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JEL Classification: E2, E3

Keywords: State-Dependence, New keynesian, Rational Expectations, Crises, price stability, Nominal GDP

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Strong evidence exists that price/wage durations are dependent on the state of the economy, especially inflation. We embed this dependence in a macro model of the US that otherwise does well in matching the economy's behaviour in the last three decades; it now also matches it over the whole post-war period. This finding implies a major new role for monetary policy: besides controlling inflation it now determines the economy's price stickiness. We find that, when backed by fiscal policy in preventing a ZLB, by targeting nominal GDP monetary policy can achieve high price stability and avoid large cyclical output fluctuations.

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1 Introduction

Modern applied macroeconomic modelling is dominated by the New Keynesian model, in which wages and prices are fixed for a set duration, either in an explicit or implicit contract. This contract duration enables monetary policy to have effects on output. However, a long line of classical thought has emphasised wage-price flexibility, and its contract equivalent, state-contingent contracts, as the way in which agents could reach optimal outcomes. According to this view, the apparent fixed duration of wage-price contracts conceals a latent variability in response to the state of the economy. This Classical view has underlain the dominant divide, even schism, in macroeconomics, between those willing to accept the idea of contract-based price/wage rigidity and those who reject this as necessarily a violation of optimising behaviour by free agents. One way of bridging this divide would be to acknowledge that it could be optimal for agents to hold off changing prices in response to small shocks for some duration because of what we might call marketing costs such as changing price lists — upsetting consumers' expectations — and are generally termed 'menu costs'; and yet that the duration for which they would be willing to do this and the size of shocks they would ignore in this way would be state-contingent. This is still not the same as the classical assumption of fully-state-contingent and flexible prices and wages; however it gets fairly close once one concedes the existence of menu costs and the strong evidence that prices and wages are not in general fully flexible, whether straightforwardly or indirectly within fully state-contingent contracts. It is this hypothesis of state-dependent variation in price/wage rigidity that we will examine in this paper.

In this paper we examine the evidence for such variation at the macro level. Even though there is now a large literature that finds evidence of this state-dependence at the level of micro data (of which we review below), at the macro level it is nevertheless usual in the dominant New Keynesian modelling approach to assume fixed contract duration. Probably the most widely used model of the US, that of Smets and Wouters (2007), hereafter SW, which in turn was derived from Christiano, Eichenbaum and Evans (2005), is a New Keynesian model of substantial size, with structural equations for consumption and investment as well as for price- and wage-setting under imperfect competition. It follows Calvo's (1983) framework, in which the probability of adjustment is constant. SW estimated the model by Bayesian means and fitted it to a long post-war period from 1966 to 2004. However, Le et al. (2011) found that when tested by the powerful method of indirect inference, the model was rejected by the sample data behaviour for the full postwar sample period from 1947 to 2004. They also found evidence of two structural breaks at 1964 and 1984 which they interpreted as being due to the beginning of serious inflation and the move to inflation targeting respectively. For the period from 1984 until 2004, 'the Great Moderation', they found that if a second flexprice sector was introduced side by side with the sticky-price one, the SW model was not rejected. They found that the weight on the flexprice sector was close to zero for both wages and prices; the Calvo parameters for the other sector were both around 0.7. However, for the previous two sub-samples they could find no model that could pass the test. Le et al. (2016) reestimated the model for the later sample but extended it until 2011, and so included the financial crisis. They also extended the model to allow for a banking sector, for the Zero Lower Bound (ZLB) and for Quantitative Easing (QE). They found that this extended model again could pass the test over the longer period from mid-1980s to the present. However the weight on the flexprice sector, for both wages and prices, rose considerably from near zero to 0.56 and 0.91 respectively; the Calvo parameters in the other sector fell to 0.63 for wages and rose to 0.97 for prices (with only the most sticky sub-sectors left in the sticky-price sector). This weight can be thought of as measuring the proportion of sectors that have price/wage rigidity of less than three months; thus they approximate to changing prices at once within the quarterly model context and so act as if flexprice. What the findings of Le et al. (2016) seem to imply is that when the stochastic environment changes so does the duration of price- and wage-setting. i.e. macroeconomic models should allow for price and wage adjustment to be state dependent rather than merely time dependent, thus letting price/wage-stickiness be state-contingent.

As noted earlier, at the micro level there has been a long list of studies trying to establish the facts about the relationship between the state of the economy, usually just inflation, and the frequency and size of price changes across different countries and across different data episodes. These studies utilise different sets of micro data on retail prices to obtain the calibrated estimates for macroeconomic models' pricing frameworks.

For the US, Bils and Klenow (2004) used the BLS micro data set from 1995–1997 and found that the median frequency of price change including price changes that occur because of sales and product substitution is 20.9%, that is, the median duration is 4.3 months. They also adjust this for sales, and report the sales-adjusted median duration as 5.5 months. They then use the price setting equation in time-dependent Calvo and Taylor models to check their ability to mimic the persistence and volatility of inflation across goods categories. They find for the goods with more infrequent price changes the models predict too much inflation persistence and too little inflation volatility, compared with the micro data; so the time-dependent models of price stickiness cannot account for the microdata evidence. Nakamura and Steinsson (2008) use more detailed data over a longer period (the data series on prices underlying the CPI index from 1988–2005): on this microdata sample they find higher median durations of 8–11 months for regular prices. With a longer sample they observe that the frequency of price changes and inflation have a relationship, i.e. the frequency of price increases covaries strongly with inflation, whereas the frequency of price decreases do not. Klenow and Kryvtsov (2008) include sale prices in their analysis and find that price changes are frequent (4–7 months depending on the treatment of sale prices) and usually large in absolute size. For a given item, price durations and absolute price changes vary over time. Like Nakamura and Steinsson (2008) they show that the fraction of items increasing prices correlates most with inflation, but unlike Nakamura and Steinsson (2008), the fraction of price decreasing items also varies with inflation. These movements of fraction of price changes offset each other, and as a result, the inflation movement is driven by the size of price changes rather than the fraction of prices changing. Using partial equilibrium versions of macro models to reproduce this micro evidence, they find that none of the time-dependent and state-dependent models they considered can explain all of micro evidence about the price setting behaviour.[1]

One disadvantage of these earlier studies is that they use data from the Great Moderation period where inflation was low and stable, which is a unique episode; hence they do not provide strong and conclusive evidence on the role of variation in inflation on the economy and the behaviour of prices. Nakamura et al. (2018) extend this data set by also including data from 1977 to capture the US Great Inflation period during the late 1970s and early 1980s. They find that instead of raising the absolute size of price changes, firms raise the frequency of price change during the period of high inflation. Similar results are also found in other studies using micro data sets for other countries. Gagnon (2009) found that in Mexico at low inflation levels, the aggregate frequency of price changes responds little to movements in inflation because movements

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[1] The other branch of literature argues that the inconsistency between microdata evidence and macro models might be corrected by introducing heterogeneity across sectors in price stickiness. That is, macro models allow for Multiple Calvo (MC) contracts for different sectors. Kara (2015) uses the SW model with MC features, where the share of each product sector is based on micro evidence, and found that the model fits the low degree of persistence in actual inflation and the low variability of reset price inflation relative to actual inflation. Nevertheless this approach does not account for state-dependence.

in the frequency of price decreases partly offset movements in the frequency of price increase. But during a period of high inflation in the mid 1990s while the absolute size of price changes varies little with inflation, the frequency of price changes becomes more responsive to inflation. He found that this behaviour can be replicated well by a simple menu-cost model with idiosyncratic technology shocks.

Alvarez, Beraja, Gonzalez-Rozada and Neumeyer (2016) use product-level-data underlying Argentina's CPI during the period of 1988–1997 with a mixed experience of deflation and very high inflation. They find that high inflation leads to more frequent price changes across all products, whereas idiosyncratic firm-level shocks would drive this frequency when inflation is low. In a similar fashion, Wulfsberg (2016) looks at another micro data set for both high inflation periods in the 1970s and 1980s and the low inflation period since the early 1990s — in this case for Norway. He finds that when inflation is high and volatile, prices change more frequently and in smaller absolute size; and when inflation is low, the frequency of price changes is low and the size of changes is high. There are some more studies in countries with high inflation. Konieczny and Skrzypacz (2005) look at a large disaggregated data set for Poland in the period 1990–1996 and find that the size and frequency of price changes are both positively correlated with the inflation rate. For the UK, Zhou and Dixon (2018) also find that prices are indeed fixed for average durations but these are state-contingent. They interpret this to mean that price-setters responded to larger macro shocks with larger and quicker than usual price changes, because the costs of not responding are unusually high, the disequilibrium being unusually large. The key implications for contract duration of varying inflation are shown in Table 1. It can be seen that duration varies very substantially with inflation, with median duration potentially moving from nearly a year to as low as one week.

