we assume p* is common across sectors.

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 $\bar{h}_w = 0.514$.[17] 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 perform without indexation but reflecting the micro-data. 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 Table 1 in the appendix). Simulations are carried using the Dynare software.

3.2 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

[17] As 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, $\overline{f}_p$ and $\overline{f}_w$, and obtained similar results.

and output response than the simple Calvo model.[18]

The intuition behind the hump is that in the *GT* model, firms that are resetting their price are less forward looking *on average* in their pricing decision 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 prices.[19]

Insert FIGURE 3 : IRFs for output and inflation with GC, GTE and Calvo price and wage-setting .

3.3 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

[18] An alternative model to produce a hump would be the simple Taylor 4 quarter model, which generates a hump in the IRF of inflation four quarters after the shock, as is illustrated for instance in De Walque et al (2006) and Dixon and Kara (2010). However, the IRF is too spiky and does not generate much persistence beyond 4 quarters.

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

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 too high: the probability of being able to reset price is estimated to be around 9.2 percent per quarter, and for the wage is 26.3 percent per quarter.[20] 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 (unless otherwise specified). 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 a 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. 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

[20] 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.

SW. Our assumption of a GT is an alternative model that is consistent with the microdata.

Insert FIGURE 4: GTE and indexation compared.

In Figure 4 we can see that in comparison to the original SW IRF, when calibrated to the French data both the SW model with indexation and the GT yield a hump that is too early. We now consider the opposite exercise: we calibrate the GT using the original estimated SW Calvo reset operabilities for wages and prices ($\xi_p = 1 - \bar{h}_p = 0.908$ and $\xi_w = 1 - \bar{h}_w = 0.737$), which we call the $SW - GT$ model. The latter model is thus a GT model calibrated so that the distribution of distribution is exactly the same as that implied by the Calvo assumption of SW (see Dixon and Kara 2011 section 6). In Figure 5 we depict the original SW alongside the $SW - GTE$ (using a different scale to Figure 4). Here we see the GT implied by the original SW estimated reset parameters implies a hump of 8 quarters and an even more persistent response of inflation. We believe that this reinforces the conclusions of the previous paragraph: first, that it is the reset probabilities that are crucial in generating the timing of the hump and persistence in the original SW model, second that when calibrated consistently, the GT yields a similar IRF for inflation to the SW with indexation.

Insert FIGURE 5: IRF for GTE using SW estimated reset probabilities

Finally, 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 in the French data, or those of the wage durations. To investigate this further we simulated a version of the model in which the GT 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 6, 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 accounts for the hump. The model with GT in wages and price produces and 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.

Insert Figure 6: Inflation IRFs in GTE, GTE wages-only, GTE prices-only.

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 that 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 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.

Two remarks are in order to qualify the role of price and micro patterns. First, our results are influenced by the distribution of wage data and the possibility discussed in section 3.2. that due to predetermination of some wage changes the share of short wage spells is overestimated. We have performed sensitivity checks, modifying the wage distribution by switching all the mass of spells with duration 2 quarters to that of spells of four quarters (i.e. we assume every 2 quarter spell is the part of a "mis-measured" four quarter spell). While the IRF with the resulting GT-wage model was closer to the "full GT" case than in figure 6, it still failed to produce a hump and especially persistence. Our result is in this dimension robust. Second, our conclusion on the preeminence of price patterns seems to superficially contradict a result in CEE, who argued that wage rigidity, not price rigidity, is crucial to generate a hump-shape of the inflation response. However, the underlying exercise performed by CEE is not the same as ours: CEE compared full wage flexibility versus full price flexibility. We have checked in our models that wage flexibility is also crucial, in the sense that if all wage rigidity is removed, the hump-shaped response of inflation disappears. In addition, one should note that to draw their conclusion, CEE do not use actual US micro wage data, but rather have assumed the Calvo model. The actual distribution of prices and/or wages will influence whether or not there is a hump and its timing. In the case of the French data, it is the fat tail of the price distribution that drives the result. Performing a similar comparison for the US would only be possible if there were suitable quarterly US wage micro data.

