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NO 609 / APRIL 2006

THE ELUSIVE WELFARE ECONOMICS OF PRICE STABILITY AS A MONETARY POLICY OBJECTIVE

WHY NEW KEYNESIAN CENTRAL BANKERS SHOULD VALIDATE CORE INFLATION

by Willem H. Buiter

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by Willem H. Buiter [2]

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CONTENTS

Abstract 4
Non-technical summary 5
1. Introduction 7
2. A formal model of the benchmark economy 15
  2.1 The private sector 15
  2.2 The public sector 29
  2.3 Aggregation and equilibrium 31
3. Optimal monetary and tax policy 36
  3.1 Optimal monetary and tax policy with flexible prices 37
  3.2 Optimal monetary policy with Calvo contracts under unrestricted optimal fiscal policy 40
  3.3 Optimal monetary policy with restricted monetary and fiscal rules 44
  3.4 What indexation rule? 48
    3.4.1 Woodford's indexation rule 49
    3.4.2 Ad-hoc indexation rules that permit steady states with non-zero inflation rates 51
    3.4.3 Full current indexation 53
    3.4.4 Full current indexation as relative price contracting 54
4. Optimal monetary policy with a distorted natural level of output 56
5. Conclusion: Old Keynesian wine in New-Keynesian bottles 60
References 65
European Central Bank Working Paper Series 70

Abstract

The paper studies the inflation rate associated with optimal monetary and fiscal policy in a number of standard dynamic stochastic general equilibrium models with nominal price rigidities. While the focus is on Calvo-style nominal price contracts with a range of indexation rules for constrained price setters, the conclusions have much wider validity:

(1) Regardless of whether nominal price and/or wage rigidities are due to New-Keynesian, Old-Keynesian or sticky-information Phillips curves, optimal inflation policy requires the validation, that is, the full accommodation of core producer inflation by actual producer price inflation;(2) Optimal monetary policy implements Bailey-Friedman optimal quantity of money rule.

No welfare-economics based argument for price stability as an objective (let alone *the overriding objective*) of monetary policy can be established for the class of DSGE models with nominal rigidities for which they have been proposed by Woodford and others.

JEL Classification: E3, E4, E5, E6.

KEY Words: Inflation targeting; Nominal price rigidities; New Keynesian macroeconomics; DSGE.

Non-technical Summary

The paper asks whether there are conventional welfare economic arguments in support of targeting any rate of inflation, and in particular in support of price stability as an objective (or even the overriding objective) of monetary policy. The model used is representative of the New-Keynesian stochastic dynamical general equilibrium approach with optimising economic agents constrained by ad-hoc nominal price or wage rigidities along the lines of the Calvo model (as extended by Woodford), the sticky information model of Reis and Mankiw or indeed the Old-Keynesian Phillips curves.

For this class of models the paper characterises the optimal inflation rate, or more precisely, the inflation rate supported by optimal monetary and fiscal policy. The paper considers both unconstrained optimal fiscal policy (where production or consumption tax rates can respond to detailed microeconomic information) and constrained optimal fiscal policy, where these tax rates can respond only to aggregate information.

The key results are similar for both specifications of fiscal policy, and they do not provide any support for targeting any low, constant rate of inflation, let alone for the pursuit of price stability. Instead, the optimal rate of producer price inflation validates (confirms or fully accommodates) the core inflation process generated by constrained (ad-hoc) price setters - whatever that is. By validating core inflation (positive or negative, high or low, time-varying or constant) with actual inflation, the relative price distortions emphasized by Woodford as a key reason for pursuing price stability are avoided even when inflation is non-zero.

The optimal interest rate policy is given by the 'Optimal Quantity of Money' rule, that the financial opportunity cost of holding money must be equal to zero. If the nominal interest rate on currency can be set freely by the authorities, there is no unique consumer price inflation rate associated with the optimal monetary rule. By varying the risk-free nominal interest rate on bonds (while keeping it equal to the risk-free nominal interest rate on money), any sequence of consumer price inflation rates, positive or negative, can be supported by an optimal monetary policy. With an exogenously given zero nominal interest rate on currency, the consumer price inflation rate associated with the optimal monetary policy is the consumer price inflation rate supported by a zero risk-free nominal interest rate on bonds. In a deterministic steady state that would be a negative consumer price inflation rate equal to minus the rate of time preference.