	Country	Duration in high inflation	Duration in low inflation
Nakamura et al. (2018)	USA	6.6 months (1978-1983)	9.9 months (1988-2014)
Gagnon (2009)	Mexico	3.1 months (1995-1997)	6.6 months (2000-2003) 7.0 months (2003-2004)
Alvarez et al. (2019)	Argentina	1 week	4.5 months
Wulfsberg (2016)	Norway	6.7 months (1975-1989)	12.3 months (1990-2004)
Konieczny+Skrzypacz (2005)	Poland	1.7 months	3.3 months

Table 1: Summary of Findings in the Literature

This literature shows that to establish and understand the relationship between inflation and price stickiness in macroeconomic models, we might want to use state-dependent models.

In this empirical paper we explore the implications at the macro level of allowing both wage and price contracts to be state-dependent. These pricing features have been explored at the macro level in Costain, Nakov and Petit (2017). They incorporated both state-contingent wage stickiness and price stickiness, and the state-dependent adjustment mechanism is based on the control cost model, where the price/wage decision is a random variable defined over a set of feasible alternatives and the decision-maker faces a cost function that increases with the precision of that random variable. The authors calibrated the micro data evidence of frequency of price and wage adjustments into a DSGE model for the US in which duration depends on inflation. They find that sticky wages play a big role in creating monetary non-neutrality and that the model with both forms of stickiness has larger real effects of monetary shocks than does the model with just price stickiness. Takahashi (2017) also studies a DSGE model with state-dependent price and wage setting, where the state-dependent pricing mechanism is based on a stochastic menu costs model, i.e. households face different fixed wage-setting costs that evolve independently over time. He calibrated the distribution of wage setting costs to match the US data of the fraction of unchanged wages for a year. It turns out that this distribution is very similar to the Calvo-type distribution and thus the responses to monetary shocks in this state-dependent model are very longlasting just as in the time-dependent model. However, both these papers focus on micro-data relationships from a sample period, the Great Moderation, where inflation did not vary much; this may well account for their macro models turning out quite similar to the Smets-Wouters model.

Our contribution here is that we bring to bear a full model that contains substantial state-dependence that is estimated to match closely the data behaviour over the full post-war sample, and hence the full range of inflation dependence. Alongside the state-dependence the model includes the many real rigidities in Smets and Wouters (2007), financial frictions as in Bernanke et al. (1999), and the ability to deal with the ZLB as in Le et al. (2016); we do not calibrate but rather estimate and test the model as a whole by indirect inference on unfiltered, and therefore nonstationary, macro data. In our model price/wage duration depends on a nonlinear function of lagged inflation, and inflation in turn depends on duration. We had in mind that such state-dependency could account for the failure of the SW model to pass our test for the earlier data subsamples (Le et al, 2011). It could be that the problem lay with shifting behaviour in wage/price-setting within these subsamples in response to a fluctuating macro environment: notoriously, inflation rose steadily during the 1960s, and extremely sharply during the 1970s before collapsing in the early 1980s. Possibly too the structural breaks found by Le et al. (2011) could be accounted for by this shifting wage/price behaviour. If we could find a single model that would match the data behaviour in the whole sample sufficiently well to pass our test, then this would constitute strong evidence in favour of these hypotheses. We think that the link from the macro state distributions to price-setting will be reinforced and possibly modified at the macro level because of the strong feedback in both directions, from price-setting to macro distributions and from the latter to price-setting. Thus our aim is to check whether there is evidence at the macro level that corroborates the evidence of state-dependence at the micro level, and if so just what the final macro relationships turn out to be, as well as their implications for monetary policy.

To anticipate our findings, it turns out that the model which includes state-dependence can indeed fit the facts of the full post-war period; we also find that this state-dependence opens up a key new role for monetary policy in influencing the degree of price/wage stickiness, and we make a search for optimal monetary policy rules in this new context. Because state-dependence interacts with the ZLB to create high price and output volatility in ZLB episodes that cannot be controlled by unconventional monetary measures such as QE, we find that these rules need supplementing by a fiscal commitment to stop ZLB episodes in their tracks.

In what follows we set out in Section 2 a simple micro-founded model of price and wage setting in which the recent behaviour of inflation affects the variances of idiosyncratic cost-shock distributions, so changing their Calvo probability of price/wage change. In Section 3 we apply this model to the full sample of US postwar data and test it by indirect inference. In Section 4 we describe the properties of the adjusted SW macro model. In Section 5 we consider its implications for monetary policy rules. Section 6 concludes.

2 Model

The model we consider here allows for state-dependent price and wage setting in the general equilibrium framework proposed by Le et al. (2016) which itself is developed from the model of Smets and Wouters

(2007). The model assumes that a fraction of goods markets are flexprice while the rest set prices for longer durations; similarly with labour markets. These fractions or weights are state-dependent and discussed in more detail below. Beyond the frictions in labour and goods markets, the model also incorporates financial frictions as proposed by Bernanke et al. (1999) and allows for cheap money collateral as in Le et al. (2016) to make monetary policy effective via unconventional monetary measures even at the zero lower interest rate bound (a full model listing can be found in Appendix A).

Now we turn to the state-dependent formulation in the model. In the previous studies by Le et al. (2011, 2016) it was assumed that imperfectly competitive firms and labour unions decide on changing their prices/wages based on Calvo fixed probabilities, but there were fixed weights on the fractions of goods and labour markets where there is 'long' duration of more than one quarter, and those in a 'short duration'/flexprice sector where prices and wages change continuously each quarter. That is, we assumed the structure of price/wage durations is fixed. Now we relax this assumption and assume this structure changes with the state of the economy, i.e. these durations vary as more firms/labour unions decide, in the face of aggregate shocks, to change their prices and wages continuously; and so shift from the long to the short duration sector. The short duration sector we describe as 'flexprice' (FP) since it is continuously in a quarterly context keeping prices equal to marginal costs plus the same constant mark-up as in the long-duration sector. The long duration sector we call 'New Keynesian' (NK) since it conforms to the Calvo sticky-price model.

For an imperfectly competitive firm, or for a labour union setting wages under imperfect competition, we interpret the probability of changing the price or wage as coming from the distribution of idiosyncratic shocks to the equilibrium price for the product or labour service. We assume these agents will only change prices/wages if the shock is larger than some particular value, representing the menu cost of changing prices: below this point at which, as Calvo(1983) puts it, the signal to change prices 'lights up', they would rather stabilise the price in order to insure their customers against uncertainty, which is how we may interpret the menu cost. However, above it the cost of providing this insurance is too great compared with the benefit it gives. We also assume that this idiosyncratic distribution's variance is related to the size of recent inflation shocks to the economy, denoted by Π and measured by a moving average of inflation discussed below. These shocks to other prices set off price shocks to particular markets because if prices in general have moved substantially then demand and supply for the particular product may well be affected also; for example, in a situation where many prices have changed considerably there is more uncertainty about where these demand/supply factors and so the particular price equilibrium will be. As recent inflation rises, so does the variance of the idiosyncratic distributions being used by price setters. This implies that the critical shock size now comes at a lower percentile of this more volatile distribution, as illustrated in Figure 1. This percentile is then the Calvo percentage of firms not changing their price. This Calvo parameter is therefore a reduced form function of the idiosyncratic distribution, which in turn depends on Π. This function we do not derive but we rather estimate a general form we will suggest for it from this discussion, from the macro data behaviour.

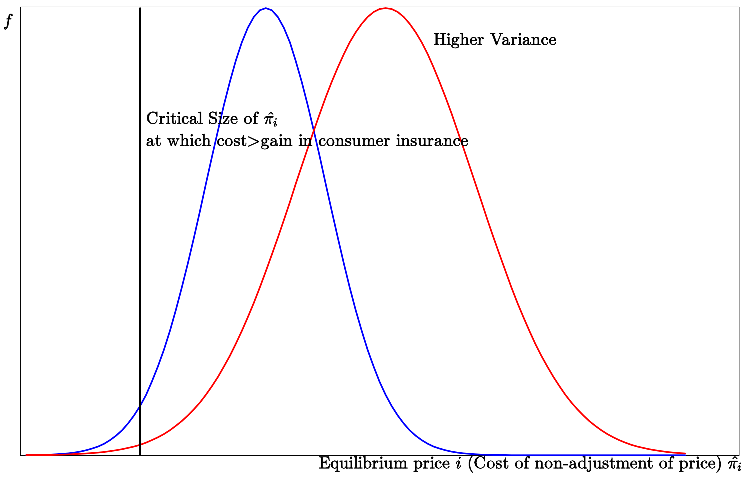

Figure 1: Distribution of Idiosyncratic Shocks

Hence the probability of not changing price is reduced by Π and so too the Calvo parameter. As a result more sectors will become flexprice (i.e. have an overall duration of 1 quarter) and in the remaining sectors the Calvo parameter may fall. However, we should note that the Calvo parameter for the sticky-price sector may actually rise as the sectors closest to the short duration sector migrate to it, leaving behind the sectors that have higher Calvo parameters. This 'abandonment effect' may more than offset the reduction effect on these remaining sectors' Calvo parameters, C, which we estimate in the usual way with the other model parameters.

