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State-dependent pricing and its implications for monetary policy

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Abstract

Strong evidence now exists both in macro and micro data that price/wage durations are depent on the state of the economy and 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 role for monetary policy in influencing the economy's price stickiness. We find that by targetin nominal GDP monetary policy can achieve high price stability while also preventing large cyclical output fluctuations.

Keywords: state-dependence; New Keynesian; Rational Expectations
crises; price stability; nominalGDP

JEL Classification: E2; E3

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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 agreed 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. In this paper we examine the evidence for such variability at the macro level; a now-large literature finds it at the level of micro data. We review this shortly.

But at the macro level, it is nevertheless usual 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 for a 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. The weight on the flexprice sector they found 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 and for Quantitative Easing. 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, both wages and prices respectively, rose considerably from near zero to 0.56 and 0.91; 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 flexprice. What the findings of Le et al (2016) seeem 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 time dependent, thus letting the prices be state-contingent.

As just noted, at the micro level there has been a long list of studies trying to establish the facts about the relationship between 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. That is price increases, not price decreases, drive inflation movements. 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 the 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. (2017) 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 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 the following table. 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 or a few weeks.

	Country	Duration in high inflation	Duration in low inflation
Nakamura et al. (2017)	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: Overview Duration found in Previous Literature

[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.

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 paper we explore the implications at the macro level of allowing for 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, 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.

Our contribution here is that we bring to bear a full model that is estimated to match closely the data behaviour over the full post-war sample. Our model thus contains the many real rigidities in Smets and Wouters (2007), financial frictions as in Bernanke et al (1999), and the ability to deal with the zero lower bound 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 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 these, we find that state-dependence opens up a key new role for monetary policy in influencing the degree of price/wage stickiness.

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 price/wage setters' idiosyncratic 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.

2 Model details

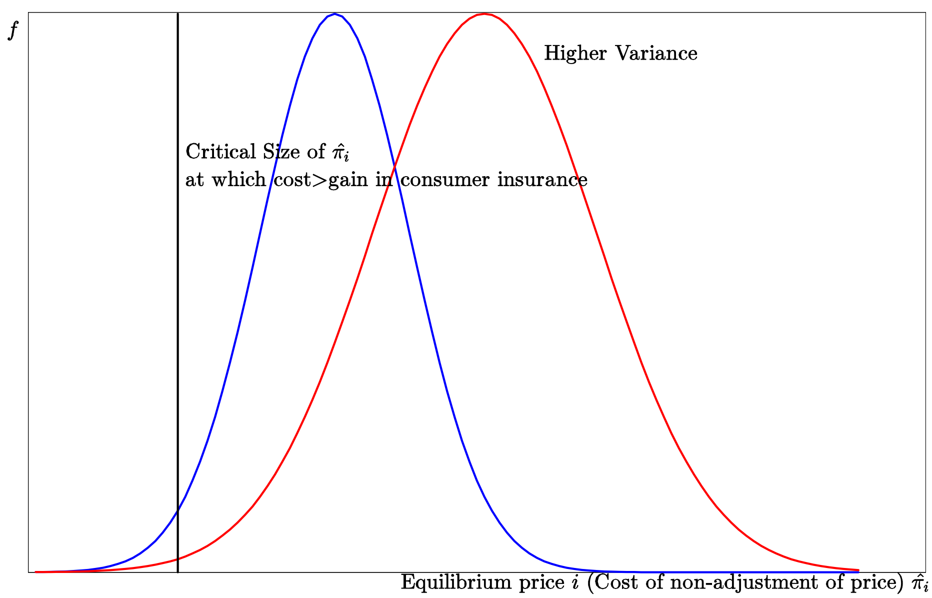
The model we consider here allows for state-dependent price and wage setting in the general equilibrium framework proposed by Le et al. (2018) which itself is developed from the model of Smets and Wouters (2007). The model assumes that goods and labour markets are partially flexprice and partially of longer duration. These fractions 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 a cheap money collateral as in Le et al (2016) to make the monetary policy effective via unconventional monetary measures even at the zero lower interest rate bound.

Now we turn to the state-dependent formulation in the model. In the previous studies by Le et al (2011, 2016, 2018) 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, that is, 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' since it is continuously keeping prices equal to marginal costs plus the same constant mark-up as in the long-duration sector; or 'New Classical' since apart from the mark-up it is behaving as if in perfect competition. The other sector we call 'New Keynesian' 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: below this they would rather stabilise the price in order to insure their customers against uncertainty. However, above it the cost of providing this insurance is too great compared with the benefit it gives.

This idiosyncratic distribution's variance we assume is related to the size of recent inflation shocks to the economy. 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.

Hence, 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 the chart below. 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, a function we do not derive but estimate from the macro data behaviour.



Hence the probability of not changing price is reduced 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.

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 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.

Notice also that 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 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 Calvo parameter in the long-duration sector is also determined similarly.

3 Intuition of how we do this:

We first take the set of parameters, weights and errors we estimated in Le et al (2018). This gives us our initial estimate of the inflation rate under 'neutral conditions'. We take the backward MA(16) of this and square it, as our measure of the neutral inflation value.The Calvo parameter is assumed to react to this with a reaction parameter, R.The whole model is now reestimated with the new varying Calvo parameters and varying shares of the flexprice sector. This estimation process is in fact a search over the parameter space, that ends with a Wald test. Thus a set of parameter values is chosen and the implied errors with that set extracted from the sample data.The resulting nonlinear, shifting-weights, model is then evaluated for its match to the auxiliary model on the sample data, and the Wald calculated. The process is then repeated for another initial parameter set, until the best-matching set is found, which is the Indirect Inference estimate.

4 Results

What we see in what follows is that if we use squared MA(16) of inflation as our inflation measure times a reaction coefficient R, we obtain the following model parameter estimates and a good Wald fit.The resulting model matches the data behaviour well, with a p-value of 0.17, well above our critical 0.05 cut-off. The parameters of the non-pricing functions are much the same as estimated in Le et al (2018) without state-dependent pricing- Below we show the shocks and innovations extracted from model and data.

Models' Coefficients			
		Estimated Model	Le et al. 2017
Elasticity of capital adjustment	φ	3.264	6.814
Elasticity of consumption	σ_c	2.365	1.700
External habit formation	λ	0.693	0.714
Probability of not changing wages	ξ_w	0.401	0.627
Elasticity of labour supply	σ_L	2.703	2.683
Probability of not changing prices	ξ_p	0.433	0.973
Wage indexation	ι_w	0.380	0.354
Price indexation	ι_p	0.172	0.168
Elasticity of capital utilisation	ψ	0.179	0.104
Share of fixed costs in production (+1)	Φ	2.369	1.761
Taylor Rule response to inflation	r_p	2.384	2.375
Interest rate smoothing	ρ	0.842	0.737
Taylor Rule response to output	r_y	0.006	0.025
Taylor Rule response to change in output	$r_{\Delta y}$	0.014	0.021
Share of capital in production	α	0.213	0.178
Elasticity of the premium with respect to leverage	χ	0.057	0.032
Money response to premium	ψ_2	0.109	0.065
Elasticity of the premium to M0	ψ	0.083	0.055
Money response to credit growth	ψ_1	0.024	0.043
Parameter to calculate NK weight		0.046	
Parameter to calculate NC weight		0.051	
Wald $(Y, \pi, R)^*$		11.553	21.904
P-value		0.169	0.07