The optimal rate of consumer price inflation implied by the Optimal Quantity of Money rule is made consistent with the optimal rate of producer price inflation implied by the core-inflation-validation rule through the appropriate choice of production or consumption tax/ subsidy rates.

The proposition that optimal producer price inflation accommodates core producer price inflation does depend on the assumption that there is no long-run (steady-state) inflation-output or inflation-employment trade-off. If there were to be (for reasons unknown to the author) a positive steady-state association between output and inflation, and if the natural output level (the level of output supported under full nominal flexibility) were to be below the socially optimal level of output, the optimal rate of inflation would, not surprisingly, tend to be higher than the rate that fully accommodates core inflation.

Woodford's arguments in support of the pursuit of price stability rely on two highly restrictive assumptions. First, core inflation is either zero or given by partial (lagged) indexation to the actual rate of inflation. Second, the analysis is restricted to a log-linear approximation at the zero inflation deterministic steady state - the only deterministic steady state rate of inflation supported by Woodford's implausible core inflation specification.

The key results of this paper, that optimal monetary policy should implement the Optimal Quantity of Money rule and that optimal producer price inflation validates core producer price inflation, are not robust to two important extensions. The first is the introduction of constraints on the ability of the authorities to impose lump-sum taxes or make lump-sum transfers. With such constraints, seigniorage revenues, that is, the real resources appropriated by the authorities through the issuance of base money, can become a valuable source of revenue for the authorities. When the interest rate on money is zero, this may raise the inflation rate associated with optimal monetary policy.

The second extension is menu costs, that is, the explicit consideration of the real resource costs associated with changing prices or renegotiating price contracts, as in the papers of Caplin and Spulber. The implications of menu costs for the optimal rate of inflation depend crucially on the details of how menu costs are modeled. If menu costs are assumed to be particularly important for the goods and services that make up the cost-of-living index, this would drive the optimal inflation rate of the cost of living index closer to zero. If, as seems more plausible, menu costs are especially important for money wages (negotiating and bargaining over wages, whether bilaterally or through organised labour unions and/or employers' associations is costly and time-consuming), a zero rate of money wage inflation would be a natural focal point of monetary policy. With positive labour productivity growth, zero wage inflation would imply a negative rate of inflation for the cost of living, consumer and producer price indices.

The paper does not argue that there are no valid arguments in favour of price stability (defined as zero inflation for some appropriate aggregate price or cost-of-living index) as an objective, or even the overriding objective, of monetary policy. What it does say is that in the popular class of models considered in this paper, price stability is not a property of optimal monetary policy if either the private price setters are capable of learning or the tax authorities are capable of implementing a simple feedback rule for the nominal interest rate and/or the indirect tax rate.

This paper demonstrates conclusively that the New-Keynesian approach it surveys does not contain the building blocks for welfare economic foundations of price stability as a target (let alone the overriding target) of monetary policy. The search for a welfare economic justification, grounded in solid microfoundations, for targeting price stability is back at square one.

1 Introduction

The pursuit of an inflation target as the overriding priority of monetary policy has become, alongside central bank operational independence, the defining attribute of a modern monetary authority in an open economy under a floating exchange rate regime.[1] The Reserve Bank of New Zealand led the way in 1989 and 1990.[2] The UK and Japan were early converts. The European Central Bank has an inflation target that dare not speak its name. Of the leading central banks only the Fed has not adopted inflation targeting and even there influential voices are arguing that it should do so.

The most common rationale for the adoption of an inflation target is that this represents a transparent and operationally simple way to pursue price stability. Given the (mainly upward) biases in the real-world price indices used to define the inflation target, a positive but low target rate of inflation can be seen as an observable, albeit imperfect, proxy for a zero rate of inflation of the unobservable true price index or ideal cost of living index.

Abstracting from measurement errors, what are the welfare economic arguments for price stability (defined as a zero rate of inflation going forward) as an objective, or even the overriding objective, of monetary policy? In a recent influential contribution to this topic, Woodford [58] has made a case for price stability as the appropriate inflation target, based on the optimisation of a utilitarian social welfare function in an economy with sluggish price adjustment.