4 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 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. Furthermore, we find that this hump shape is primarily generated by the GT in prices rather than wages. Interestingly, we find that the timing of the hump and the persistence in the original SW model are mainly determined by the Calvo-reset parameters: if we keep the original SW estimates (implausible though they are), we find that the inflation IRF resulting from a GT in wages and prices that is similar to the original SW with indexation. Likewise if we use the reset probabilities from the French data, we again find similarity between the GT and SW with indexation. In an earlier version of the paper,[21] we also considered the response of the economy to a productivity shock. We found little difference between the IRFs of output and inflation to the different pricing models.

[21] Dixon and Le Bihan (2011).

There are of course many ways to move on from this exercise. First, we might choose to re-estimate the euro area 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 wage and price-setting blocks or a prior distribution for these 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 or labour 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 wages and prices with firm-specific capital or labour would raise computational issues due to the number of cohorts that 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, the current paper does not try to directly link together wage and price rigidity. For example, if we could link together the establishments in the wage data with the CPI sectors in the price data, we might find, for example, that longer price-durations are correlated with longer wage durations. Whilst this is not possible with the CPI classification, which cannot be matched with the ACEMO dataset, modelling nominal rigidity using the PPI might make such a link possible. Fourth, 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.

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6 Appendix.

6.1 Deriving the reset wage in a GT economy.

Starting from (15), we first substitute for w^*_{t+k} using (14), and then substitute for $n(h)_{t+k}$ using (9) 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:

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

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

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

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

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

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

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 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 1. below. It is based on the mode of the posterior estimates, as reported in Smets and Wouters (2003).

Table 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	Labour 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