Table 2: Coefficient Estimates

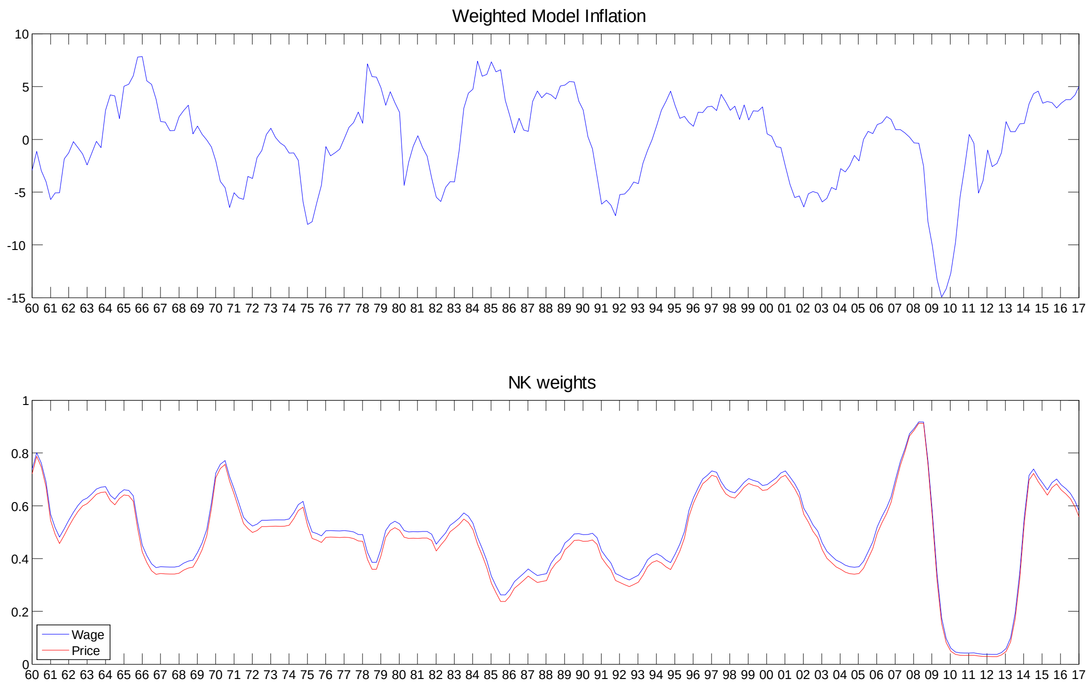


Figure 1: Time Varying NK Weights

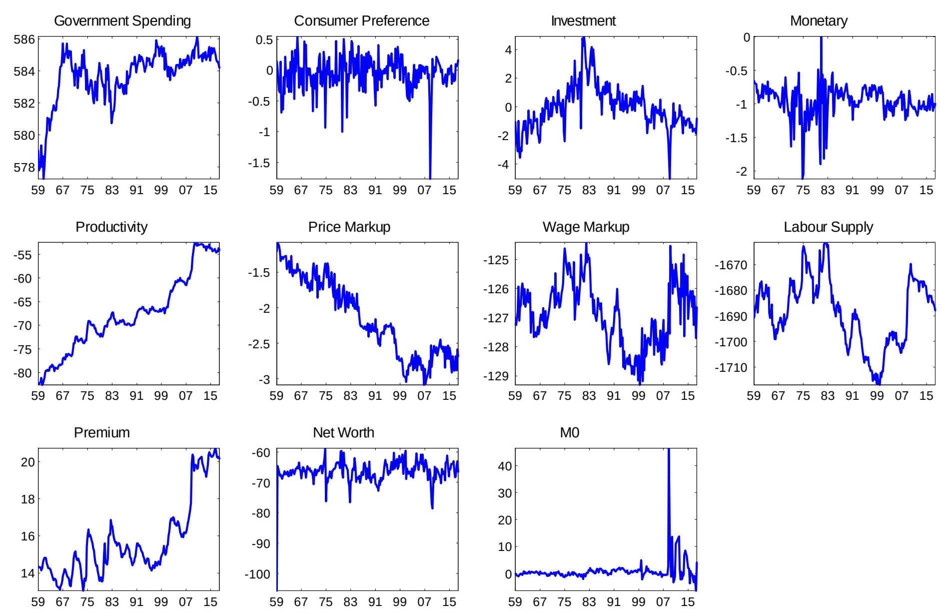


Figure 2: Residuals

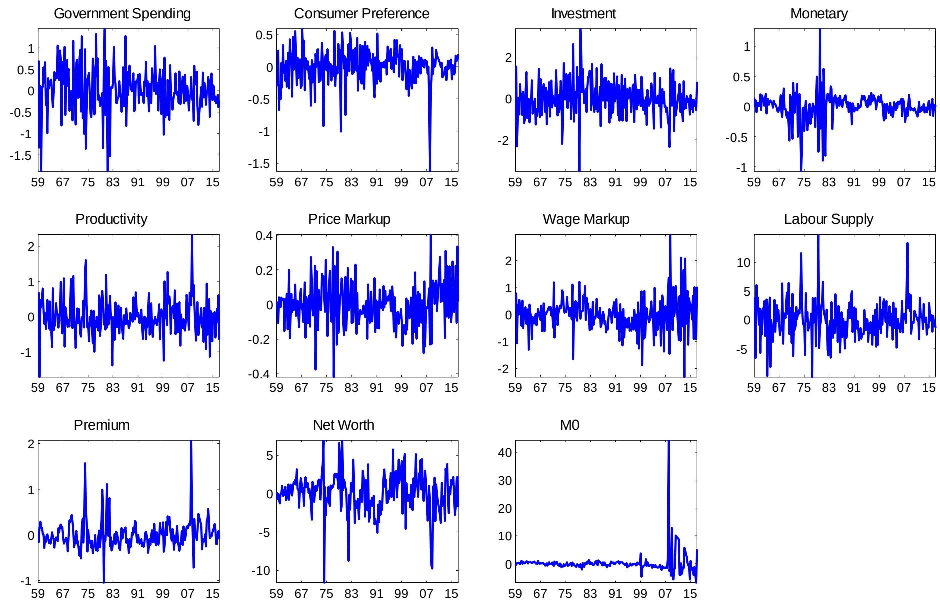


Figure 3: Shocks

5 The model's behaviour in response to shocks

We can examine this model's behaviour according to how New Keynesian 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 or New Classical, NC, version where they are at their minimum. The following charts of IRFs show both of these extremes.

We discuss their behaviour in terms of the effects of supply and demand shocks.

One problem with this discussion is that the shocks we identify may include both supply and demand elements in this sense. 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). By demand shocks we will mean the demand effects of the shocks, by supply shocks the supply effects.

What we see in these IRFs is that an NK model acts like an old Keynesian model, producing high multipliers on output for demand shocks; with fixed prices demand directly affects output. Hence demand shocks 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 NC model demand shocks affect prices, with little effect on output; prices move with marginal costs, and with interest rates clear the goods market.

Supply shocks however affect output directly in the NC 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 shocks affect prices, with an effect on output indirectly via the Taylor Rule.; these effects are weak because pass through of supply shocks to prices is very limited, prices being fixed for long periods.

Hence an NK model, relative to an NC model, stabilises output against supply shocks but destabilises it against demand shocks. For prices, the NK model stabilises inflation via the Calvo mechanism, while the NC 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 there are two pure demand shocks, a money supply and a government spending shock which illustrate this point. In both one sees a much larger output fluctuation in the NK versus the NC case. In both too inflation reacts quickly, then dies away.

The productivity shock, shown next, combines both supply and demand shocks, and so shows higher output fluctuation under NK than NC around the same long-run change.

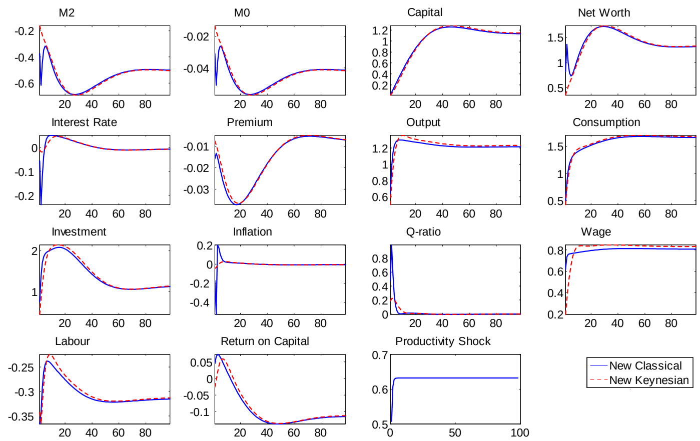


Figure 4: IRFs to a Nonstationary Productivity Shock

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 the following Figure. 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 NC.

