Sticky prices and volatile output

*Martin Ellison**
and
*Andrew Scott***

*European University Institute, Florence.
E-mail: ellison@datacomm.iue.it

**CEPR and Department of Economics, London Business School.
E-mail: ascott@lbs.ac.uk

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Abstract

We examine the effect of introducing a specific type of price stickiness into a stochastic growth model subject to a cash in advance constraint. As in previous studies we find the introduction of price rigidities provides a substantial source of monetary non-neutrality, which contributes significantly to output volatility. We show that the introduction of this form of sticky prices improves the model's performance at explaining inflation but worsens it for output. The most dramatic failure of the model is the extremely high-frequency fluctuations in output that it generates. Sticky prices not only fail to produce persistent business cycle fluctuations but they generate extreme volatility at very high frequencies.

Key words: business cycles, cash in advance, sticky prices
JEL classification: E31, E32

Summary

Cycles in economic activity have been evident for most of recorded history, yet economists are still struggling to explain convincingly the patterns revealed in these cycles. Keynesian macroeconomics was an attempt in the 1930s to show how aggregate demand failure could generate recessions, from which there would be no rapid or automatic recovery. However, this relied upon arbitrary assumptions about rigidities in prices and wages that few find plausible today. A more recent agenda within macroeconomics has focused on building explicit dynamic models of the economy that can potentially replicate the observed patterns of business cycles in advanced industrial economies. The current paper offers a contribution to this agenda.

A key component of the modern approach is to build models in which economic agents (households and firms) behave optimally, both currently and over time, subject to the constraints imposed upon them by factors such as accumulated assets, currently available resources and shocks hitting the economy. The behaviour of households as consumers and suppliers of labour should be consistent with the behaviour of firms as producers of goods and employers of labour. Models incorporating these characteristics have grown out of the so-called ‘real business cycle’ literature but are now generally referred to as dynamic stochastic general equilibrium models (DSGE).

Another key goal of the modern business cycle literature is to build models in which prices adjust to clear markets. Early Keynesians assumed that markets did not work flexibly, otherwise prices would always adjust to equate demand and supply, in which case there could be no unemployment. The Austrian School of the inter-war period tried but failed to build market clearing into their models of the cycle. The real business cycle literature revisited this challenging task with partial success, and DSGE models continue to be developed with this goal in mind.

The current paper presents a specific form of DSGE model. Special assumptions are that firms sell their output in imperfectly competitive markets (so firms have some discretion over the price they set for their product) and consumers are infinitely lived but operate under a cash-in-advance constraint. Two alternative assumptions about price flexibility are used. In one case, all firms can set whatever price they choose in each period, and in the other, only a random selection of firms can change their price in each period. The latter is referred to as the ‘sticky price’ case.

The method adopted is to derive a set of equations explaining the optimal behaviour of households and firms, and their interaction; then quantitatively to calibrate all the parameters in the various equations; and finally to simulate the dynamic behaviour of the economy in response to various ‘shocks’.

One of the main results that emerges from this study is that the incorporation of sticky prices (generally thought necessary in the past to explain real world business cycles) improves the ability of the model to mimic at all frequencies the inflation behaviour observed in real economies. However, the bad news is that, under sticky prices, this model generates short-run output fluctuations well in excess of those observed in data from real economies. The incorporation of

sticky prices also worsens the ability of this particular form of DSGE model to explain output fluctuations at business cycle frequencies.

In short, it is shown that the incorporation of sticky prices is not a sufficient condition for improving the realism of common forms of DSGE business cycle models. Future research may determine whether it is necessary, or whether some other form of real rigidity might suffice to reconcile optimisation-based cycle models with reality.