A key result of this paper is the demonstration that Woodford's argument for targeting zero inflation is generically incorrect in the class of models he considers. I show that in a wide class of models, which includes all models considered by Woodford, monetary and

[1] See e.g. Mishkin [47], King [38], Svensson [55], and Svensson and Woodford [56] and the other papers contained in the volume edited by Bernanke and Woodford [6].

[2] The exact dating of the adoption of inflation targeting by the New Zealand authorities is difficult. According to the Assistant Governor of the Reserve Bank of New Zealand (Archer [?], footnote 3): "By mid 1989 announced policy included a specific target for inflation and a specific date for that target to be achieved, a target that the Reserve Bank was following. But it was not until early 1990 that the full formal paraphernalia of inflation targeting New Zealand style was in place."

fiscal policy are optimal if the following conditions are satisfied. First, the pecuniary opportunity cost of holding base money is zero - the Bailey-Friedman Optimal Quantity of Money rule. This ensures that shoe-leather costs are minimized and that there is no distortion in the relative price of cash goods and credit goods. Second, the cross-sectional distribution of relative prices, freely flexible or set by constrained price setters, is optimal. This requires that actual inflation validates, that is, confirms or fully accommodates 'core inflation', defined below. Third, the deterministic steady state level(s) of output (and employment) is (are) either efficient or independent of the steady-state rate of inflation (the long-run Phillips curve is vertical).

The class of models for which Woodford proposes that price stability is optimal are New-Keynesian dynamic stochastic general equilibrium models with Calvo-type nominal price contracts. In the Calvo model, opportunities to set prices optimally arrive randomly. Price setters that are not free to set their price optimally instead use a simple, ad-hoc indexation rule. The indexation rule adopted by the constrained price setters generates what I will call 'core inflation'. A central proposition of this paper is that in all Calvo-type models, relative price variability is optimal when the actual rate of producer price inflation equals the core producer price inflation rate generated by the constrained price setters. Optimal monetary and fiscal policies equate actual and core inflation. I refer to this as optimal inflation *validating* or *confirming* core inflation.[3] The same conclusion continues to apply when Calvo-style staggered overlapping nominal price contracts are superimposed on staggered overlapping nominal wage contracts, as in Benigno and Woodford [4] and [5]. Indeed, the proposition that optimal inflation validates core inflation is also applicable to the "sticky information" version of the Phillips curve proposed by Mankiw and Reis [45](see also [53] and [2]) and to other ad-hoc Phillips curve models with the long-run natural rate property.

Zero inflation is therefore optimal if and only if core inflation happens to be zero.

[3] The optimal inflation rate 'fully accommodates' core inflation would be another way of characterising the optimal rate of inflation.

This is always the case in the original Calvo [19] model, where constrained price setters are assumed to keep their nominal prices constant - zero indexation. This rather extreme assumption is also used in [4] and [5]. The other price indexation rules considered in Woodford [58], including full current indexation (with or without complete contemporaneous information), full one-period lagged indexation and partial one-period lagged indexation do not in general imply that zero producer price inflation is optimal. For instance, with partial one-period lagged indexation, zero inflation is, not surprisingly, optimal if the economic system starts from a steady state with zero actual and core inflation. This is the special case of the rule that 'optimal inflation validates core inflation' when core inflation is zero. Of course, for any non-zero initial rate of core inflation, optimal inflation would not be zero under the partial one-period lagged indexation rule.

Woodford's analysis does not uncover the general rule that optimal inflation validates core inflation because his approach compounds a number of unnecessary restrictive features. First, the analysis of his non-linear stochastic model focuses on the (log)linear approximation to this model evaluated at the zero inflation deterministic steady state. Second, under the partial lagged indexation rule, the only deterministic steady state inflation rate is zero. In addition, the target (optimal) rate of inflation is restricted to be constant. In combination these features conspire to obscure the general rule.