Output IRFs for all shocks with demand elements (implicitly the output gap under NK is the difference between the NK and NC output effect; there is of course no output gap under NC) are seen in the following Figure

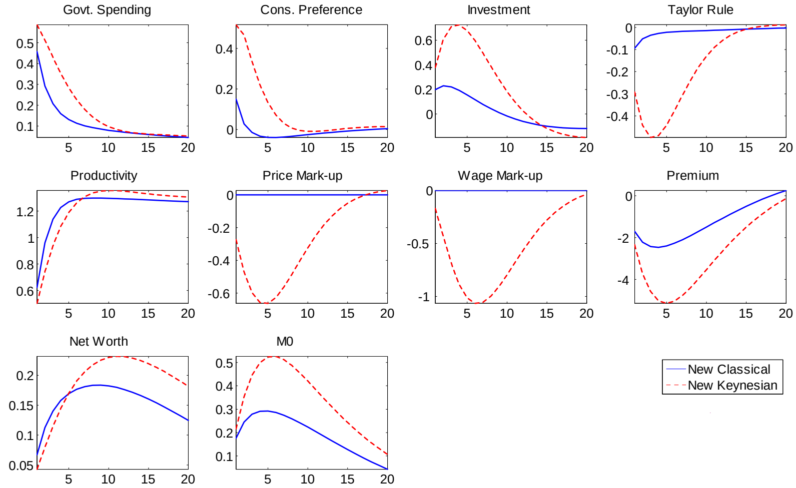


Figure 5: Output IRFs in response to all shocks

6 Variance decomposition

We show now how the baseline model (as estimated) responds to shocks on average, via its variance decomposition. As we would expect the productivity shock dominates output variation at all time periods, since it is non-stationary. Over shorter time periods demand shocks dominate output, notably government spending.

	r	inv	pk	kp	pinf	w	c	y	lab	rk	s	cy	n	yk	mzero	mtwo
g_shock	0.09	0.00	0.00	0.00	0.08	9.12	1.66	58.78	8.29	15.01	0.08	0.10	0.17	0.14	0.00	0.15
r_shock	0.03	0.00	0.00	0.00	0.06	6.93	22.60	8.04	0.39	6.36	0.00	0.03	0.01	0.02	0.00	0.01
inv_shock	0.00	84.90	0.00	94.73	0.00	0.33	0.15	3.10	0.60	5.77	0.24	0.01	0.19	0.04	0.00	8.27
pi_shock	1.35	0.00	0.00	0.00	0.00	0.04	0.60	0.16	0.02	0.05	0.00	1.75	0.00	0.00	0.00	0.00
prod_shock	73.11	11.81	73.89	4.77	67.30	35.78	53.82	22.38	85.95	45.04	16.44	70.95	53.30	65.23	0.02	41.68
rk_shock	0.21	0.00	0.00	0.00	0.19	0.45	0.08	0.06	0.02	0.28	0.00	0.27	0.00	0.00	0.00	0.00
w_shock	0.01	0.00	0.00	0.00	0.01	18.76	0.36	0.61	1.16	10.89	0.00	0.02	0.00	0.00	0.00	0.00
NCw_shock	25.19	3.29	26.11	0.50	32.36	28.58	20.73	6.66	3.54	16.57	1.82	23.71	7.51	34.58	0.00	6.26
prem_shock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	55.87	2.18	0.00	0.00	0.00	0.00
networth_shock	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.21	0.04	0.03	18.02	0.69	38.82	0.00	0.02	35.78
mzero_shock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.52	0.29	0.00	0.00	99.96	7.85

Table 3: Variance Decomposition (short 5 year period)

	r	inv	pk	kp	pinf	w	c	y	lab	rk	s	cy	n	yk	mzero	mtwo
g_shock	0.19	0.00	0.00	0.00	0.11	2.55	0.64	28.67	5.04	4.07	0.08	0.11	0.09	0.07	0.00	0.10
r_shock	0.03	0.00	0.00	0.00	0.02	0.98	4.12	1.94	0.14	0.84	0.00	0.02	0.00	0.00	0.00	0.00
inv_shock	0.24	52.42	0.00	78.23	0.02	0.44	0.14	3.38	0.97	11.63	0.65	0.09	0.46	0.15	0.05	4.25
pi_shock	1.12	0.00	0.00	0.00	0.00	0.01	0.14	0.06	0.01	0.01	0.00	0.33	0.00	0.00	0.00	0.00
prod_shock	90.14	46.17	96.11	21.31	88.4	50.56	84.23	60.28	86.75	59.24	81.07	89.72	92.92	94.14	2.36	87.64
rk_shock	0.61	0.00	0.00	0.00	0.13	0.12	0.04	0.04	0.01	0.07	0.00	0.17	0.00	0.00	0.00	0.00
w_shock	0.06	0.00	0.00	0.00	0.01	1.87	0.06	0.09	0.24	0.99	0.00	0.03	0.00	0.00	0.00	0.00
NCw_shock	7.61	1.41	3.89	0.46	11.32	43.43	10.62	5.29	6.81	23.12	1.57	8.06	1.84	5.63	0.04	1.67
prem_shock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.25	0.91	0.00	0.00	0.00	0.00
networth_shock	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.26	0.05	0.04	4.56	0.39	4.69	0.00	0.02	5.24
mzero_shock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.81	0.16	0.00	0.00	97.53	1.09

Table 4: Variance Decomposition

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

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.

7.1 The impact of changing duration on the economy

In our sample period data- see above- we can see a sub-period where demand shocks were small, and productivity shocks large (and largely positive)- the Great Moderation; and other sub-periods- the Great Inflation of the 1970s and the Financial Crisis of the late 2000s- when demand shocks were large and productivity growth shocks small. This suggests from an output stability viewpoint it would have been best to have an NC model in the 1970s and late 2000s but an NK model during the Great Moderation. In fact while our estimates suggest we did have an NC model in the 1970s when inflation was highly variable,we had an NK model when the Financial Crisis struck in 2008, an inheritance from the Great Moderation, when it was beneficial. But it meant that the Crisis produced a very severe downturn that was hard to reverse through normal monetary policy tools; what was needed was a shift to high wage/price flexibility.but this took some time to come through.

7.2 The impact of monetary policy on price duration

This analysis suggests a potential role for monetary policy beyond merely direct stabilisation of the economy through some Taylor Rule . Thus as we have just seen, the considerable success of monetary policy in stabilising inflation in the Great Moderation contributed to this being an NK period, while the monetary policy failure to prevent the Great Recession ushered in an NC period during the financial crisis..

7.2.1 Should monetary policy engineer shifts in pricing duration or remain passive?

Could then there be a role for monetary policy in engineering suitable shifts in the NC-NK balance of the economy to cope with the changing balance of shocks?

One question must be whether there is some form of Taylor Rule that would somehow automatically engineer such shifts while also acting as an efficient direct stabiliser.

It might well be that no Rule can improve on the economy's own ability to shift. Thus, with no assistance from monetary policy, most economies shifted to more wage/price flexibility after the Crisis. Arguably this helped the eventual recovery to strengthen. Also as the era of the Great Moderation dawned from the mid 1980s, the weakness of demand shocks relative to supply shocks generated inflation stability that shifted the economy to an NK structure appropriate to the shock constellation.

7.2.2 Or should monetary policy pursue a stable price-duration structure and respond to shocks actively given that structure?

Yet another possibility is that monetary policy should aim to preserve a continuing NK or NC structure and be calibrated to directly prevent output instability under that structure. One such idea would be to keep an NK structure with extreme price stability by targeting a price level target, encouraging long term nominal contracts as during the gold standard. But to ensure the Taylor Rule would counter demand shocks robustly as they arose.

We now proceed to investigate these issues by repeated bootstrap simulations of the model under varying monetary regimes.

7.3 How crisis-ridden is the economy with different stable price-duration structures?

One could reasonably argue that a fully NK world in which prices have stability akin to that of the gold standard, should on money-theoretic grounds be best from a welfare viewpoint: simply because the information in the price system is maximised, with nominal variability suppressed. We can measure this by the variability of inflation; as we see from our simulations this is minimised in an NK world, and is greater in an NC world.

However, the problem of an NK world is its vulnerability to demand shocks. This can be seen in the next table. The NK world generates 52 crises every 1000 years where output falls for six years; that is 300-odd years of severe crisis, hence occurring 30% of the time. It also creates 880 years of crises lasting 4 or more years. This is intolerable.