1 Introduction

A number of recent studies (eg Rotemberg and Woodford (1992), King and Watson (1996), King and Wolman (1996) and Yun (1996)) have introduced price rigidities into a stochastic dynamic macroeconomic model. The motivation for this work is clear: to try to explain the apparent impact that monetary shocks have on the business cycle (see, *inter alia,* Sims (1992), Christiano, Eichenbaum and Evans (1995) and Strongin (1995)) and the observed correlations between real and nominal variables. While these studies have achieved some successes and suggested fruitful areas for future research, they have also revealed a potential problem with the sticky price assumption. As shown in Ball and Romer (1990) and Chari, Kehoe and McGrattan (1996), sticky prices alone fail to account for the observed persistence of output over the business cycle. The purpose of this paper is to reveal an additional problem with a particular class of sticky price models. Sticky price models fail not just because they do not generate enough output fluctuations at business cycle frequencies but because they generate far too much volatility at very high frequencies. The volatility induced at these high frequencies is far in excess of that observed in the data.

To establish our result we use a standard monetary model (essentially that of Yun (1996), which combines a stochastic growth model with a cash in advance constraint (Cooley and Hansen (1995)) and sticky prices (Calvo (1983)), solved using parameterised expectations (den Haan and Marcet (1990)) and show that this model: (i) has the ability to offer a better explanation of inflation behaviour at all frequencies; (ii) generates short-run output fluctuations way in excess of those observed in the data; and (iii) worsens the ability of the stochastic growth model to explain output fluctuations at business cycle frequencies.

While (i) and (iii) have been stressed in the literature, (ii) has to date not been emphasised.

The plan of the paper is as follows. In Section 2 we outline our model while Section 3 discusses our calibration and solution methods. Section 4 then examines the performance of our simulated models in matching the data, and a final section concludes.

2 The model

We choose as our core model a stochastic growth model consisting of a continuum of imperfectly competitive firms (distributed over the interval (0,1)) where consumers are subject to a cash in advance constraint. We examine two assumptions about firms: in our central case firms can change prices whenever they so desire and the model is characterised by flexible prices; in the other case we follow Calvo (1983) and assume that every period only a randomly selected group of firms can alter prices. This combination of stochastic growth model, cash in advance constraint and sticky prices makes our model essentially a variant of Yun (1996). Readers wanting a more detailed economic explanation of the model should consult Yun (1996) as in what follows we offer only a mathematical outline.

Consumers are infinitely lived and have preferences given by the utility function:

$$E_0 \sum_{t=0}^{\infty} b^t \left\{ \frac{\left[C_t^j (1-H_t)^{1-j}\right]^{1-t}}{1-t} \right\} \quad \textbf{(1)}$$

where C_t is consumption,[(1)] H_t is hours worked, *ß* is the discount factor, f measures the weight of utility from consumption relative to utility from leisure and t is the coefficient of relative risk aversion. Households are endowed with one unit of time each period and supply labour to firms which produce intermediate goods. Households are also engaged in accumulating capital, which they rent to firms. It is assumed that households enter period *t* with nominal money balances, m_{t-1}, carried over from the previous period. In addition, these balances are augmented with a lump-sum transfer equal to $(g_t - 1)M_{t-1}$ where M_{t-1} is the aggregate money supply in period $t - 1$ which, because of our representative agent model, equals m_{t-1}. The money stock then follows the law of motion:

$$M_t = g_t M_{t-1} \quad \textbf{(2)}$$

where we assume g_t follows the autoregressive process:

$$1\text{n}(g_{t+1}) = rg1\text{n}(g_t) + x_{t+1} \quad \textbf{(3)}$$

where $x_{t+1} \sim iid(1\text{n}(g)(1 - r_g), s_x^2)$, and we assume that g_t is revealed to all agents at the beginning of period *t*. Household purchases are subject to the cash in advance constraint:

$$P_t C_t \leq m_{t-1} + (g_t - 1)M_{t-1} \quad \textbf{(4)}$$

where P_t is the aggregate price level (defined explicitly in (**7**) below), and assuming $g_t > b, \forall t$ is sufficient to ensure that this constraint always binds. The capital stock obeys the law of motion $k_t = (1-d)k_{t-1} + x_t$, where x_t denotes investment and d is the depreciation rate. The consumers' period-by-period budget constraint is:

$$C_t + x_t + \frac{m_t - m_{t-1}}{P_t} \leq w_t H_t + r_t K_{t-1} + \prod_t^h + (g_t - 1)\frac{M_{t-1}}{P_t} \quad \textbf{(5)}$$

where $\prod_t^h$ represents the consumers' share of profits received from shareholdings and w_t and r_t denote the real wage and the rental price of capital respectively.