The general rule that optimal inflation validates core inflation of course cannot apply if core inflation and actual inflation cannot be brought into equality with one another other. Either the constrained price setters or the monetary and fiscal authorities (or both) can be the active party in the process of equating actual and core inflation. For this to fail, it must be the case both that private price setters never learn (that is, there is no learning taking place that drives core inflation closer to actual inflation and equates steady state actual inflation and core inflation), *and* that the policy authorities are unwilling or unable to use their monetary and fiscal instruments to drive actual and core inflation together.

The optimality of core inflation validation requires the economy to have the property that, across deterministic steady states, the actual level of real output does not depend on the rate of inflation. If instead the non-stochastic steady-state Phillips curve is non-vertical but has a positive association between inflation and real output (as it will in the original Calvo [19] model and in [4] and [5]), there is a conventional welfare-economics argument for a positive rate of inflation (or, more generally, a rate of inflation in excess of core inflation) if there are real distortions (e.g. monopoly power in the output market) that make the natural level of output smaller than the socially efficient level of output. This argument stands or falls with the plausibility of the long-run (in the strict sense of comparisons across deterministic steady states) non-vertical Phillips curve. Both on theoretical and empirical grounds, I reject a permanent inflation-output trade off that can be exploited by systematic and fully anticipated policies - indeed even across deterministic steady states. It is surprising indeed to see the roadkill of the Phelps [48][49][50][51]-Friedman [32]-Lucas [39][40][41][42] revolution of the late 1960s and early 1970s resurrected in the first decade of the 21st century.

The paper studies optimal monetary and fiscal policy and the inflation rate associated with optimal policy in a standard of New-Keynesian dynamic stochastic general equilibrium model. Optimal policy is derived from the optimisation of a utilitarian social welfare function by a benevolent government capable of credible commitment. Consumption, labour supply, production of market goods, price setting, portfolio choice and money demand are derived from the optimising choices of a (quasi-) representative infinite-lived household-producer in an endowment economy.[4] For simplicity, there is assumed to be a sufficiently rich set of financial markets to permit efficient risk-trading and, in equilibrium, complete risk sharing. There is Dixit-Stiglitz [25] monopolistically competitive price setting by producers of differentiated commodities. The paper considers Calvo-style staggered overlapping price contracts with a number of price indexation rules for the constrained price setters (see [19]), and includes full nominal price flexibility as a special case.[5]

[4] Quasi-representative, because individual endowments may differ and the tax rates faced by individual household-producers may differ.

[5] In an earlier and longer version of the paper, nominal prices set one period in advance are also

There are a few relatively minor differences between the model of this paper and the 'industry standard' found e.g. in Woodford [58], as well as two key differences. Cosmetic differences include the feature that the demand for money reflects both the 'credit goods - cash goods' variant of the cash-in-advance model and the Allais-Baumol-Tobin shoe-leather costs approach. Leisure does double duty as non-market good and credit good. It follows that there are two monetary distortions when the pecuniary opportunity cost of holding money is positive: shoe-leather costs are excessive and the relative price of cash goods to credit goods is too high. This emphasis on the role of money is intended as an antidote to some recent theoretical work that over-anticipates possible future technological and institutional developments leading to a cashless society, that is, a world without a unique, distinct, government-issued means of payment and medium of exchange (see e.g. Friedman [31], Freedman [30], Costa and deGrauwe [23], Goodhart [36], Hall [37] and Woodford [58]). This paper's maintained hypothesis is that the means-of-payment/medium of exchange role of money still matters, although the cashless economy (there monetary policy has become pure numérairology) is considered as a special case.

The key differences between the existing literature and the model of this paper are, first, the attention paid to the price indexation rule adopted by constrained price setters in the Calvo-style price setting model and, second, the careful modelling of the 'non-Keynesian' effects of fiscal policy - specifically the rules governing direct and indirect tax rates. Because the authorities are assumed to have unrestricted access to lump-sum taxes, there is Ricardian equivalence: holding constant the sequence of real public spending on goods and services, the growth rate of the nominal money stock and all non-lump-sum taxes, the timing of lump–sum taxation has no implications for either nominal or real equilibrium values. Real public spending is assumed to be exogenous.