If we look at the frequency of crises in the other model worlds we find that it remains considerable. However, the NC world, where output is flexprice and so dominated by supply shocks, is far more stable than the NK world; the number of severe crises falls to 40 per thousand years.. As for the status quo policy of an existing Taylor Rule where shocks lead to switching NK and NC worlds, again the presence of the NK influence, strengthening the effects of demand elements, is destabilising compared to NC; again we get some 50 crises per thousand years.

	Output drops for x quarters					
	4	8	12	16	20	24
New Classical	149.49	103.05	79.18	62.30	50.42	40.37
New Keynesian	115.42	94.26	80.18	69.00	59.61	51.82
Switching	124.25	97.92	82.00	69.43	59.49	51.12

Table 5: Frequency of Crises: Crises per 1000 years

8 Policy analysis: Investigating a Rule forcing a stable NK structure but responding strongly to output shocks — Nominal GDP targeting

We now consider optimal monetary policy in this environment. We are looking for a policy rule that minimises the extent of crises. Our estimated parameters and shifting weights correspond to the estimated Taylor rule in our sample. These give us our baseline stability measures.

What we now see in this model is that changing the rule does two things: first, it changes stability holding Calvo parameters constant. Second, it changes those parameters as it changes inflation variability.

Consider this last channel. If the rule achieves minimal inflation variability, the economy will move to one of extreme wage/price rigidity, a highly New Keynesian model, where demand shocks (usually temporary) impinge on output and hardly at all on prices; supply shocks, if permanent as with productivity, will change prices and output permanently but gradually. Temporary supply shocks will not disturb prices or therefore output. This would closely correspond to the 'Great Moderation' episode. Provided demand shocks are small and of low persistence, this should be a world of great output stability.

On the other hand a large persistent demand shock, such as occurred in the Financial Crisis, would set off a large output shock of long duration.

Imagine now by contrast that the policy rule achieves much higher inflation variability because it has a weak inflation response. Then the economy would move closer to a flexprice world, a New Classical model. Here supply shocks would have immediate pass-through to prices and output would respond minimally to demand shocks which would mainly affect prices through market-clearing. In this world a large demand shock would not much affect output; output would be dominated by supply shocks.

When we consider our baseline sample world, we find alternation between NK and NC worlds as the dominant shocks change in nature. During the Great Moderation demand shocks were small and we had an NK world. During the Financial Crisis, they were large and persistent, with big output effects and the world switched to NC.

In considering whether the policy rule could have improved output stability over the sample, we need to ask how it can be framed to respond well to the mix of shocks. Thus had it responded strongly to the output fall at the start of the financial crisis, output would have been more stable due to this, and also because prices would have moved more and the world become NC faster. This suggests that a Nominal GDP target rule could do well in these circumstances, as it responds strongly to output.

When supply shocks dominate, we will get a Great Moderation, NK, world; a standard Taylor rule, responding strongly to inflation, maintains that world, which generates great output stability. A price level targeting rule, giving yet more inflation response, enhances this. A nominal GDP target includes a price level target within it.

What this brief discussion suggests is that a nominal GDP target rule may perform best in most shock environments.This question- of whether and if so how monetary policy rules can assist- is one we will investigate empirically with a range of rules.

9 Replacing the existing Taylor Rule with one targeting Nominal GDP

A natural way to contend with the demand-vulnerability of the NK world is, as we have argued, to use a strong monetary reaction to the output gap, alongside the price-stabilising feature necessary to produce an NK world. Think of the last as price-level targeting; then adding the first moves us to nominal GDP targeting, with equal weights on the price level and output gap targets.

	Output drops for x quarters					
	4	8	12	16	20	24
NGDPT	110.91	68.67	49.86	36.56	28.39	22.11

Table 6: Frequency of Crises for the Model with a Nominal GDP Target: Crises per 1000 years

When we employ a nominal GDP targeting Taylor Rule we find much greater stability occurs than with a New Keynesian model under a normal Taylor rule — see Table 6. Thus we get 132 years per thousand where a long 6-year crisis, a Great Recession is occurring — one third of the NK world — and 300 years where crises of 4-5 years (a normal recession) are occurring, half the NK world frequency. To put this another way, besides a fairly normal quota of about 6 recessions per century, we get only two Great Recessions a century under this Targeting 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 as can be seen in Figure.6 It can also be seen from the sample of simulations this rule (in green) keeps output on a rather stable course, relative to NC, NK and the status quo Switching/Taylor Rule case as seen in Figure 7.

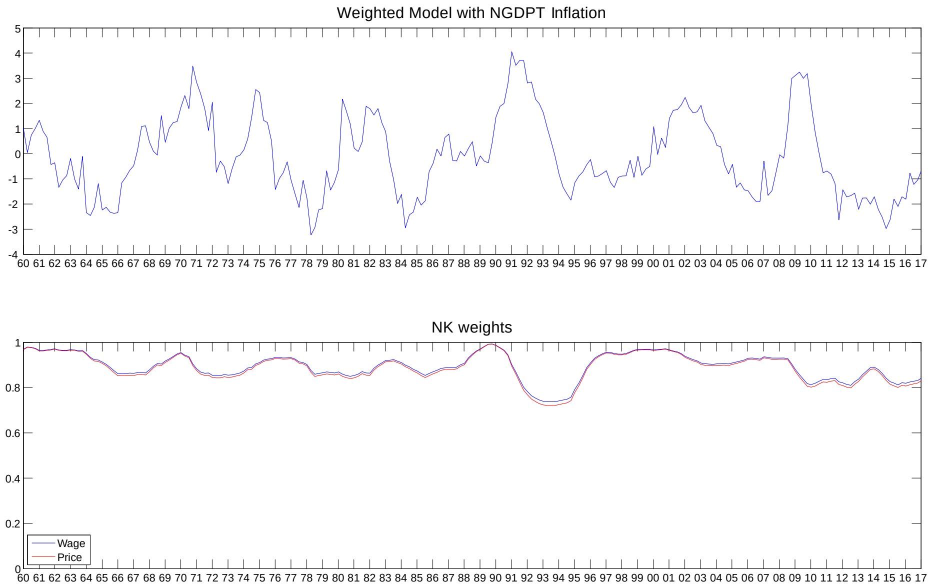


Figure 6: New Keynesian Weights in NGDPT Model

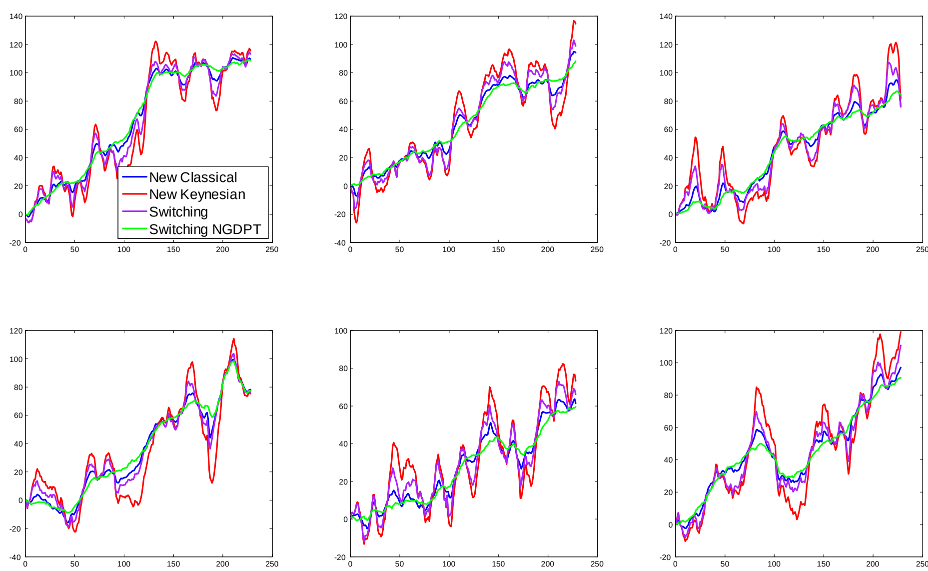


Figure 7: Output Simulations Comparison

10 Evaluating stability in alternative ways

In our analysis to this point we have treated all variation in output around a loglinear trend as equally welfare-reducing. However it can be argued that we should regard movements in output that would occur in the flexprice world as welfare-optimising, 'natural rate' movements.. In what follows we compute the output gap and also target nominal GDP relative to both a constant price level and also the flexprice output level-thus a Nominal GDP of stable prices and the natural rate.