Notice that in all this we are not changing our basic assumption that the macro shocks are drawn from constant distributions and are known to all agents. We assume that the idiosyncratic distributions, known only to the agents concerned, change over time as the draws from these macro distributions become by chance larger or smaller for a substantial period of time and so affect inflation. These draws disturb the micro distributions because a succession of large macro shocks disturbing inflation create uncertainty about micro conditions. For a simple example one may think of the labour market in conditions where unemployment has been high for some time and wages have been falling: plainly the union's members will in some cases have lost jobs and in others fear they came close to it, while generally the union will face high member uncertainty about likely job offers. Also, while macro shock distributions are constant, the model wage/price parameters are changing so that the model is now nonlinear — its behaviour is changing in response to the history of shocks. This nonlinearity will feed back into macro variables' volatility which in turn will react on the wage/price parameters.

We now turn to our assumptions on the parameters driving these shifts. We are looking for a function relating wage/price parameters to the past history of inflation. A natural candidate is the square of a moving average of inflation over the recent past, say four years; this is our Π. It allows for offsetting effects where inflation rises have been later reversed by inflation falls; but it will strongly register a sustained rise in inflation or a sustained fall into deflation. The response to this of the short-duration sector weights we allow to be determined empirically, by indirect inference estimation. The weights on the NK sectors are calculated according to the function $\omega^i = \exp(-\theta_i \Pi)$, where $i = \pi, w$. We add this price/wage setting state-dependence to the model of Le et al. (2016), a model that includes a variant monetary policy based on QE when the ZLB is triggered. The resulting nonlinear, shifting-weights, model is then estimated and evaluated using the method of Indirect Inference on unfiltered US quarterly data from 1959–2017[2].

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[2] For a description of the Indirect Inference method see Le et al. (2016).

3 Results

3.1 Parameter Estimation

Table 2 reports the model's parameter estimates. This model matches the data behaviour well, with a p-value of 0.21, comfortably above the usual 0.05 level of model rejection. The parameters of the non-pricing functions are much the same as estimated in Le et al. (2016) without state-dependent pricing. However, whereas the model in Le et al. (2016) was only able to fit the Great Moderation period, having introduced state-dependent pricing to the model it can now explain the dynamic behaviour of major macroeconomic variables for the much longer sample of 1959–2017. This shows that as the parameters have not changed a lot, the state-dependent mechanism is vital in fitting long samples with possible regime changes. The p-value of the current model is also much higher than that of the model without state dependence. The residuals and shocks extracted from the estimated model and data can be found in Appendix B. Since these are largely independent of the state-dependent mechanism they are much the same as those in Le et al. (2016). Figure 2 shows how the weights on NK prices and wages change over time due to fluctuations in inflation. As inflation increases in the 1970s the NK weights decrease, then rise back close to 1 for the Great Moderation period. These weights produce durations that are in line with Nakamura et al. (2018).

Models' Coefficients			
		Estimated Model	Le et al. (2016)
Elasticity of capital adjustment	φ	6.881	6.814
Elasticity of consumption	σ_c	1.283	1.700
External habit formation	λ	0.767	0.714
Probability of not changing wages	ξ_w	0.635	0.627
Elasticity of labour supply	σ_L	2.865	2.683
Probability of not changing prices	ξ_p	0.746	0.973
Wage indexation	ι_w	0.376	0.354
Price indexation	ι_p	0.107	0.168
Elasticity of capital utilisation	ψ	0.128	0.104
Share of fixed costs in production (+1)	Φ	1.083	1.761
Taylor Rule response to inflation	r_p	2.913	2.375
Interest rate smoothing	ρ	0.732	0.737
Taylor Rule response to output	r_y	0.019	0.025
Taylor Rule response to change in output	$r_{\Delta y}$	0.019	0.021
Share of capital in production	α	0.222	0.178
Elasticity of the premium with respect to leverage	χ	0.032	0.032
Money response to premium	ψ_2	0.059	0.065
Elasticity of the premium to M0	ψ	0.058	0.055
Money response to credit growth	ψ_1	0.052	0.043
Parameter response of NK weight — prices	θ_π	0.052	
Parameter response of NK weight — wages	θ_w	0.071	
Wald $(Y, \pi, R)^*$		15.525	21.904
p-value		0.21	0.07

Table 2: Coefficient Estimates

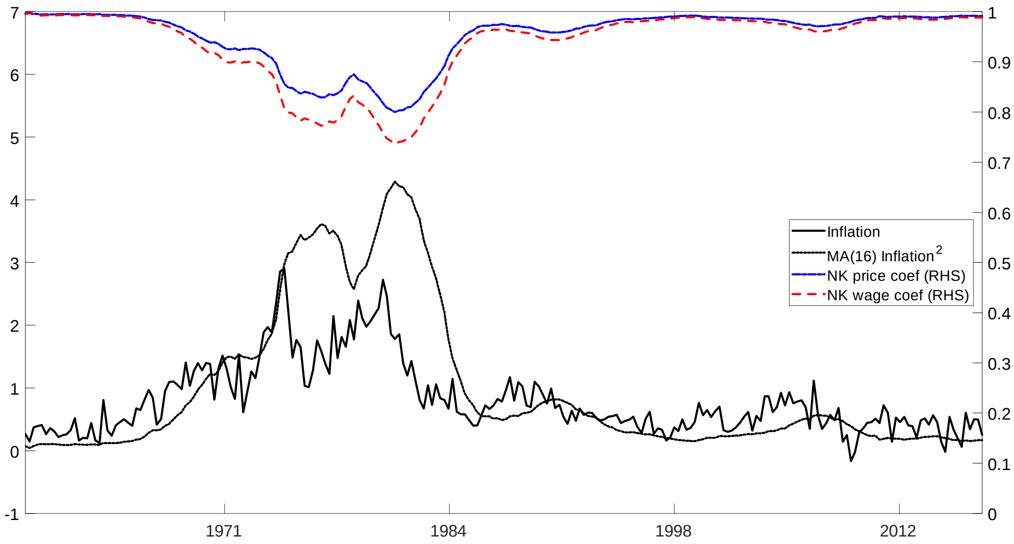

Figure 2: Time Varying NK Weights

3.2 Impulse Response Function Analysis

We now discuss the model's behaviour in response to shocks and examine its behaviour according to how New Keynesian (NK) it is. At the one extreme is an entirely NK version in which NK weights are maximum with corresponding Calvo parameters. At the other is a flexprice (FP) version where they are at their minimum. The following charts of IRFs show both of these extremes. As the weight on the NK sectors increases/decreases the model behaviour will move towards/away from the NK IRFs.

Notice that the shocks we identify may include both supply and demand effects or elements which we distinguish from the originating shocks themselves. For example, a productivity shock (which has a permanent effect here) raises supply (directly and via the capital it induces); it also raises demand (consumption reacts to its implied permanent income; investment via the need for more capital).

What we see in these IRFs is that an NK model acts like an old Keynesian model, producing high multipliers on output for demand effects; with fixed prices demand directly affects output. Hence demand elements create output turbulence. Inflation does not react much in the short run but in the medium run reacts substantially to the resulting persistent output gaps. By contrast under an FP model demand elements affect prices, with little effect on output; prices move with marginal costs and so the output gap and, with interest rates clear the goods market.

Supply elements however affect output directly in the FP model through the production function generating output supply; prices and interest rates adjust to bring demand into balance with this supply. In the NK model supply elements affect prices, with an effect on output indirectly via the Taylor Rule; these effects are weak because pass through of supply elements to prices is very limited, prices being fixed for long periods.

Hence an NK model, relative to an FP model, stabilises output against supply disturbances but destabilises it against demand ones. For prices, the NK model stabilises inflation via the Calvo mechanism, while the FP model keeps it related to marginal costs; on balance the NK model stabilises inflation the most, maximising the duration of fixed prices and wages.

In the IRFs that follow — and are shown fully in the Appendix C — there are two pure demand shocks, a government spending shock and a shock to the Taylor Rule in Figures 3 and 4 which illustrate this point. In both one sees a much larger output fluctuation in the NK versus the FP case, where inflation responds sharply to stabilise output.