The demand for intermediate good *i* is given by standard Dixit and Stiglitz (1977) preferences, namely:

$$D_t^i = \left(\frac{P_t^i}{P_t} \right)^{-e} D_t \quad \textbf{(6)}$$

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(1) C_t actually represents a measure of total consumption and is defined by the aggregator function $\int_0^1 C(i)^{(e-1)} di^{e/(1-e)}$, where e is the elasticity of demand.

where D_t is the demand for the composite good at time $t(\int_0^1 D_t(i)^{(e-1)/e} di)^{e/(e-1)}$, e is the elasticity of demand for good i and P_t is an aggregate of individual prices defined by:

$$P_t = (\int_0^1 P_t(i)^{1-e} di)^{1/(1-e)} \quad \textbf{(7)}$$

The firm produces output of good *i*, Y_t^i, according to the production technology:

$$Y_t^i = q_t K_{t-1}^{i^a} H_t^{i^{1-a}} - F_t^i \quad \textbf{(8)}$$

where F_t^i denote the firm's fixed cost of production, which we assume so as to ensure that long-run industry profits are zero, and where q_t is a stochastic productivity term following the process:

$$1\text{n}q_t = r_q 1\text{n}q_{t-1} + g + e_{t+1} \quad \textbf{(9)}$$

where $e \sim iid(0, s_e^2)$. Firms are assumed to minimise costs, which leads to first-order conditions:

$$w_t = (1-a) mc_t q_t K_{t-1}^a H_t^{-a} \quad \textbf{(10)}$$
$$r_t = a mc_t q_t K_{t-1}^{a-1} H_t^{1-a}$$

where mc_t is the real marginal cost of production *(MC_t/P_t)* and period profits are defined as:

$$\Pi_t^i = (\frac{P_t^i}{P_t} - mc_t)(\frac{P_t^i}{P_t})^{-e} q_t K_{t-1}^{i^a} H_t^{i^{1-a}} - F_t^i \quad \textbf{(11)}$$

In the case of flexible prices the firm has to choose prices so as to maximise (**11**) subject to (**6**)-(**10**).

2.1 Inflexible prices

We assume, following Calvo (1983), that in every period a proportion of firms $(1-w)$ are allowed to change their prices to a new optimal level while the remainder keep their prices fixed.[(2)] The average duration of a price that the firm sets is given by $(1-w)/w$. Denoting the new optimal price that firms set by $P_{t,t}$ this price adjustment rule implies that:

$$P_t^{1-e} = (1-w) P_{t,t}^{1-e} + w P_{t-1}^{1-e} \quad \textbf{(12)}$$

A firm will set its optimal price by maximising the present discounted value of expected future profits with respect to $P_{t,t}$ where expected future profits are defined by:

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(2) This is our main difference from the model of Yun (1996) who allows those who do not change prices to their new optimal level to adjust prices by the rate of inflation. As a result, our model contains a greater degree of price rigidity.

$$\sum_{k=0}^{\infty}(wb)^k E_t \frac{\Delta_{t+k}}{\Delta}(\frac{P_{t,t}}{P_{t+k}} - mc_{t+k})(\frac{P_{t,t}}{P_{t+k}})^{-e} q_{t+k} K^{ia}_{t+k-1} H^{i^{1-a}}_{t+k} \quad \textbf{(13)}$$

where $\Delta_t = E_t(bP_t l_{t+1})$ and l_t denotes the consumer's marginal utility of wealth. This definition of future profits takes into account both the stochastic nature of whether the firm will change prices (w) and that the firm will have to hold prices fixed during periods when it cannot change prices. Under inflexible prices the firm maximises **(13)** subject to (**6**)-(**10**). This leads to a first-order condition for $P_{t,t}$ of:

$$P_{t,t} = \frac{e\sum_{k=0}^{\infty}(wb)^k E_t\left(\Delta_{t+k} P^e_{t+k} q_{t+k} K^{i^a}_{t+k-1} H^{i^{1-a}}_{t+k} mc_{t+k}\right)}{(e-1)\sum_{k=0}^{\infty}(wb)^k E_t\left(\Delta_{t+k} P^{e-1}_{t+k} q_{t+k} K^{i^a}_{t+k-1} H^{i^{1-a}}_{t+k}\right)} \quad \textbf{(14)}$$

In the case of perfect price flexibility $(w = 0)$ this expression collapses to the more familiar $P_{t,t} = eMC_t/(e-1)$.

3 Calibration and solution

We calibrate the model using UK quarterly data assuming a discount factor of 0.99 and a depreciation rate of 2.5%. Following the empirical analysis of Holland and Scott (1998), we set a in the production function to 0.4436 and assume that the productivity shock follows the process:

$$1\text{n}q_t = 0.0021 + 1\text{n}q_{t-1} + e_t \quad \textbf{(15)}$$

where $s_e = 0.00925$. Based on the panel data estimates of Attanasio and Weber (1993) we set the coefficient of relative risk aversion equal to one so that utility is logarithmic. We set the weight of leisure with respect to consumption in the utility function such that the steady-state supply of labour is equal to a. Using the results of Garratt and Scott (1996) we use M0 (narrow money) to calibrate the money supply process such that:

$$\ln g_t = 0.011 + 0.3633 \ln g_{t-1} + x_t \quad \textbf{(16)}$$

where $s_e = 0.0122$.

Crucial to our simulation properties are the elasticity of demand and the degree of price stickiness. Haskel *et al* (1995) estimate the price to marginal cost ratio for the United Kingdom to be 1.94, which gives us a value of 2.64 for the elasticity of demand, e. A study of pricing policy in UK companies (Hall, Walsh and Yates (1996)) finds that approximately 6% of companies do not change their price over a year, suggesting that $w^4 = 0.06$ so that $w \approx 0.5$—only 50% of firms are able to change their prices in a quarter.(3)

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(3) The Hall *et al* (1996) paper also reveals that only 20% of firms change their prices once a quarter, which suggests that $w = 0.5$ may overstate price flexibility. We therefore also performed simulations for $w = 0.25$. These results are available upon request but the main findings of our paper remain unaltered.

To solve the model we utilised the parameterised expectations algorithm of den Haan and Marcet (1990), which has the advantage of being able to capture non-linearities present in the model that are normally excluded via the use of quadratic approximations around the steady state. We used a second-order polynomial in the state variables $(k_{t-1,}P_{t-1,}e_{t,}g_t)$ and included the cross-products $k_{t-1}e_t$ and $P_{t-1}g_t$ in order to arrive at an 'accurate' solution. To gauge accuracy we used the test statistic proposed by den Haan and Marcet (1994) and for the flexible (inflexible) price model found 5.6% (4.2%) of simulations in the lower tail and 3.2% (6%) in the upper tail, which we interpreted as strong grounds for accuracy given the stringency of this test.

4 Results

Table A shows the stylised facts from UK data as well as from simulations of our flexible and inflexible price ($w = 0.5$) model. The data is for the United Kingdom over the period 1965–95 and is explained in the data appendix. The relatively small changes in calibration that result from using US data do not alter the implications of our analysis for sticky prices.