We go on to consider the implications of this welfare debate for monetary policy here.

11 Two concepts of welfare

There are two ways we could evaluate our representative agent's welfare. One is to treat the flexprice solution as the optimum, and minimize the expected utility deviations (the weighted sum of the variances in consumption and leisure; or roughly the variance of the output gap) from that solution. Another is for the social planner to rearrange the shocks, keeping costs the same, in order to smooth utility maximally over time; as if the present value of supply due to the shocks could be converted into equivalent wealth and consumed at an optimal constant or constantly trending rate. In this case we minimise the expected utility deviations from the trend. It is this concept that is appealed to when policymakers argue for stabilising economies against supply shocks like the 'resource curse', the situation where the expansion of a natural resource sector reduces the size of other sectors. This concept also lies behind concern over crises like the financial crisis and the Great Recession, when a violent collapse in demand greatly damaged the world economy, pushing interest rates to the zero bound and apparently causing a slowdown in productivity growth, partly related to the zero bound (see Liu, Mian and Sufi, 2019). Tough regulations on banks and the rest of the financial system have been introduced to stop such crises.

Within the model we have here, with its explicit flexprice solution, these two different approaches, which are often assumed to coincide, may be capable of giving quite different results. We examine the effects of monetary policy rules under both.

If we just consider output, it is plain that the output gap measures the difference between the 'natural rate' NC solution due to the supply elements permitted by market-clearing and actual output which can only differ due to NK price-setting. This in turn allows demand elements to affect output. We can think of the output gap as being caused by these demand elements. Monetary policy can stabilise by responding to these elements.

On the other hand if it is detrended output that needs to be stabilised, then monetary policy is responding to both supply and demand elements.

Notice that both approaches share the same negative effect of price distortions due to inflation on consumer surplus. Thus inflation under an NK model produces differential price relatives which reduce surplus.Under a pure NC model this effect will not occur; hence it is directly associated with an output gap.

How are we then to regard inflation under a pure NC model? The variance of inflation is much greater in an NC than in an NK world; there will be deflation as often as inflation. It is usual to regard this uncertainty surrounding the general price level as damaging to welfare because it reduces the information about relative prices contained in prices. There is now a signal extraction problem: how much is the price change 'pure inflation'? Unfortunately there is no agreed measure of welfare loss from this problem. We will therefore treat it qualitatively and assume that a priority claim on monetary policy is to create price stability.

The consequence of this assumption is that we are looking if possible for a monetary rule that incentivises price stability: which in turn leads to an NK world. This is a world that under either of our welfare approaches creates instability, whether of the output gap or simply of output. This is because demand shock elements now disrupt output, on top of any effect of supply shocks; it is true that supply elements are dampened on output by NK price-setting, but the effect of demand elements more than offsets this as we saw above in our comparison of output stability under NK and NC; output is far more unstable under NK than NC.

12 The central dilemma of monetary policy under the output gap welfare measure

On the one hand if monetary policy did not target inflation but allowed natural flexprice variability to occur, output would always be at flexprice levels, which are the 'natural rate' and so optimal. On the other hand if monetary policy targets inflation with the aim of achieving price stability, it will create an NK world in which output gaps would be generated by demand shocks. It is in such a world that policy should respond strongly to output gaps as well as prices- a nominal GDP target.

Because of the importance of minimising crises our NominalGDP target has been minimised relative to a loglinear trend, not a price trend and flexprice output. We now review whether it also succeeds in minimising the other welfare cost measures around flexprice outcomes that we have discussed,

13 Results under output gap welfare measure

In this section we investigate whether these different approaches make any serious difference to our policy results. If, as appears from our IRFs, it is demand elements that cause not only output gaps under NK circumstances but also overall output fluctuations, with supply elements under NK being naturally stabilised, then there should be little difference for our Nominal GDP targeting rule, either in exactly what output deviation it is targeted on or in the results for welfare in exactly how output fluctuations are measured.

Our rule that explicitly minimises crisis frequency also performs well on other welfare measures that are computed as deviations from the flexprice viewed as the optimum. On all measures, the rule improves substantially on all the other NK outcomes. This confirms that the rule is effectively stabilising the demand shocks to which the NK economy is prone. By definition the best outcome on this welfare criterion is the flexprice NC economy. However, this case, as we have seen, delivers very poor welfare on our main crisis-frequency measure.

	NK	Switching	NGDPT Switching
var(cons)	90.9373	15.8261	7.8206
var(hours)	12.4834	2.2328	0.6700
Welfare 1	103.4207	18.0589	8.4906
var(output)	132.5037	28.2989	14.3100
var(inflation)	3739.6468	3767.7703	3396.0805
Welfare 2	3872.1505	3796.0692	3410.3905

Table 7: Welfare Measures

We can see therefore that our suggested rule is robust to welfare measures that take flexprice outcomes as optimal. At the same time, if we were to take the NC flexprice case as optimal, we would be faced with extreme inflation instability and 40 crises per millenium, both of which seem unacceptable on other welfare grounds.

14 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 bfore 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 relative to a simple loglinear trend performs well according to a number of welfare criteria. Notably it 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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16 APPENDIX: all model IRFs