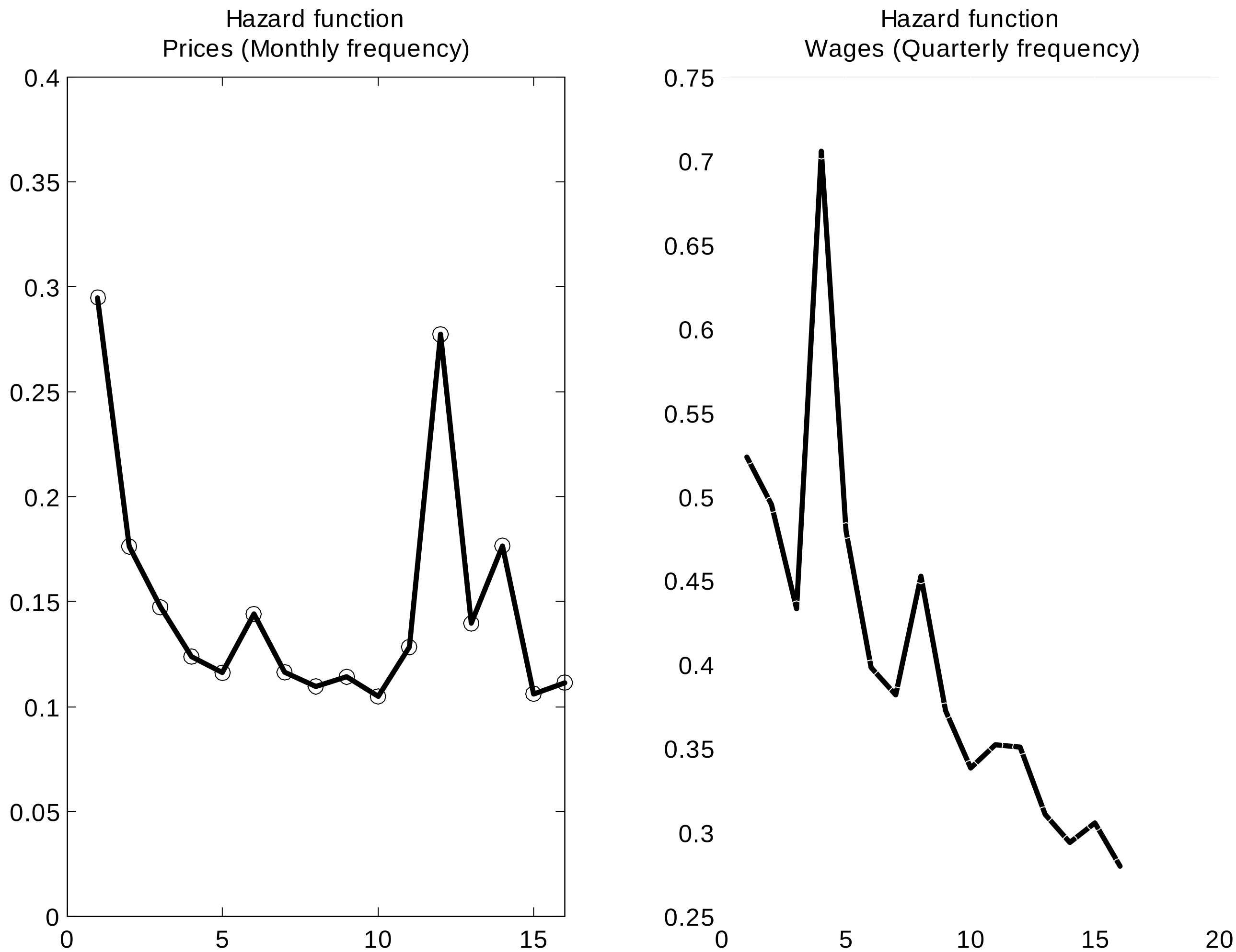

Hazard function
Prices (Monthly frequency)
Hazard function
Wages (Quarterly frequency)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0
5
10
15
20