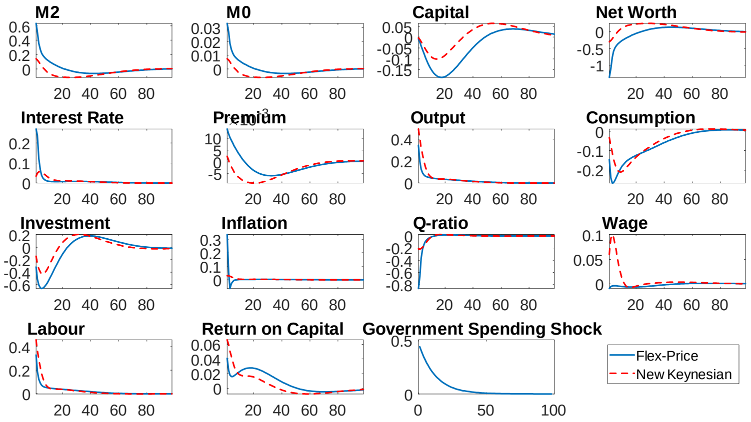

Figure 3: IRFs to a Government Spending Shock

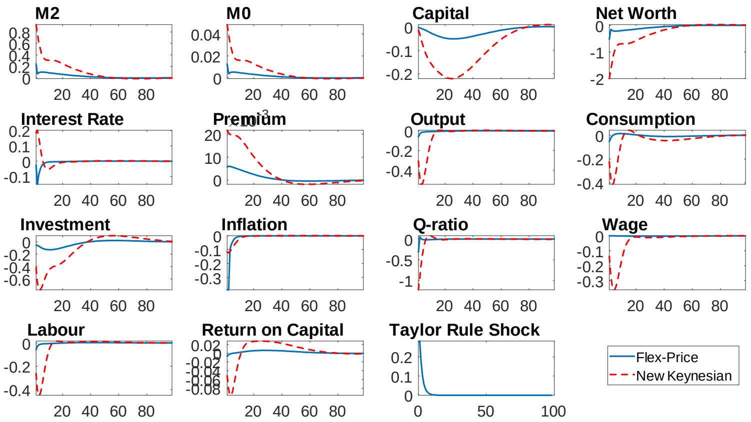

Figure 4: IRFs to a Taylor Rule Shock

The productivity shock, shown in Figure 5, combines both supply and demand elements, and so shows higher output fluctuation under NK than FP around the same long-run change.

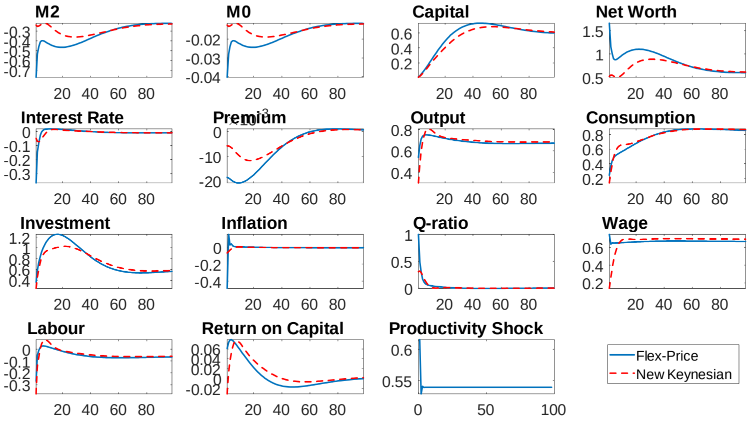

Figure 5: IRFs to a Nonstationary Productivity Shock

The other shocks are all mainly demand shocks: the consumer preference shock plainly is, while the net worth, premium and investment shocks all disturb investment demand, leaving long run supply the same. Accordingly all show more output fluctuations under NK than NC. We show these output IRFs to all the shocks in Figure 6 (as noted the full set of IRFs is shown in the appendix). We omit the labour supply shock (to the utility cost of labour) from the output IRFs here because it has no demand element: under NK it has no effect on employment or output, as it has virtually no effect on wages; it simply has a temporary effect on employment and so output under FP.

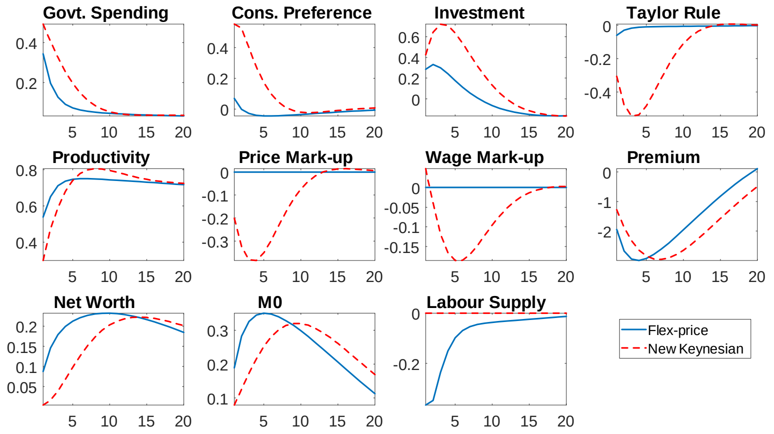

Figure 6: Output IRFs to various shocks under NK and Flex-Price models

3.3 Variance Decomposition

We show in Tables 3 and 4 how the model responds to shocks on average, via its variance decomposition for the long- and short-run respectively. As we would expect, demand shocks, notably government spending, dominate output in the short run while in the long run the non-stationary productivity and government spending jointly dominate. This result is in line with the fact that the weights on the NK sectors are high. Monetary policy shocks account for about a tenth of output variance in both the short and long run.

Shock\Variable	Int. Rate	Inv.	Infl.	Wage	Cons.	Output	Hours	Premium	Net Worth	M0	M2
Govt Spending	2.47	3.60	3.34	4.02	7.71	23.10	13.09	2.87	4.16	42.47	2.99
Consumer Pref.	1.27	1.56	1.81	2.18	18.31	2.83	1.96	1.12	1.52	1.33	61.58
Investment	3.14	55.31	3.92	4.83	5.01	9.87	6.46	3.77	8.44	2.79	2.89
Interest Rate Rule	15.82	10.16	9.11	7.86	9.81	9.22	10.47	8.10	10.19	8.92	8.40
Productivity	28.46	10.12	29.24	21.57	29.46	23.05	48.79	12.65	13.93	28.90	8.56
Price Mark-up	5.28	7.16	9.46	6.15	6.68	6.49	7.13	5.67	7.61	6.46	6.27
Wage Mark-up	2.09	3.46	3.12	3.93	3.13	3.34	3.33	2.48	3.31	2.91	2.88
Labour Supply	4.48	3.07	5.04	6.65	3.43	3.98	2.93	2.49	3.17	2.70	2.69
Credit Premium	3.63	0.82	4.34	6.50	1.67	2.81	0.76	29.91	1.45	0.49	0.60
Net Worth	3.70	1.97	4.57	5.92	2.99	4.20	2.68	7.46	35.67	1.59	1.69
Monetary Base	29.66	2.77	26.05	30.38	11.81	11.13	2.40	23.48	10.54	1.45	1.45

Table 3: Long Run Variance Decomposition

Shock\Variable	Int. Rate	Inv.	Infl.	Wage	Cons.	Output	Hours	Premium	Net Worth	M0	M2
Govt Spending	1.12	1.65	2.01	7.18	5.61	55.15	40.56	1.01	1.37	53.10	1.06
Consumer Pref.	0.16	0.36	0.57	3.31	71.03	10.65	7.37	0.23	0.27	0.34	82.98
Investment	0.11	74.02	0.57	1.64	0.99	9.08	6.85	0.21	0.31	0.24	0.24
Interest Rate Rule	80.01	14.68	22.76	23.67	12.87	11.55	12.32	8.96	17.44	13.27	9.88
Productivity	4.71	3.83	10.64	10.16	5.52	7.33	28.02	2.49	4.92	27.93	2.51
Price Mark-up	12.76	3.14	59.07	8.75	2.72	3.24	3.14	2.13	4.61	3.39	2.17
Wage Mark-up	0.39	1.12	1.93	24.94	0.42	1.13	0.64	0.50	0.80	0.53	0.36
Labour Supply	0.74	1.12	2.40	20.18	0.76	1.28	0.68	0.62	1.39	1.19	0.75
Credit Premium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.88	0.00	0.00	0.00
Net Worth	0.01	0.08	0.05	0.16	0.09	0.59	0.43	7.28	68.90	0.02	0.04
Monetary Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.69	0.00	0.00	0.00

Table 4: Short Run Variance Decomposition (5 year)

4 What is the potential role of monetary policy in a model with state-dependent pricing?

We now turn to a discussion of how monetary policy can best respond to shocks within this model of the US economy. The model we have estimated reveals that the changing duration of pricing has major effects on how shocks impact on the economy; and that in turn monetary policy, through its influence on inflation, has major effects on price-duration.

To compare different monetary policy rules the standard way in New Keynesian models is to evaluate welfare through the variance of inflation since this is related to the extent that relative prices are disturbed from their zero margin optimum over marginal cost; to generate this optimum it is usually assumed that a government subsidy offsets the steady state margin. Since the Financial Crisis and the Great Recession attention has also been focused on the ability of policy to avoid crises, viewed as long recessions — Le et al. (2016) showed via simulation analysis how many crises were likely under various rules. An alternative way of measuring this output tendency is to measure output volatility directly, around a measure of trend output. Here we construct this trend output measure as the balanced growth path we find in the data plus simulated productivity shocks; these two elements together constitute the deterministic plus the stochastic trend in output, that we estimate constitute the optimum equilibrium output path. We embed this also as the target for GDP in our nominal GDP targeting rule, as what the central bank would use in practice as a model-free estimate. According to our model, this may not be the true estimate of the FP model solved path which corresponds to the welfare-maximising path; this would rather be the balanced growth path plus the simulated effect on output of all shocks under the flexprice model. So below we compute welfare under this alternative optimum output path, as part of our robustness checks.