The interesting fiscal instruments in this model are the non-lump-sum taxes and subsidies. Woodford [58] introduces a production tax/subsidy in his model to permit the

considered.

consideration of the case where the excess burden of monopoly power is eliminated by production or consumption subsidies and the deterministic steady state level of output is efficient. In the present paper, there are both commodity-specific proportional production taxes/subsidies and a uniform consumption tax/subsidy or final sales tax/subsidy. An immediate consequence of introducing a consumption tax is the need to distinguish between the market prices faced by consumers (and the associated aggregate consumer price index) and the prices set by producers (and the associated aggregate producer price index or factor cost price index). Calvo-style nominal rigidities are associated with the prices set by producers. The consumption tax (the only *indirect* tax in our model), drives a wedge between consumer prices and producer prices. In conjunction with commodity-specific production taxes (the distortionary *direct* taxes in our model) they can either, if the authorities are informed and flexible, completely undo the inefficiencies introduced by any Calvo-type price setting scheme and indexation rule, or, if the taxes are restricted to simple feedback rules, eliminate enough of these inefficiencies to ensure that the real equilibrium (relative prices, real output, real consumption, real interest rates) becomes invariant under alternative inflation rates of the consumer and producer price indices.

In the model of this paper, optimal monetary policy always implements the Bailey-Friedman Optimal Quantity of Money (OQM) rule: the pecuniary opportunity cost of holding money is set equal to zero (see Bailey [3] and Friedman [33]).[6] If the nominal interest rate on money can be set freely, the OQM rule does not pin down the risk-free nominal interest rate on bonds. The rate of inflation of consumer prices (and for constant indirect taxes) also for consumer prices, varies one-for-one with the common value assigned to the two risk-free nominal interest rates, but that common value itself can be anything. If the nominal interest rate on money is constrained to equal zero, the optimum rate of consumer price inflation is that associated with a zero risk-free nominal interest rate on bonds. In the familiar special case of a non-stochastic steady state,

[6] The optimality of the OQM rule holds also when prices are set one period in advance (see Buiter [12]).

the rate of consumer price inflation will then be equal to minus the pure rate of time preference.

The rate of producer price inflation depends, given the rate of consumer price inflation, on the behaviour over time of the consumption tax rate. If the nominal interest rate money is constrained to be zero, a zero nominal interest rate on bonds is required to support the OQM equilibrium. In this case the consumption tax rate can be dedicated to neutralising the effects on the real economy of any distortionary price indexation rule adopted by the constrained price setters. If the nominal interest rate on money can be set freely, the nominal interest rate on bonds can be used to pursue and achieve the optimal rate of inflation of consumer and producer prices, even with a constant indirect tax rate.

If the nominal interest rate on money can be chosen freely, the validation of the core producer price inflation rate by the actual producer inflation rate and the OQM rule can be achieved with a constant indirect tax rate (and therefore with consumer price inflation equal to producer price inflation), by using the nominal interest rate on bonds as the flexible (time- and state-contingent) instrument. If the nominal interest rate on money is constrained to be zero, the optimal producer price inflation policy can, through the flexible use of the indirect tax rate, be made consistent with the optimal consumer price inflation rate implied by the OQM rule when the interest rate on bonds is zero. Taking the 'microeconomic', relative price effects of production taxes and the consumption tax seriously and endowing the authorities with sufficient information, flexibility and sense to use these fiscal instruments effectively, therefore leads to conclusions that are radically different from those obtained by Woodford (see Woodford [58], especially Chapter 6).

Outside the cashless economy, zero inflation for the consumer price index *never* characterises optimal monetary policy when the nominal interest on money is constrained to be zero. Zero inflation for the producer price index only occurs for a set of parameter values of measure zero.[7]

[7]This holds also for the Calvo model with partial, lagged indexation for which Woodford establishes that, starting from a zero inflation steady state, a zero rate of inflation is optimal. Generically, the optimal rate of producer price inflation in the Calvo model equals the core inflation rate - whatever

For a zero rate of consumer price inflation to be the *only* possible inflation rate under optimal monetary policy, each of the following conditions would have to hold:

(1) Either there is no money (the cashless economy case) or the nominal interest rate on money can be set freely to implement the OQM rule. This is practically unlikely unless the authorities can be convinced to implement Gesell's proposal for a carry tax on currency (see Gesell [34], Goodfriend [35] and Buiter and Panigirtzoglou [16], [17]) or Eisner's proposal for the introduction of a virtual currency (see Eisler [27], Einaudi [26], Davies [24] and Buiter [11]).