Figure 2

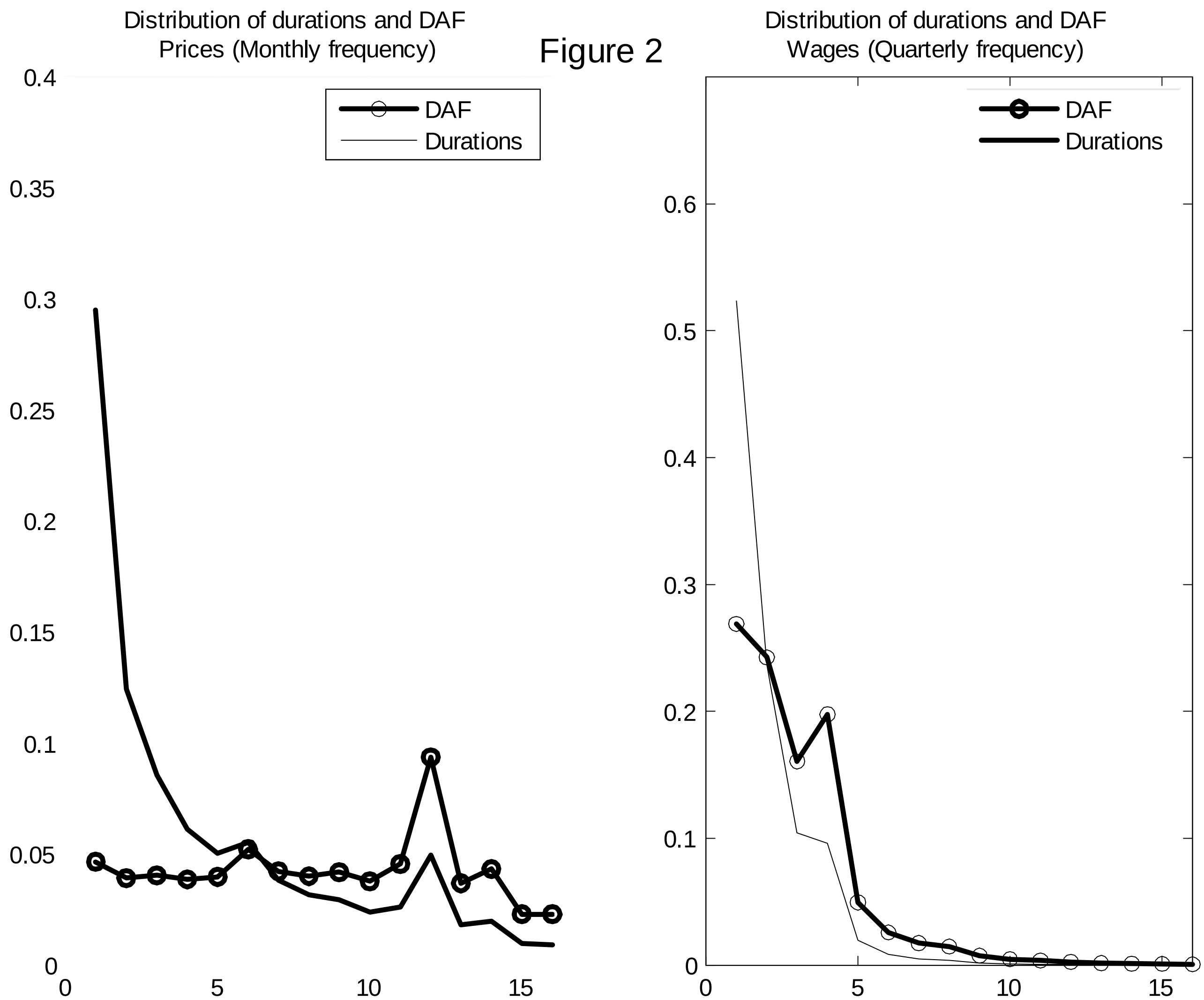
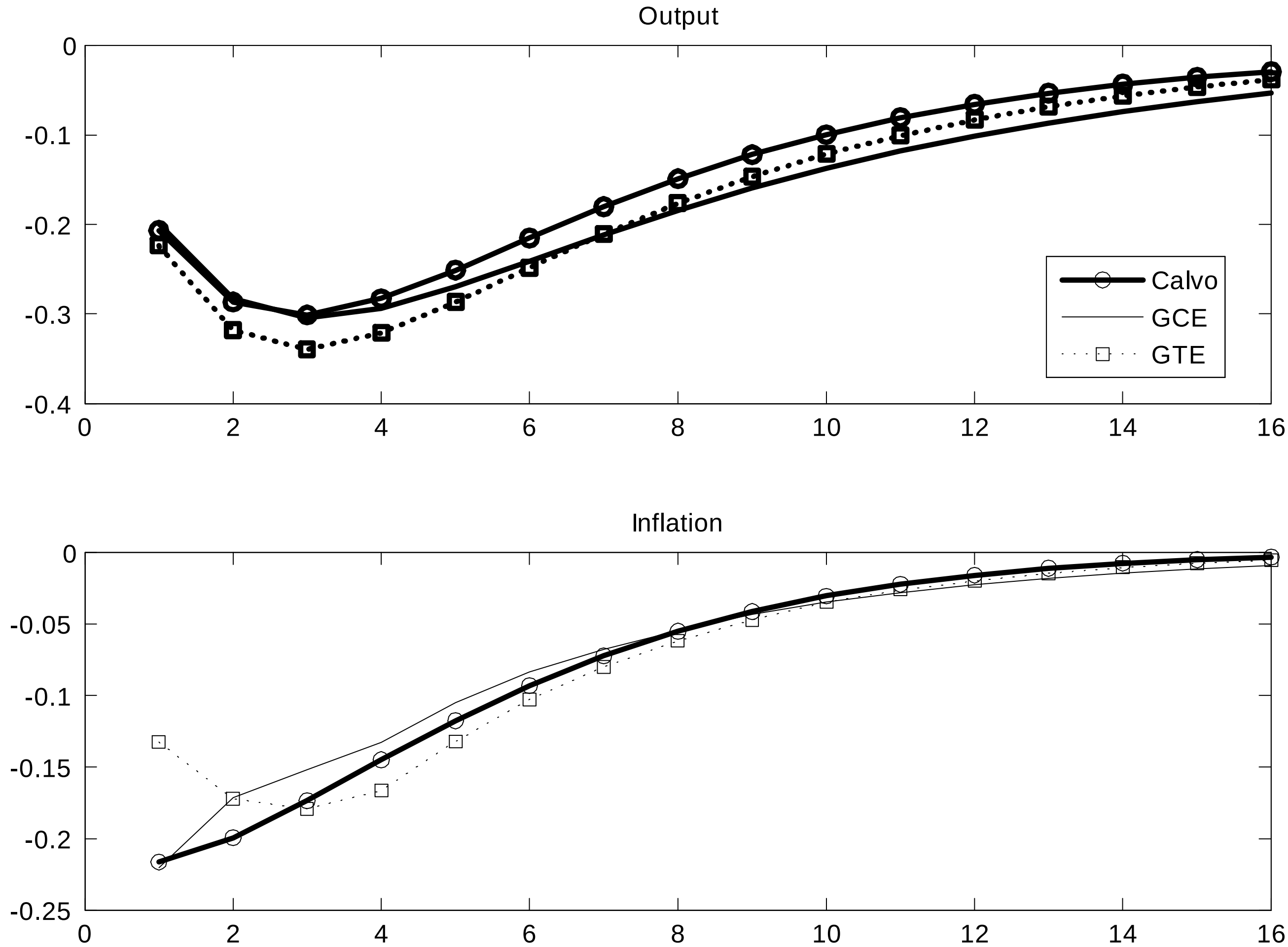