Since there is little agreement in the policy debate on any one of these measures of stabilisation success, we use our simulation analysis to generate all of them, in the hope that we can find a monetary rule that would produce a broadly attractive result from most viewpoints- and so is generally robust.

In our discussion that follows, we aim to review first of all the economy's behaviour under the default option of the monetary behaviour we have estimated for the model: namely a Taylor Rule in normal times, accompanied by a QE rule under the ZLB whenever this hits. We then compare the results we obtain when we substitute new policy rules, notably those targeting Nominal GDP.

Figure 7 (a replica of Figures 11 and 12 from Le et al. (2016)) illustrates how in our previous model with fixed duration, the Taylor Rule default monetary policy — in BLUE — was unable to stabilise output, whereas our Nominal GDP targeting policy (the green solid line) succeeded well, as did a number of close variations on this targeting rule, also shown. These variations included Price Level Targeting (PLT) and the addition of a more aggressive QE rule under the ZLB (dubbed 'Monetary Reform' or 'Reform').

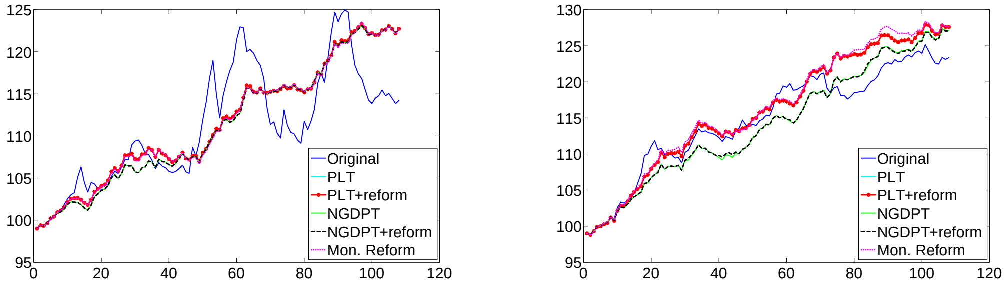

Figure 7: Two examples of simulated output under different rules

With the introduction of varying duration this instability of output now spreads to inflation, as illustrated by Figure 8 for a typical simulation — Simulation 15 below — under default policies (shaded areas show the ZLB episodes). What this shows is how inflation fluctuates as the ZLB hits, causing substantial variation in NK-flexprice weights which in turn feed back into inflation variance. Notice that output remains moderately smooth.

To summarise the difference between the new endogenous-duration model and the previous fixed-duration one, the Taylor Rule default monetary policy loses the ability to stabilise inflation whereas previously it lacked the ability to stabilise output.

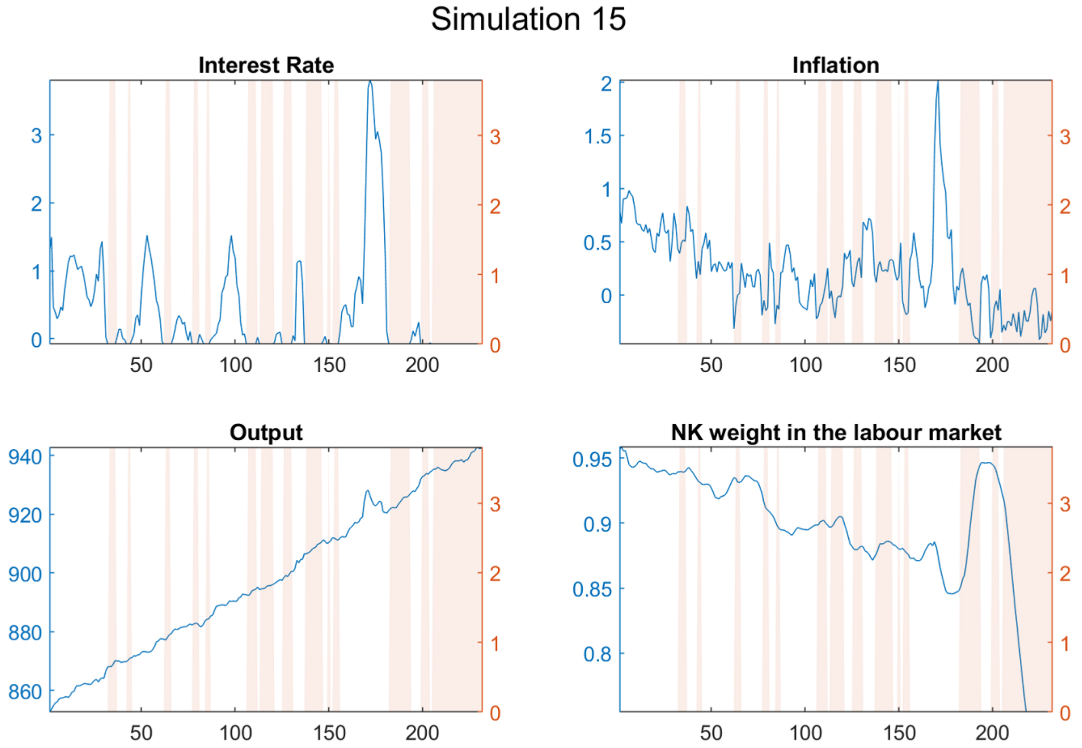

Figure 8: Taylor Rule with ZLB Simulation Example

To restore the powers of monetary policy we again need to turn towards Nominal GDP targeting. However, we also need a policy that switches off the ZLB, with its destabilising effect on inflation. To achieve this we need the extra instrument of fiscal policy to kick in to prevent the ZLB, since by construction the monetary policy rule cannot do so. Illustrative simulation results for this policy can be seen in the RED lines of simulation 15 in Figure 9. Here the existence of this fiscal guarantee, or 'fiscal backstop', switches off the ZLB, while nominal GDP targeting stabilises inflation, output remaining broadly smooth.

When we employ this nominal GDP targeting interest rate rule with the fiscal backstop preventing the ZLB, we broadly recover the stability we found in our previous work from Nominal GDP targeting with the ZLB but without state-dependence (Le et al, 2016). Table 5 summarises our average simulated results for each Targeting Rule. If we compare the stability results for this rule with those for our estimated baseline Taylor Rule we find that it greatly reduces the variance of inflation and the variation of output around our Target trend, so also our chosen welfare cost measure which combines the two, with weights determined by the relative variance. It also keeps the number of long crises (4–6 years long, Great Recessions) down to one

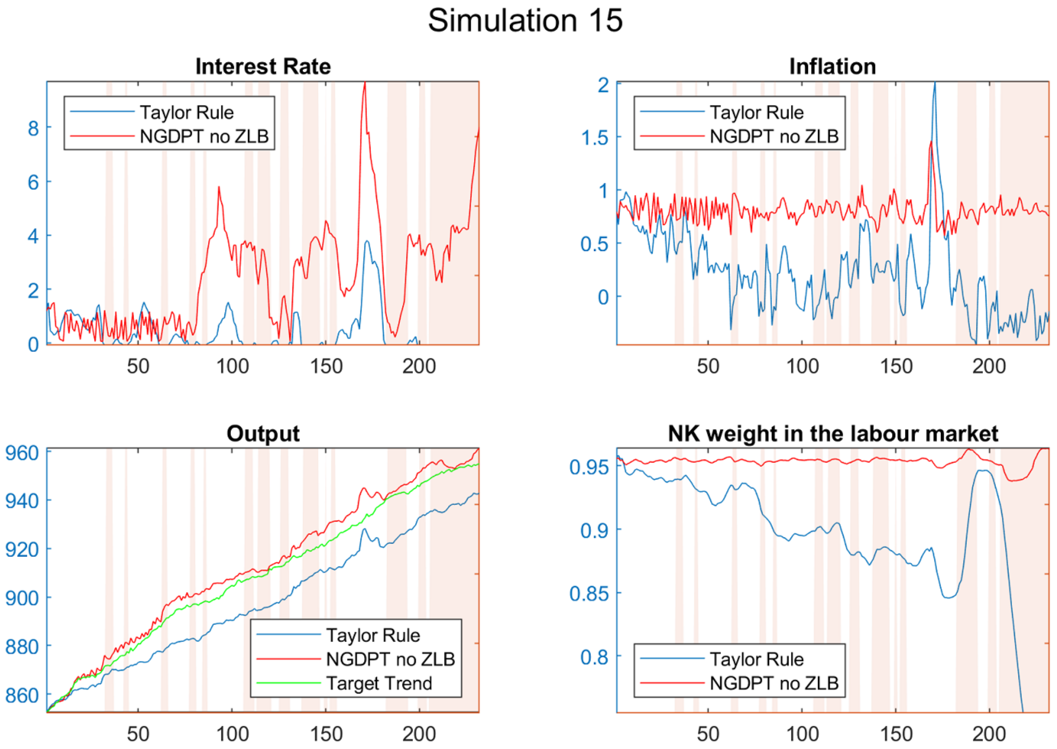

Figure 9: NGDPT with no ZLB Simulation Example

per century, roughly matching the Taylor Rule.