Both the flexible and inflexible price model do a reasonable job of reproducing the observed volatility of prices and inflation. The flexible price model however fails to reproduce the observed volatility of output and also fails to replicate enough persistence. However, the problems with the sticky price model are also apparent from Table A—it generates a huge increase in output volatility in excess of that observed in the data and dramatically reduces the persistence of output fluctuations. The explanation of these results can be seen in Chart 1, which shows estimated impulse response functions of output with respect to a monetary shock. We estimate these impulse response functions using the methodology of Blanchard and Quah (1989) and bivariate VARs, and identify monetary shocks by assuming they have no long-run impact on output. In the flexible price model the cash in advance constraint generates only a small non-neutrality, such that the impulse response function rarely deviates from the horizontal axis. The sticky price model generates an impulse response function similar in shape to that obtained from the data. However, the peak in the impulse response function is much more pronounced in the sticky price model, by a factor of around 4.5. Further, the impulse response function for the sticky price model peaks in the first quarter and then rapidly declines, compared with the gradual build-up to a third-quarter peak observed in the data. Not only are non-neutralities more pronounced in the sticky price model but their impact is much less persistent. Assuming sticky prices therefore leads to enormous short-run impact but little propagation.

Charts 2 and 3 show the spectral density of output and inflation calculated from the data as well as that constructed from our flexible and sticky price model. The strengths and weaknesses of the sticky price model are evident from these figures. The flexible price model displays a flat spectrum for output with no noticeable business cycle peak. The sticky price model generates more business cycle volatility (too much compared with the data) but also produces substantial volatility at higher frequencies far in excess of that observed in the data. By far the largest part of output fluctuations in the sticky price model comes at these higher frequencies. Therefore the failure of this particular sticky price model is not just that it fails to produce enough output volatility at business cycle frequencies (as noted by Chari *et al* (1996)) but it also produces far too much volatility at high frequencies. Chart 3 reveals the more positive features of the sticky price model. The flexible price model generates too much inflation volatility especially at high frequencies, whereas the sticky price model captures reasonably well the spectral shape of inflation. In other words, assuming sticky prices removes the problem of predicting too much high-frequency inflation volatility but only at the cost of creating the same problem for output. We can use the analysis of Watson (1993) to be more precise about the model failures. Denoting the data by X_t (an m x 1 vector) and the simulated data by Y_t then we have $Y_t = X_t + u_t$ where u_t denotes the approximation error and let $A_z(e^{iw})$ denote the autocovariance generating function of z at frequency w. Watson (1993) suggests the following as a lower bound estimate of the relative mean square approximation error:

$$R(w) = \frac{A_u(e^{iw})}{A_Y(e^{iw})} \quad \textbf{(17)}$$

which is the variance of the error relative to the variance of the data at each frequency and is plotted for output in Chart 4. The higher is this measure the worse the performance of the model. Chart 4 shows that for output this measure of fit is worse for the sticky price model at nearly all frequencies and substantially worse at business cycle and very high frequencies. Chart 4 shows that the particular fixed price model we examine performs worse at explaining output than flexible price models. The sticky price model generates too little in the way of business cycle fluctuations and far too much volatility at high frequencies.

5 Conclusions

Using a conventional monetary model we examine via simulation a class of sticky price models. We show how the assumption of sticky prices leads to a huge increase in output volatility. This volatility is too dramatic and too high-frequency to be consistent with the data. This failure is in addition to the well-documented failure of sticky price models to generate persistent business cycle fluctuations. Our simulations reveal that this latter failure is so pronounced that assuming sticky prices leads to a deterioration of this particular model’s ability at explaining business cycle behaviour. The major success of assuming sticky prices is that it is better at capturing the behaviour of inflation, in particular at reducing high-frequency fluctuations in inflation. However, this improvement in explaining inflation is at the expense of creating an exactly similar problem for output.

We stress that, as with all simulation-based analysis, these results have only been established for the particular class of sticky price model that we examine. However, as we examine a paradigmatic model of sticky nominal prices we believe that the results of this paper have relevance to the wider sticky price literature. Our results confirm the findings (albeit in another dimension) of Ball and Romer (1990), Chari, Kehoe and McGrattan (1996) and Jeanne (1997) in showing that sticky prices do not appear to be a sufficient condition for remedying the performance of standard business cycle models. Whether they are a necessary condition and what additional assumptions, such as adding real rigidities in order to reduce short-term output volatility, might help is something we intend to examine in future research.