Distribution of durations and DAF
Prices (Monthly frequency)
DAF
Durations
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
Distribution of durations and DAF
Wages (Quarterly frequency)
DAF
Durations
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15

Figure 3



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

Figure 4

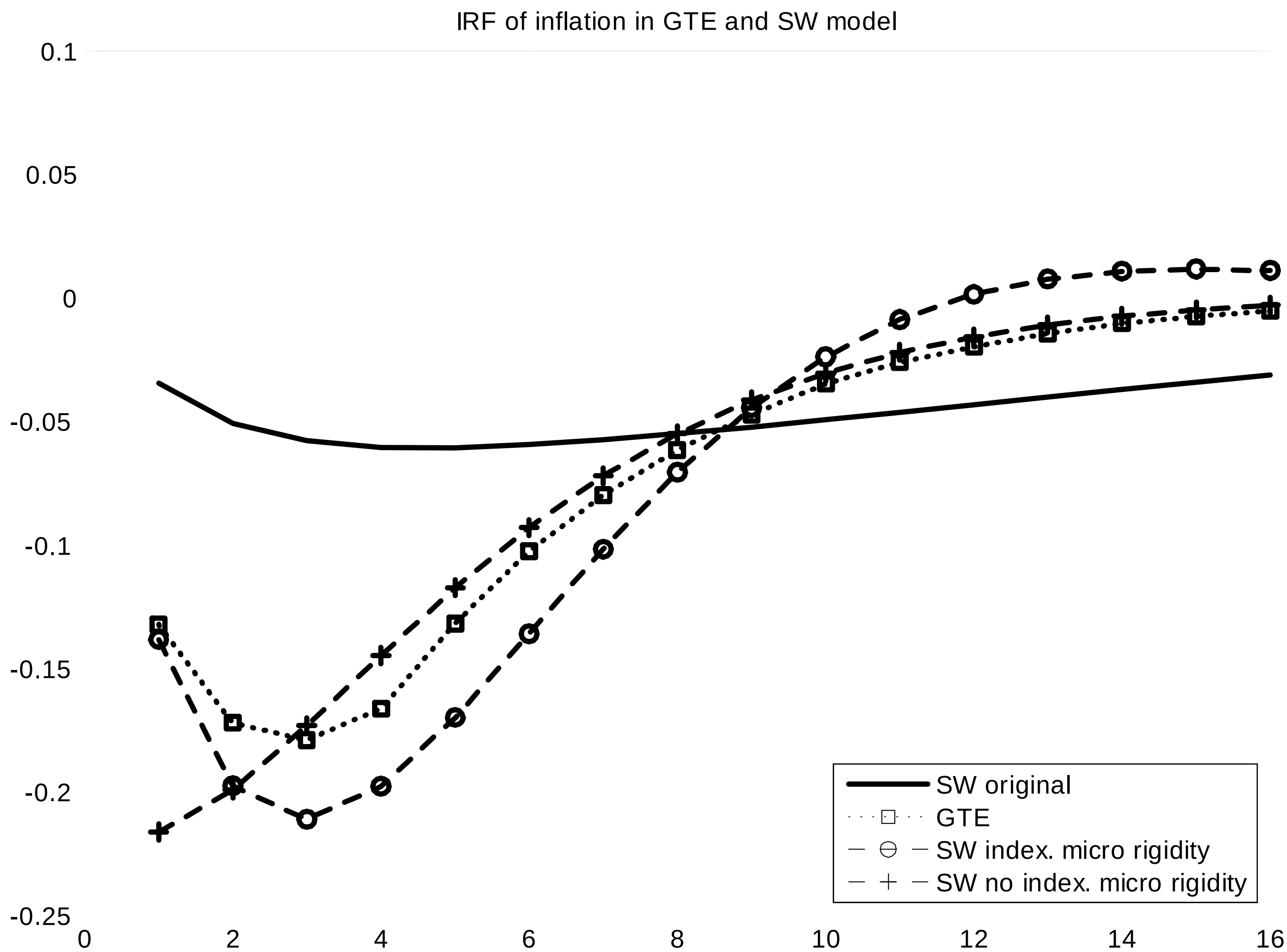

IRF of inflation in GTE and SW model
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
2
4
6
8
10
12
14
16
SW original
GTE
SW index. micro rigidity
SW no index. micro rigidity