(2) The constrained price setters of the Calvo model implement an arbitrary price indexation rule that supports only a zero producer price inflation rate as a non-stochastic steady state. An example is Woodford's partial, one-period lagged indexation rule.

(3) The authorities target a *constant* rate of inflation. They do not use either the short risk-free nominal interest rate on bonds (if the nominal interest rate on money can be chosen freely) or their direct and indirect tax instruments (if the nominal interest rate on money is constrained to equal zero) to implement policies that make the real equilibrium inflation-neutral and the OQM rule optimal.

(4) The natural level of output is efficient.

If the first condition holds and the authorities use their tax instruments and the nominal interest rate on bonds optimally, a zero rate of consumer price inflation is consistent with optimal monetary policy, but so is any other rate of consumer price inflation, for any indexation rule.

This paper does not base the evaluation of the merits of alternative inflation targets in a non-linear stochastic dynamic model with Calvo-style price setting, on a log-linear approximation to that model at a deterministic steady state with a zero rate of inflation. The results are global.

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that happens to be. At a zero inflation determininstic steady state, Woodford's partial lagged price indexation rule has zero producer price inflation as the only *constant* optimal rate of producer price inflation. He misses the time- and state-contingent optimal producer price inflation process supported by his indexation rule.

The most important result for monetary policy makers is that, tor the New-Keynesian models considered by Woodford and in this paper, there are no robust welfare economic foundations of price stability as an objective of monetary policy. Instead, in New Keynesian models, optimal inflation policy validates (that is, accommodates or confirms) the core inflation rate generated by the constrained price setters' indexation rule. The welfare economic rationale for targeting price stability continues to be elusive.

2 A formal model of the benchmark economy

2.1 The Private Sector

There is a continuum of households on the unit interval. Each household acts as a consumer, shopper, portfolio investor, money manager, worker-producer-supplier and price setter.[8] Household j, $j \in [0,1]$ maximizes at $t = 0, 1, 2, ...$ the utility function given in (1).[9] The expectation operator conditional on information available at time t is E_t, C_t^j is household $j's$ consumption of the composite market good in period t and ℓ_t^j is household $j's$, consumption of non-traded leisure in period t. The information available to each agent is the same and can be summarised each period by a vector of state variables σ_t. The period sub-utility function for market consumption goods, u, is increasing, strictly concave, twice continuously differentiable and satisfies the Inada conditions. The period sub-utility function for leisure, v, is non-decreasing, concave and twice continuously dif-

[8] This 'yeoman farmer' approach in which households produce and supply goods directly, and in which only the potential labour time of household-producer j can be used in the production of consumption good variety j, can easily be extended to include separate households and firms and homogeneous or heterogeneous labour markets.

[9] When Calvo-type price contracts are considered, we should re-interpret the model as one in which there is a continuum of differentiated household-supplier *types* indexed by j, $j \in [0,1]$ and a continuum of identical household-suppliers of each type indexed by l^j, $l^j \in [0,1]$.

ferentiable. It satisfies an Inada condition.

$$E_t U_t^j \equiv u(C_t^j) + v(\ell_t^j) + \sum_{k=t+1}^{\infty} \beta^{k-t} E_t \left[u(C_k^j) + v(\ell_k^j) \right] \tag{1}$$

$$1 > \beta > 0; C^j, \ell^j \geq 0$$

$$u' > 0;\ u'' < 0; \lim_{C^j \searrow 0} u'(C^j) = +\infty; \lim_{C^j \nearrow \infty} u'(C^j) = 0;$$

$$v' > 0,\ v'' \leq 0;\ \lim_{\ell^j \searrow 0} v'(\ell^j) = +\infty$$

$$C^j = \left(\int_0^1 c^j(i)^{\frac{\eta-1}{\eta}} di \right)^{\frac{\eta}{\eta-1}},\ i \neq j \tag{2}$$