This is achieved while also largely keeping the world close to totally NK, with NK weights between 0.8 and 1.0 and so high price stability.

	Crises/1000 years 4–6 years long	var(π)	var(y)*	Welfare$^+$	Av. NK weight wage	Av. NK weight price
Taylor Rule	8.10	0.1127	25.2419	0.1755	0.9377	0.9516
NOMGDPT (noZLB)	9.72	0.0176	16.8902	0.0598	0.9534	0.9658

* Deviation from target trend

$^+$ Weighted welfare=0.9975*var(π)+0.0025*var(y)

Table 5: Crises and Welfare Comparison

We also checked the robustness of our welfare measures for our chosen rule to using a model-estimated optimum equilibrium output path. For this alternative measure we used the BGP trend plus the flexprice model solution for the effects on output of all the model shocks. It can be seen in the Table 6 that the welfare results for the chosen Nominal GDP target rule still show a marked improvement on the Taylor Rule, though a smaller one on the output element.

To illustrate what is going on in this Table 5 we show in Figure 10 a number of illustrative simulations

	var(π)	var(y)*	Welfare$^+$
Taylor Rule	0.1127	20.8553	0.16453
NOMGDPT (noZLB)	0.0176	20.15076	0.06791

* Deviation from Optimum output under FP model

$^+$ Weighted welfare=0.9975*var(π)+0.0025*var(y)

Table 6: Welfare Comparison for Mistaken Equilibrium Output Path

with results for the Taylor Rule and Nominal GDP target and show the target trend for output. It can also be seen that this rule (in Red) keeps output on a rather stable course, relative to the status quo Taylor Rule case (in Blue), while eliminating unstable behaviour in inflation and price/wage duration.

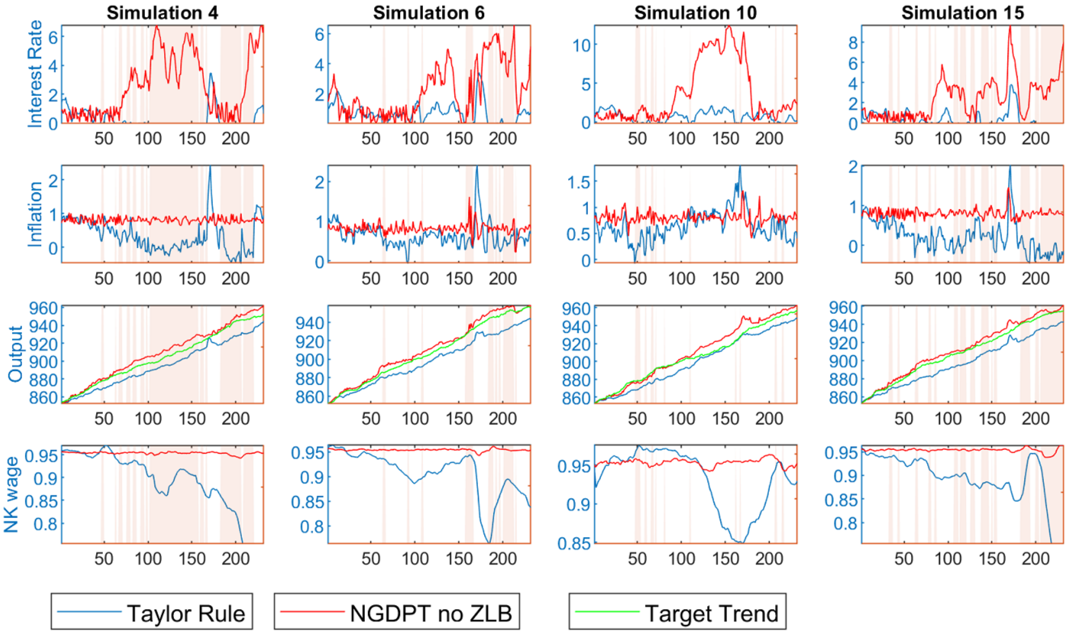

Figure 10: Simulation Comparison between Taylor Rule and NGDPT with no ZLB

5 Conclusions

In this paper we have investigated how US macroeconomic behaviour is affected by state-dependence in price/wage duration. Current major macro models assume constant duration but there is considerable evidence now both in macro and micro data that duration varies with the state of the economy, especially with inflation. We have reestimated a fairly successful DSGE model to include state-dependence and found that with this extension it can match US behaviour over the whole postwar period, whereas with constant duration it failed to match it before the mid-1980s. We found that duration fluctuated over the whole period quite substantially, between strongly New Keynesian periods such as during the Great Moderation and much closer to flexprice periods such as during the Great Inflation and the Great Recession.

The role of monetary policy becomes two-fold in such a world, since any monetary rule does not merely respond to shocks but also affects the extent to which the economy is New Keynesian and hence its fundamental responses to shocks. We investigate how such a powerful twin role might be best discharged; and we find that an interest rate rule targeting Nominal GDP, with a differential response to prices and output, the first relative to a simple loglinear trend, the second relative to a flexprice equilibrium trend, performs well according to a number of welfare criteria, provided it is buttressed by a fiscal backstop that prevents the Zero Lower Bound taking hold by pushing interest rates away from it. Notably this rule achieves a world in which prices are heavily stabilised much as they would have been under the gold standard, leading to long price/wage durations; but also one where the demand shocks to which such a New Keynesian world is highly vulnerable are strongly stabilised.

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6 APPENDIX A: Model Listing

Consumption Euler equation

$$c_t = \frac{\frac{\lambda}{\gamma}}{1+\frac{\lambda}{\gamma}} c_{t-1} + \frac{1}{1+\frac{\lambda}{\gamma}} E_t c_{t+1} + \frac{(\sigma_c - 1)\frac{W_* L_*}{C_*}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}\left(l_t - E_t l_{t+1}\right) - \left(\frac{1-\frac{\lambda}{\gamma}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}\right)\left(r_t - E_t \pi_{t+1}\right) + eb_t \tag{1}$$

Investment Euler equation

$$inn_t = \frac{1}{1+\beta\gamma^{(1-\sigma_c)}} inn_{t-1} + \frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}} E_t inn_{t+1} + \frac{1}{\left(1+\beta\gamma^{(1-\sigma_c)}\right)\gamma^2\varphi} qq_t + einn_t \tag{2}$$

Tobin Q equation

$$qq_t = \frac{1-\delta}{1-\delta+R_*^K} E_t qq_{t+1} + \frac{R_*^K}{1-\delta+R_*^K} E_t rk_{t+1} - E_t cy_{t+1} \tag{3}$$

Capital Accumulation equation

$$k_t = \left(\frac{1-\delta}{\gamma}\right) k_{t-1} + \left(1 - \frac{1-\delta}{\gamma}\right) inn_t + \left(1 - \frac{1-\delta}{\gamma}\right)\left(1+\beta\gamma^{(1-\sigma_c)}\right)\gamma^2\varphi\,(einn_t) \tag{4}$$

Labour demand

$$l_t = -w_t + \left(1 + \frac{1-\psi}{\psi}\right) rk_t + k_{t-1} \tag{5}$$

NK Price Setting equation (π_t^{NK})

$$\pi_t = \begin{array}{l} \frac{\beta\gamma^{(1-\sigma_c)}\iota_P}{1+\beta\gamma^{(1-\sigma_c)}\iota_P} E_t \pi_{t+1} + \frac{\iota_P}{1+\beta\gamma^{(1-\sigma_c)}\iota_P} \pi_{t-1} - \left(\frac{1}{1+\beta\gamma^{(1-\sigma_c)}\iota_P}\right) \\ \left(\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_p\right)\left(1-\xi_p\right)}{\xi_p\left(\left(\phi_p-1\right)\epsilon_p+1\right)}\right)\left(\alpha rk_t + (1-\alpha)\,w_t - ea_t\right) + ep_t \end{array} \tag{6}$$

NK Wage Setting equation (w_t^{NK})

$$w_t = \begin{array}{c} \tfrac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}} E_t w_{t+1} + \tfrac{1}{1+\beta\gamma^{(1-\sigma_c)}} w_{t-1} + \tfrac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}} E_t \pi_{t+1} - \tfrac{1+\beta\gamma^{(1-\sigma_c)}\iota_w}{1+\beta\gamma^{(1-\sigma_c)}} \pi_t \\ + \tfrac{\iota_w}{1+\beta\gamma^{(1-\sigma_c)}} \pi_{t-1} - \tfrac{1}{1+\beta\gamma^{(1-\sigma_c)}} \left(\tfrac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_w\right)(1-\xi_w)}{(1+\epsilon_w(\phi_w-1))\xi_w} \right) \\ \left(w_t - \sigma_l l_t - \left(\tfrac{1}{1-\frac{\lambda}{\gamma}} \right) \left(c_t - \tfrac{\lambda}{\gamma} c_{t-1} \right) \right) + ew_t \end{array} \tag{7}$$