Table A: Stylised facts for output and inflation

Variable	Std. Dev.	t-3	t-2	t-1	t	t+1	t+2	t+3
		Cross-correlation of output with:						
UK data								
Output	1.66	0.434	0.624	0.810	1.000	0.810	0.624	0.434
Prices	2.32	-0.439	-0.545	-0.605	-0.611	-0.524	-0.391	-0.216
Inflation	1.03	-0.244	-0.240	-0.144	-0.019	0.171	0.266	0.360
Flexible price model								
Output	1.12	0.267	0.462	0.700	1.000	0.700	0.462	0.267
Prices	2.34	0.007	-0.035	-0.091	-0.177	-0.137	-0.108	-0.092
Inflation	1.61	-0.030	-0.058	-0.078	-0.121	0.059	0.040	0.025
Inflexible price model								
Output	3.72	-0.048	0.001	0.142	1.000	0.142	0.001	-0.048
Prices	1.91	-0.302	-0.336	-0.300	0.359	0.357	0.300	0.238
Inflation	1.33	-0.066	-0.042	0.062	0.925	0.004	-0.079	-0.084

Chart 1: Impulse response function of monetary shocks on output

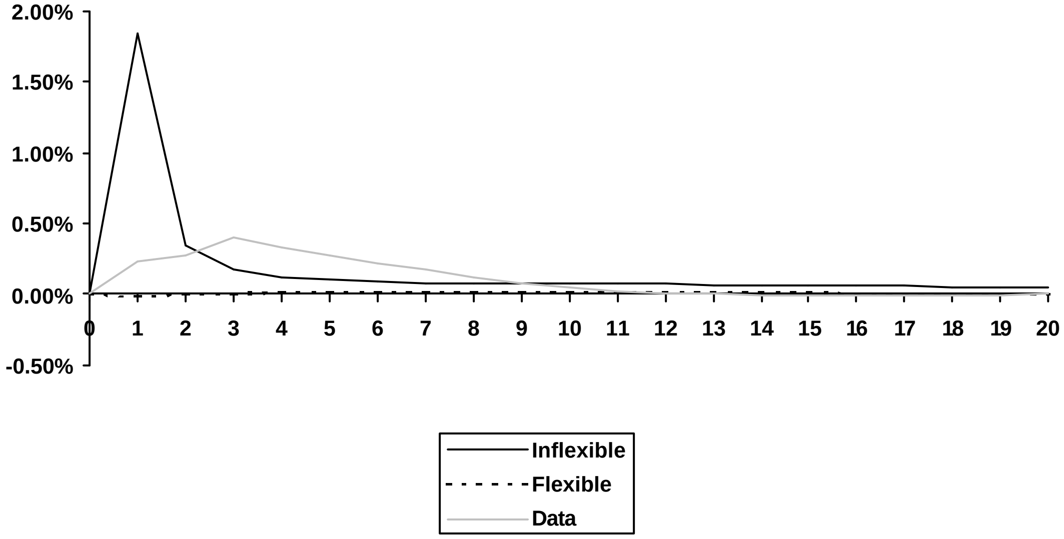


Chart 2: Output spectra