Figure 5

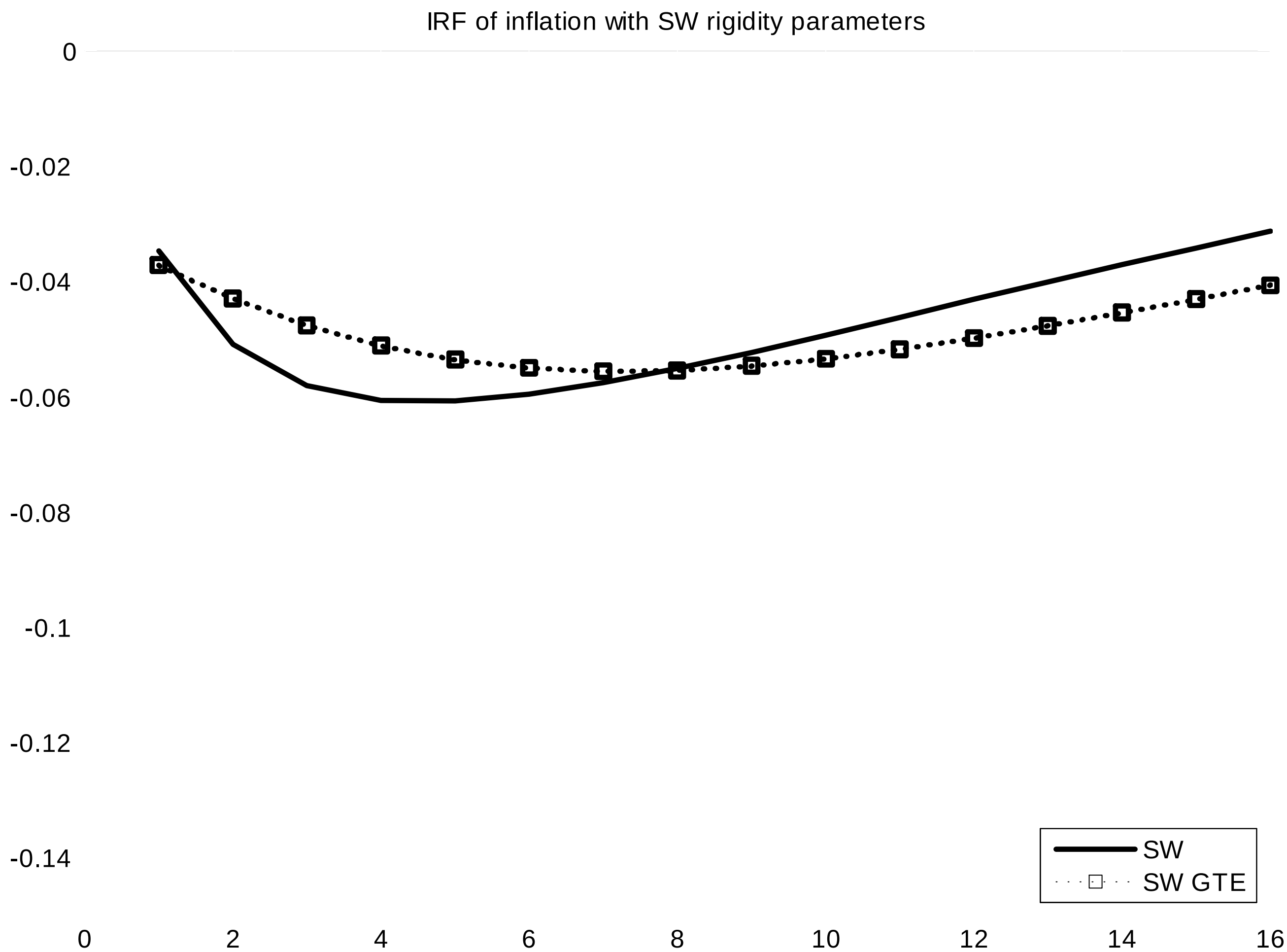
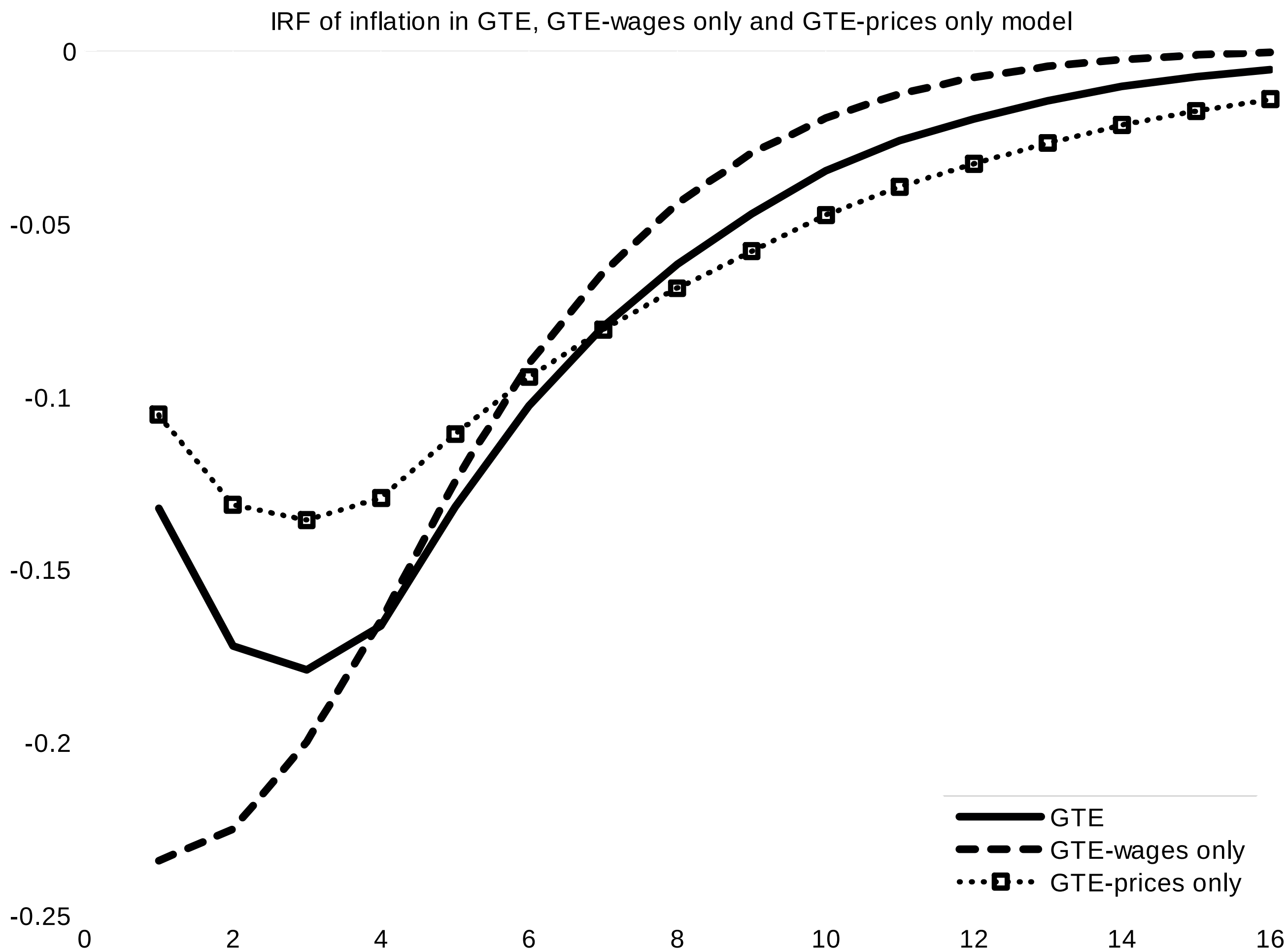

IRF of inflation with SW rigidity parameters
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
0
2
4
6
8
10
12
14
16
SW
SW GTE

Figure 6


IRF of inflation in GTE, GTE-wages only and GTE-prices only model
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
2
4
6
8
10
12
14
16
GTE
GTE-wages only
GTE-prices only