FP Marginal Product of Labour (w_t^{FP})

$$rk_t = \frac{1}{\alpha}\left[(1-\alpha)\,w_t + ea_t\right] \tag{8}$$

FP Labour Supply (π_t^{FP})

$$w_t = \sigma_l l_t + \left(\frac{1}{1-\frac{\lambda}{\gamma}}\right)\left(c_t - \frac{\lambda}{\gamma}c_{t-1}\right) - (\pi_t - E_{t-1}\pi_t) + ew_t^S$$

Weighted Inflation

$$\pi_t = \theta_\pi \pi_t^{NK} + (1-\theta_\pi)\pi_t^{FP} \tag{9}$$

Weighted Wage

$$w_t = \theta_w w_t^{NK} + (1-\theta_w) w_t^{FP} \tag{10}$$

Market Clearing condition in goods market

$$y_t = \frac{C}{Y}c_t + \frac{I}{Y}inn_t + R_*^K k_y \frac{1-\psi}{\psi} rk_t + c_y^e c_t^e + eg_t \tag{11}$$

Aggregate Production equation

$$y_t = \phi\left[\alpha\frac{1-\psi}{\psi}rk_t + \alpha k_{t-1} + (1-\alpha)\,l_t + ea_t\right] \tag{12}$$

Taylor Rule

$$r_t = \rho r_{t-1} + (1-\rho)\left(r_p \pi_t + r_y y_t\right) + r_{\Delta y}\left(y_t - y_{t-1}\right) + er_t \text{ for } r_t > 0.0625 \tag{13}$$

Premium

$$E_t cy_{t+1} - \left(r_t - E_t \pi_{t+1}\right) = pm_t = \chi\left(qq_t + k_t - n_t\right) - \psi m_t + \xi_t + epr_t \tag{14}$$

Net worth

$$n_t = \frac{K}{N}\left(cy_t - E_{t-1} cy_t\right) + E_{t-1} cy_t + \theta n_{t-1} + enw_t \tag{15}$$

Entrepreneurial consumption

$$c_t^e = n_t \tag{16}$$

M0

$$\Delta m_t = \psi_1 \Delta M_t + errm_{2t} \text{ for } r_t > 0.0625 \text{ and } \Delta m_t = \psi_2 (s_t - c^*) + errm_{2t} \text{ for } r_t \leq 0.0625 \tag{17}$$