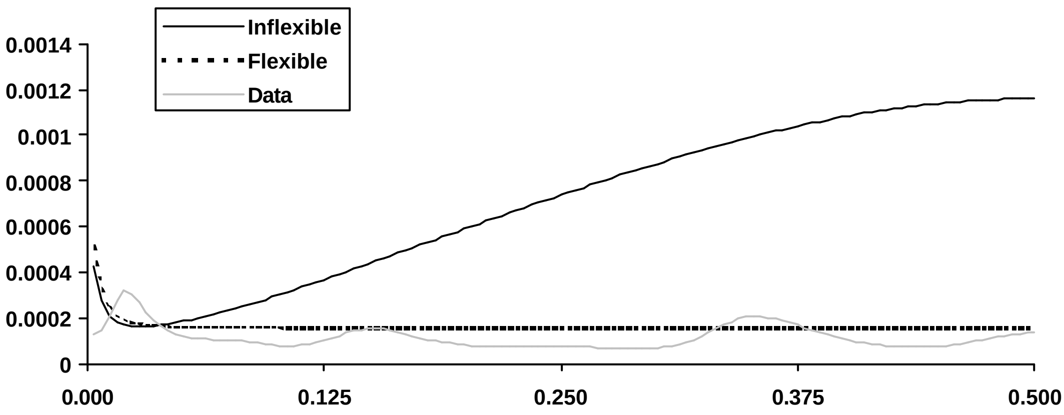


Chart 3: Inflation spectra

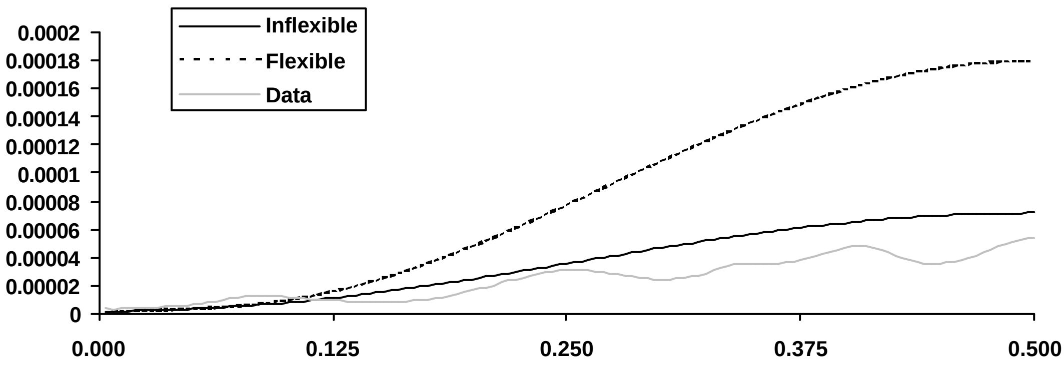
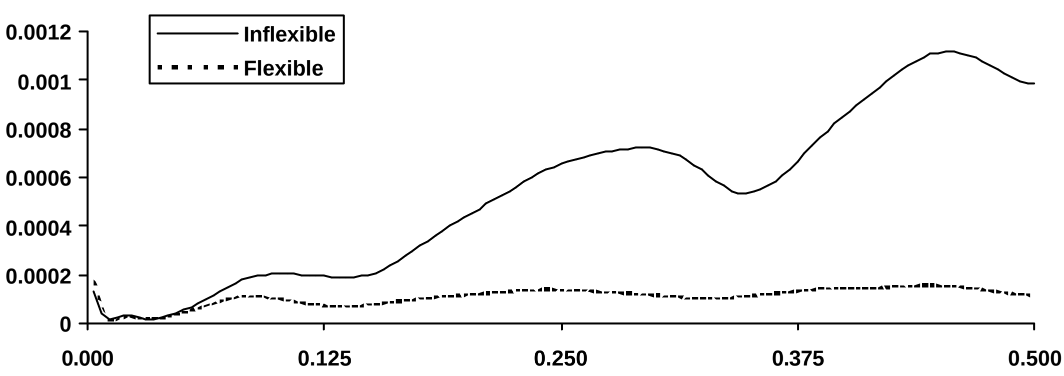


Chart 4: RMSE approximation error for output



Data appendix

All the data used in this paper are publicly available from the ONS and are seasonally adjusted. The period examined is 1969 Q3 to 1995 Q2 (104 observations), which we chose due to the unavailability of data on narrow money prior to 1969. Data and solution programs are available upon request. The data are:

(i) Real aggregate output is GDP at factor cost (£ million, 1990 prices); CSO code CAOP.

(ii) Prices are measured using the GDP deflator (1990 = 100); CSO code DJCM.

(iii) Inflation is measured as the quarterly rate of change in the GDP deflator.

(iv) Narrow money M0 (£ million); CSO code AVAE.

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