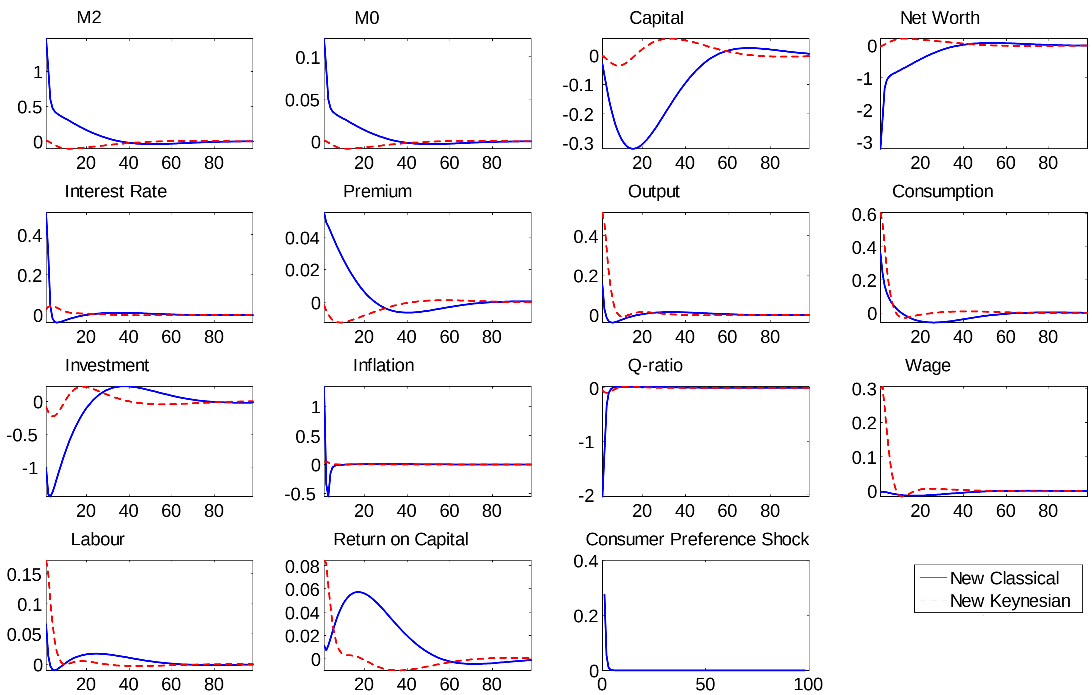

Figure 8: IRFs to a Consumer Preference Shock

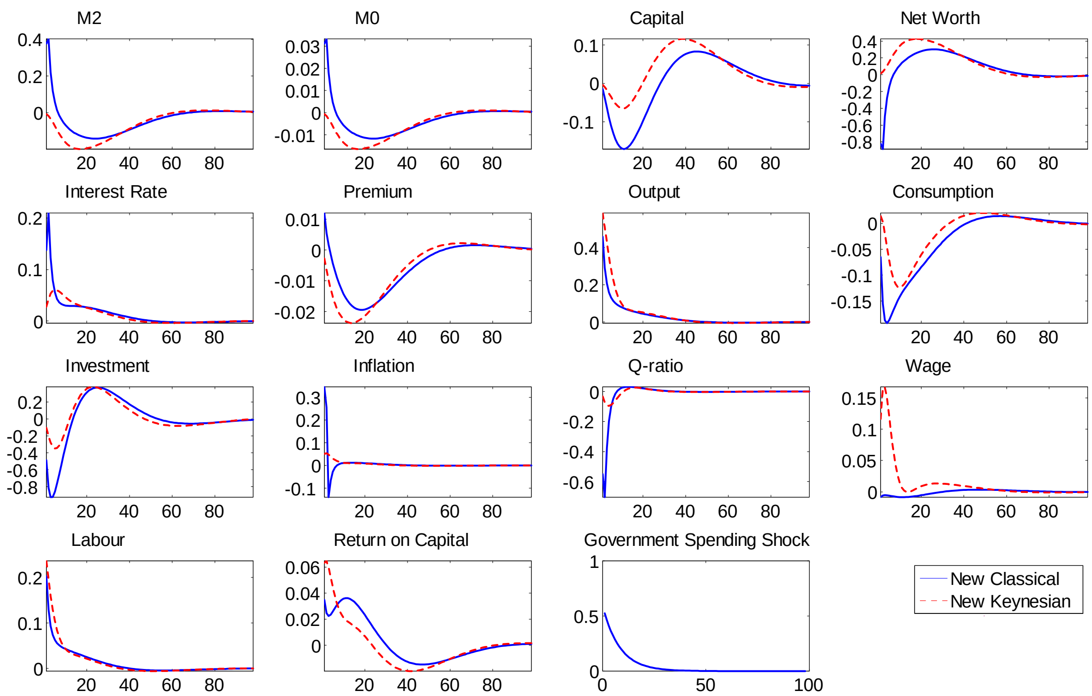

Figure 9: IRFs to a Government Spending Shock

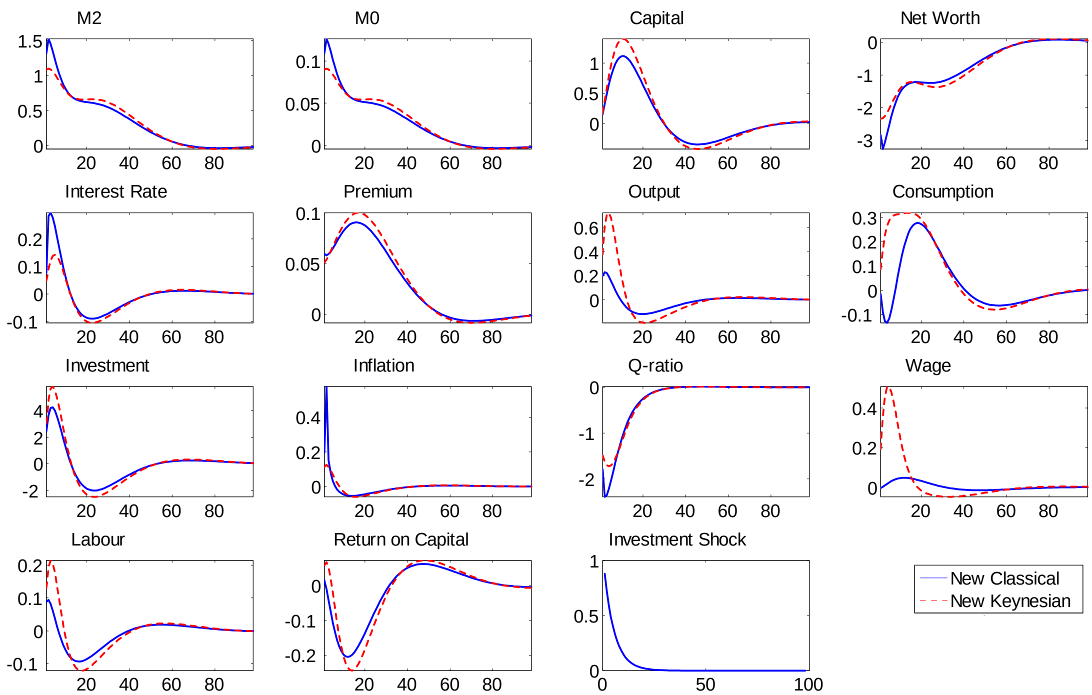

Figure 10: IRFs to an Investment Shock

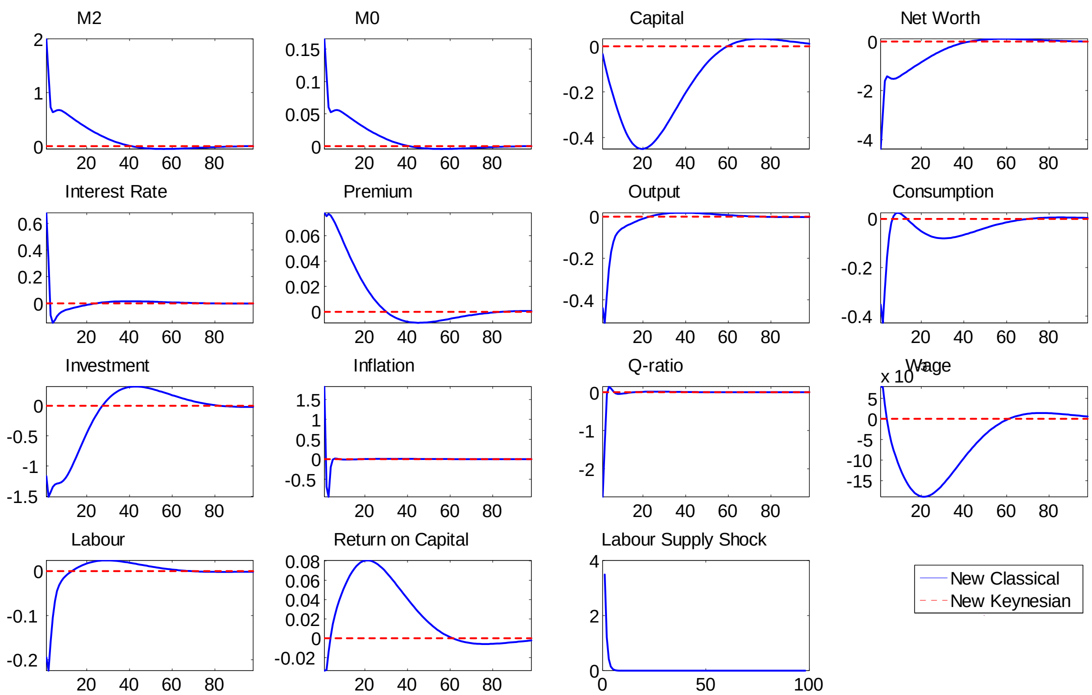