M2

$$M_t = (1 + \nu - \mu) k_t + \mu m_t - \nu n_t \tag{18}$$

7 APPENDIX B: Residuals and Shocks

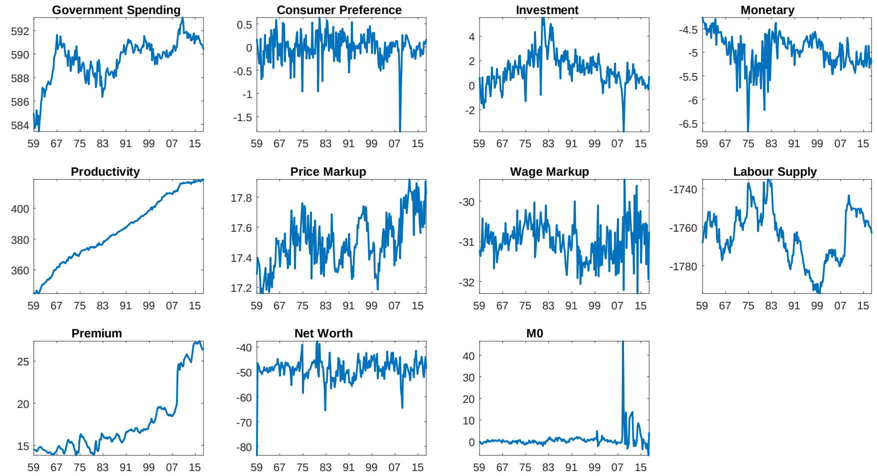

Figure 11: Residuals

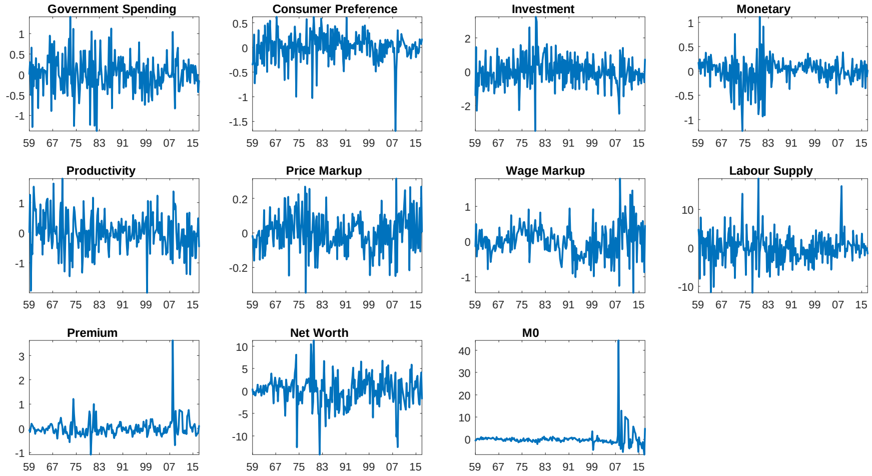

Figure 12: Shocks

8 APPENDIX C: all model IRFs

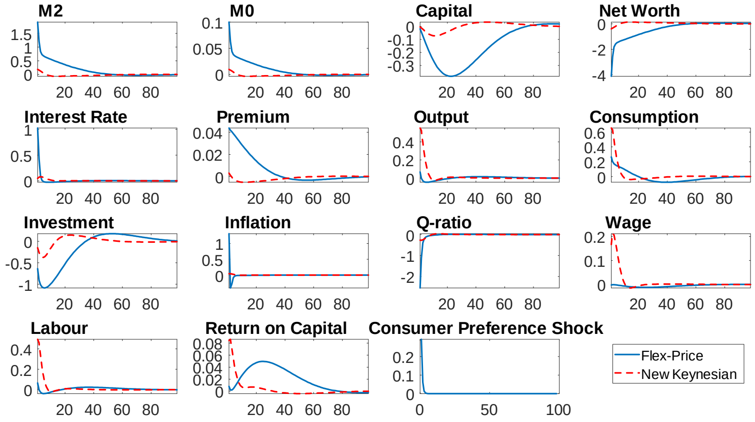

Figure 13: IRFs to a Consumer Preference Shock

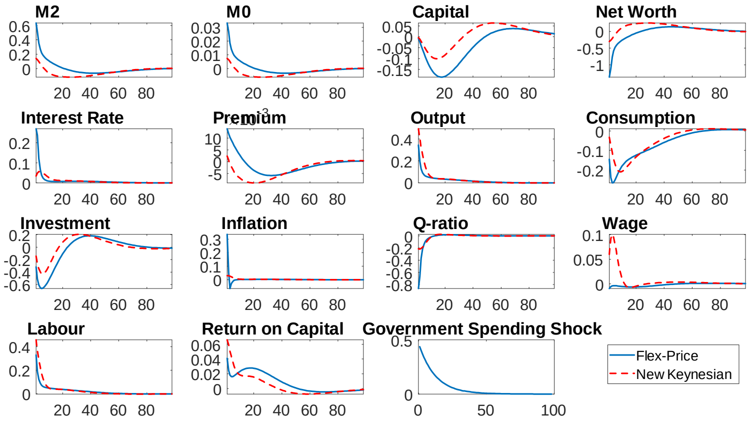

Figure 14: IRFs to a Government Spending Shock

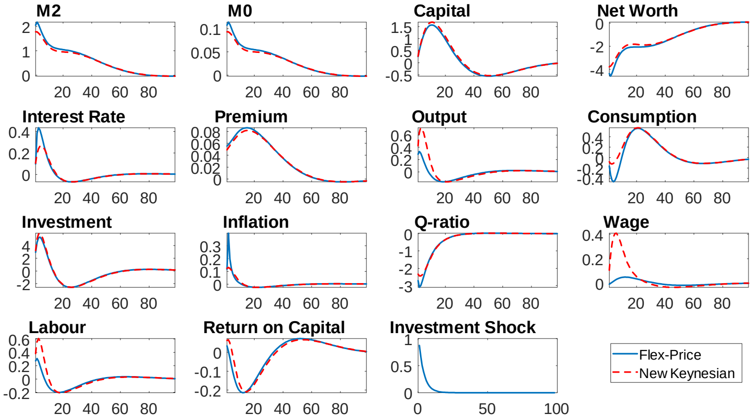

Figure 15: IRFs to an Investment Shock

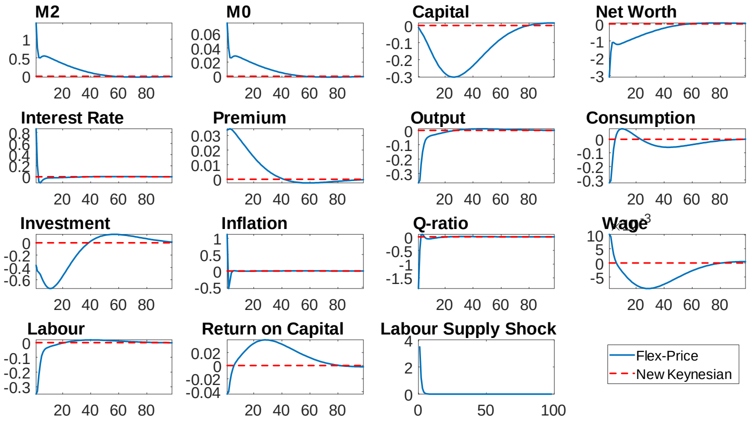

Figure 16: IRFs to a Labour Supply Shock

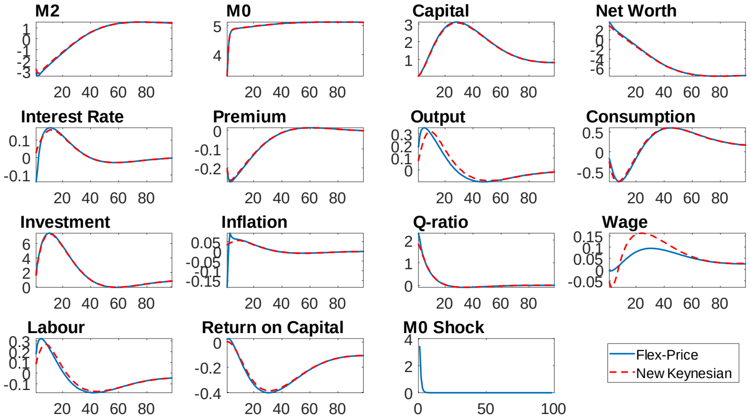

Figure 17: IRFs to a Money Supply Shock

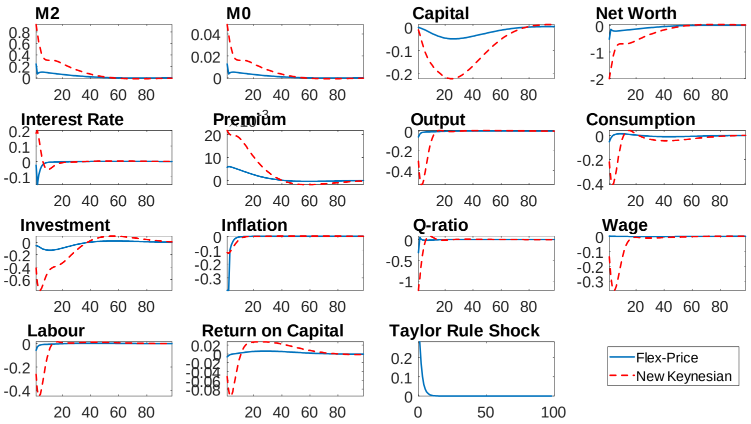

Figure 18: IRFs to a Taylor Rule Shock

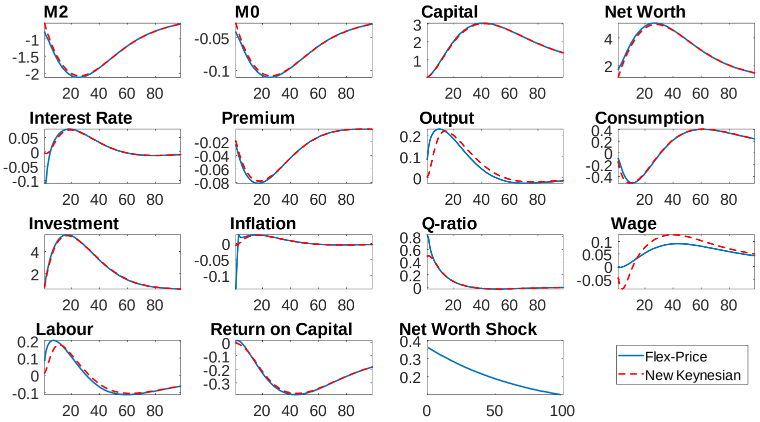

Figure 19: IRFs to a Net Worth Shock

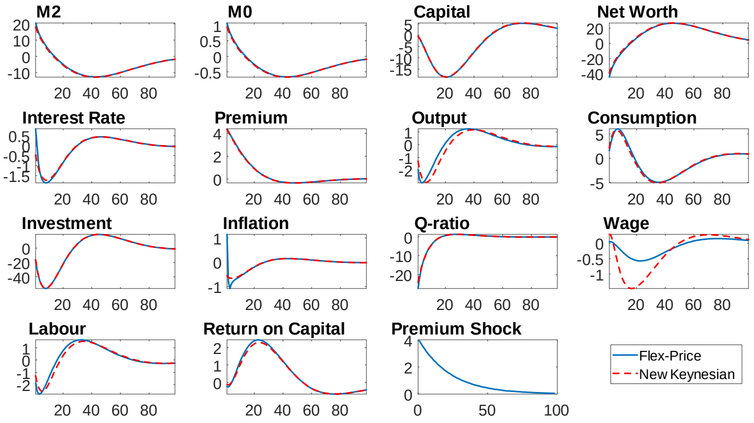

Figure 20: IRFs to a Premium Shock

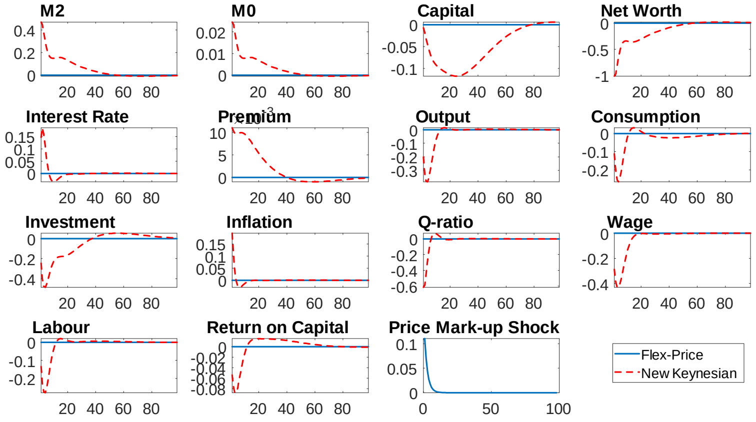

Figure 21: IRFs to a Price Mark-up Shock

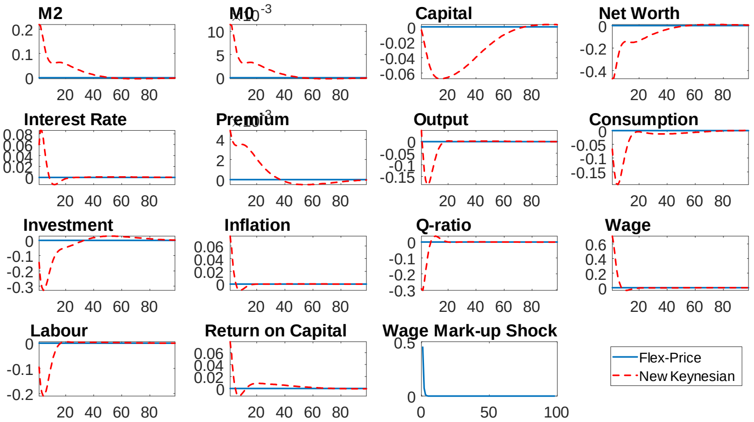

Figure 22: IRFs to a Wage Mark-up Shock

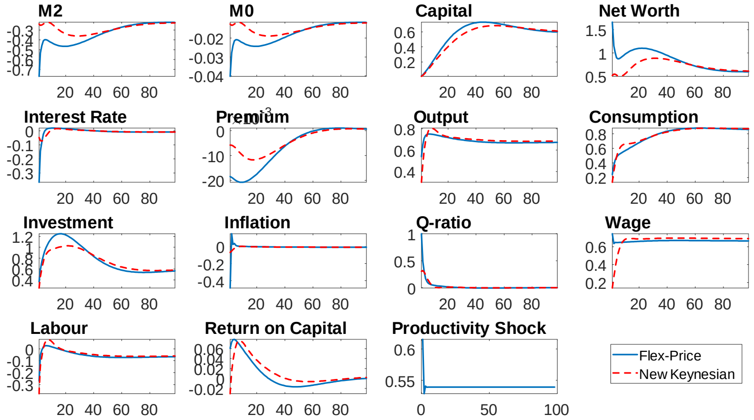

Figure 23: IRFs to a Nonstationary Productivity Shock