Figure 11: IRFs to a Labour Supply Shock

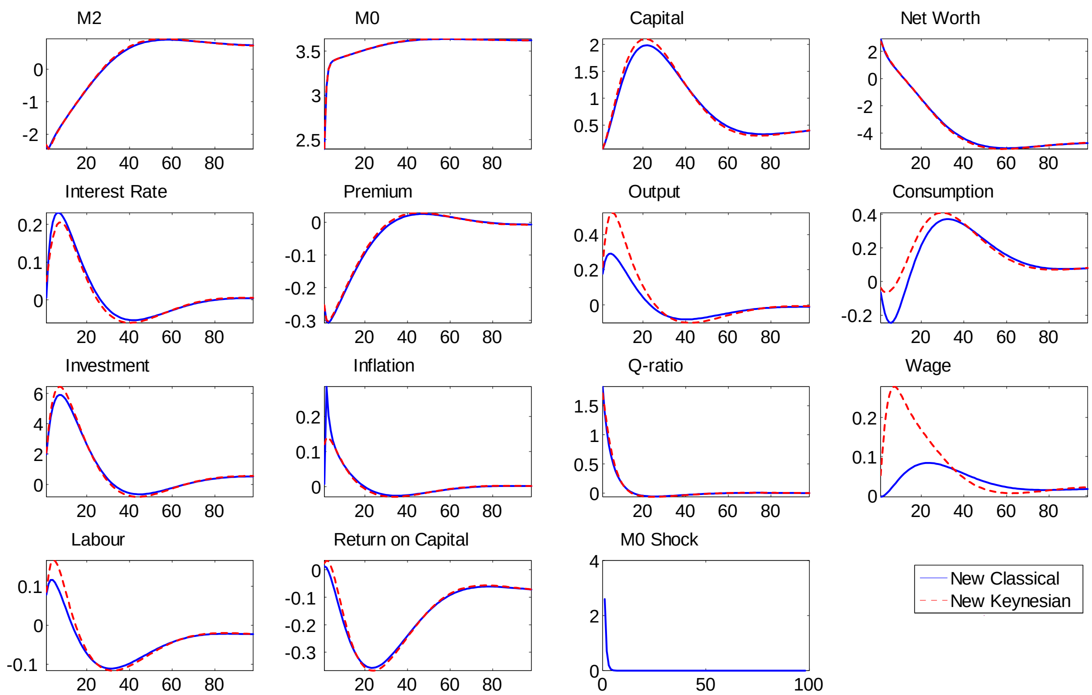

Figure 12: IRFs to a Money Supply Shock

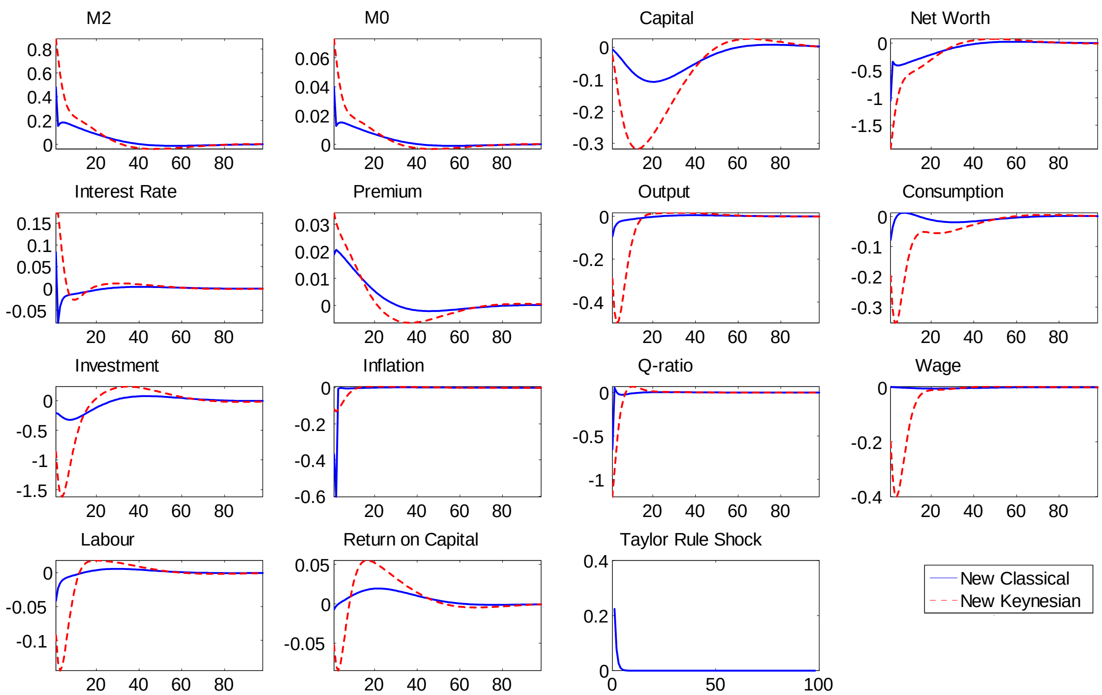

Figure 13: IRFs to a Taylor Rule Shock

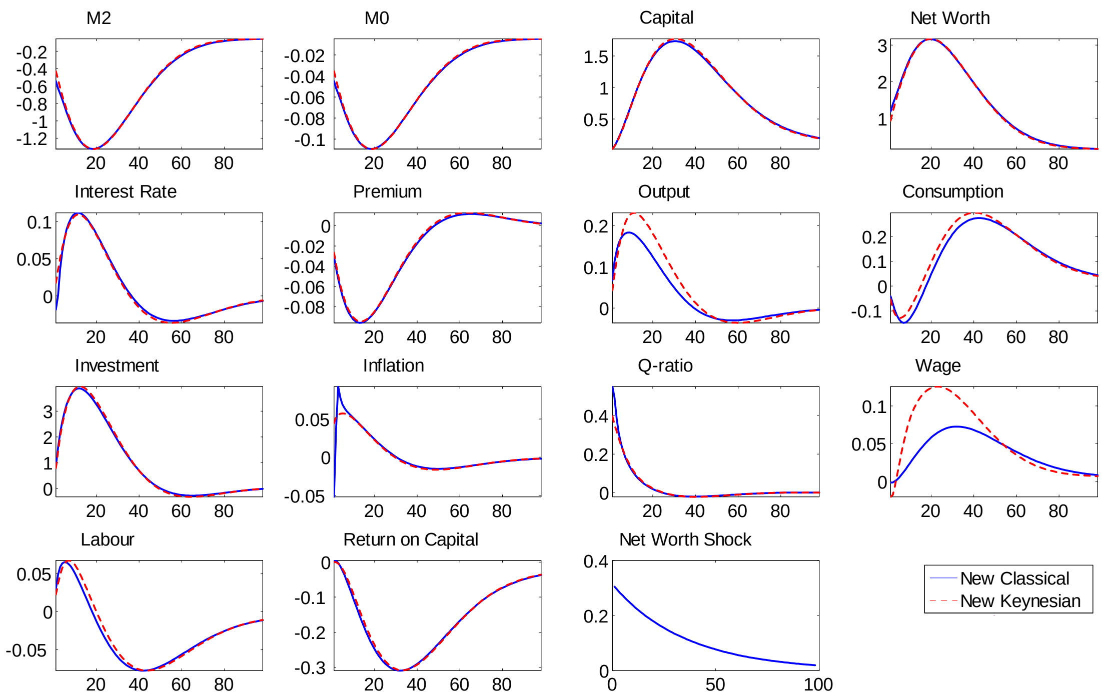

Figure 14: IRFs to a Net Worth Shock

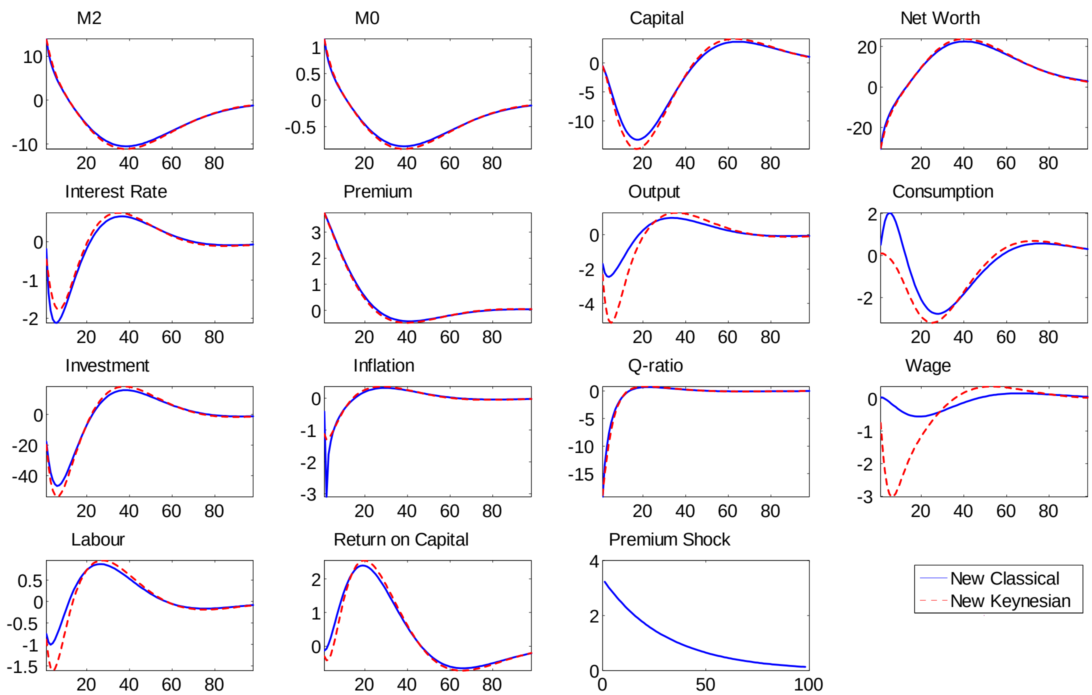

Figure 15: IRFs to a Premium Shock

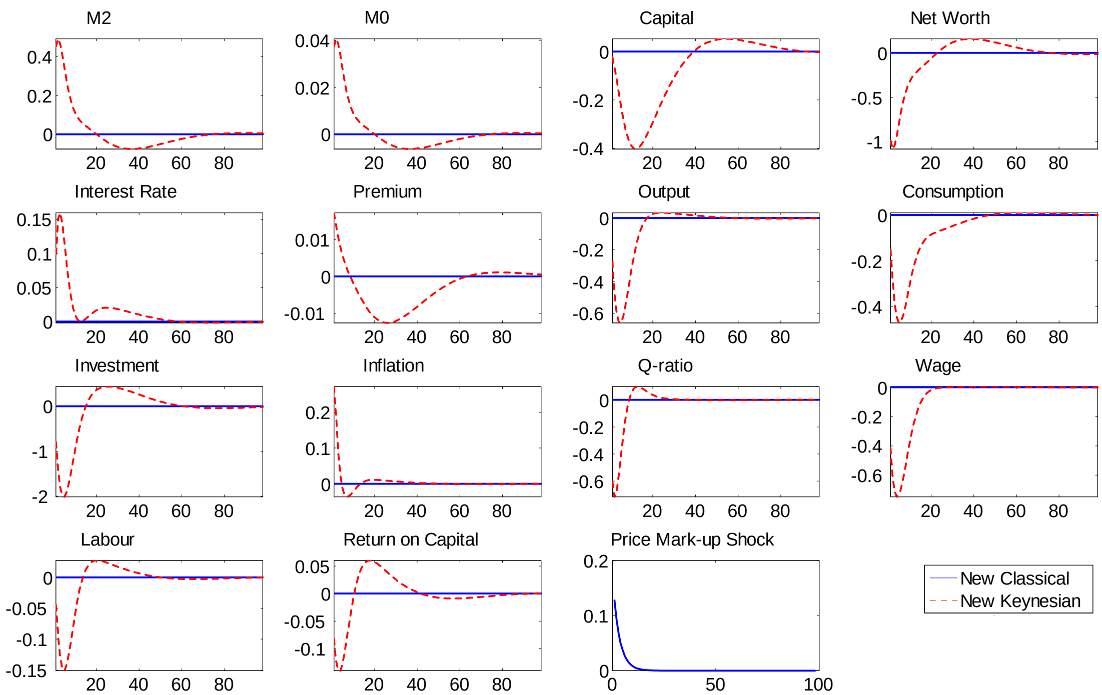

Figure 16: IRFs to a Price Mark-up Shock

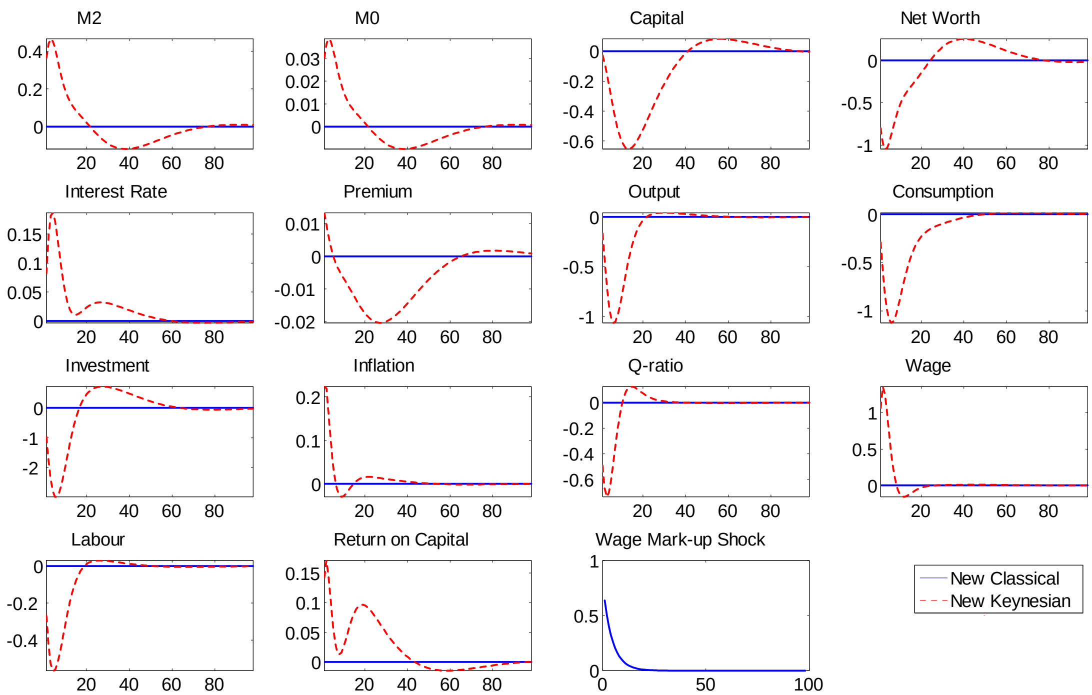

Figure 17: IRFs to a Wage Mark-up Shock

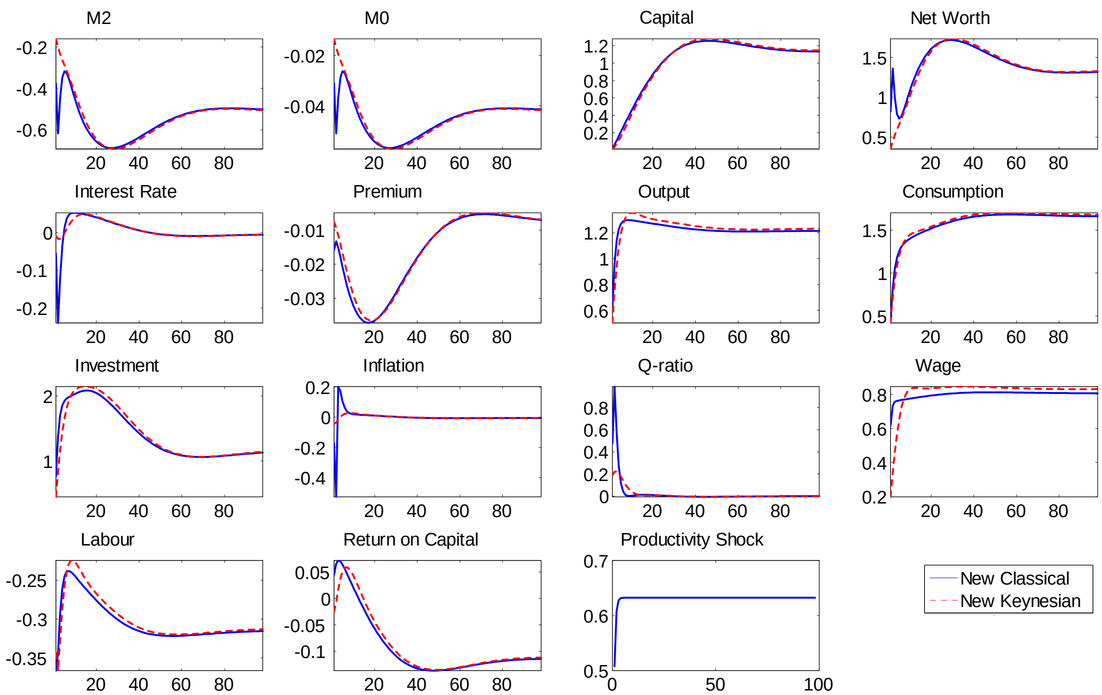

Figure 18: IRFs to a Nonstationary Productivity Shock