$$c^j(i) \geq 0; \eta > 1;$$

The composite consumption good is a Dixit-Stiglitz [25] CES composite commodity, defined in (2) with static elasticity of substitution $\eta > 1$. There is a continuum of different varieties of the consumer goods on the unit interval. Each type of household produces one variety. The amount of variety i consumed by household j in period t is $c_t^j(i)$. Each period, t, every household j is endowed with an amount $e_t^j > 0$ of non-tradable perishable 'potential labour time'. The household can transform this endowment one-for-one either into leisure, $\ell_t^j \geq 0$, output of the variety j market consumption good $y_t^j \geq 0$, or 'shoe-leather' inputs into cash management, $s_t^j \geq 0$, as shown in (7). Household j consumes all varieties except the j^{th} variety it produces itself.[10] Each household j acts competitively as a consumer, taking consumer prices $\tilde{p}(i)$, $i \in [0,1]$, $i \neq j$ as given. It sets its period-t producer price $p_t(j)$ as a monopolistic competitor and conjectures that the aggregate private and public demand for its product in period t depends, as shown in (8), on economy-wide real aggregate demand Y_t (defined below in equation (46)) and on the relative price of the consumption good it supplies, $\tilde{p}_t(j)$, and the composite consumer

[10] As long as the price of variety j is positive, we could, because of the continuum of varieties assumption, let household-producer j consume its own variety as well without changing any results. If the number of varieties and the number of household-producers were finite, this would not be the case.

good, $\tilde{P}_t$. It takes as given the general level of consumer prices $\tilde{P}_t$ and economy-wide real private consumption, C_t, public consumption, G_t, and output, Y_t, of the composite commodity.[11] The prices paid by consumers in period t include a proportional aggregate sales tax or consumption tax at the rate $\zeta_t > -1$, the only indirect tax in the model. In addition there are commodity-specific production taxes (subsidies if negative) at proportional rates $\theta_t(j) > -1$ in period t on good j, so producer j receives per unit of output sold: $p_t(j)[1+\theta_t(j)]^{-1}$, while the consumer pays :

$$\tilde{p}_t(j) = (1+\zeta_t)\, p_t(j). \tag{3}$$

The consumer price index $\tilde{P}$ and the producer price index P are defined in (4) and (5), respectively:

$$\tilde{P}_t = \left(\int_0^1 \tilde{p}_t(i)^{1-\eta} di\right)^{\frac{1}{1-\eta}}, \tag{4}$$

$$P_t = \left(\int_0^1 p_t(i)^{1-\eta} di\right)^{\frac{1}{1-\eta}}. \tag{5}$$

Since the sales tax rate is the same for all commodities,

$$\frac{\tilde{p}_t(i)}{\tilde{P}_t} = \frac{p_t(i)}{P_t}.$$

The inflation factor of the market price index or consumer price index between periods t_0 and t_1 , denoted $\tilde{\Pi}_{t_1,t_0}$ is

$$\tilde{\Pi}_{t_1,t_0} \equiv \frac{\tilde{P}_{t_1}}{\tilde{P}_{t_0}},$$

and the inflation factor of the price index at factor cost or producer price index between periods t_0 and t_1, denoted Π_{t_1,t_0}, is

[11] The conjectured demand function (8) will turn out to be the actual equilibrium demand function.

$$\Pi_{t_1,t_0} \equiv \frac{P_{t_1}}{P_{t_0}},$$

so

$$\tilde{\Pi}_{t_1,t_0} = \Pi_{t_1,t_0}\left(\frac{1+\zeta_{t_1}}{1+\zeta_{t_0}}\right). \tag{6}$$

We also have:

$$e_t^j \geq \ell_t^j + y_t^j + s_t^j, \tag{7}$$
$$\ell_t^j,\ y_t^j,\ s_t^j \geq 0$$

and

$$y_t^i = \left(\frac{p_t(i)}{P_t}\right)^{-\eta} Y_t = \left(\frac{p_t(i)}{P_t}\right)^{-\eta}(C_t + G_t) \tag{8}$$

Household j pays direct taxes and an indirect tax. Direct taxes are a lump-sum tax, T_t^j in nominal terms, and the proportional tax on the production of its market good. The indirect tax is the proportional sales tax on all consumer spending.

There is a complete set of time and state-contingent financial markets. There also is money (cash or currency), an unbacked, irredeemable and inconvertible liability of the government. The quantity held at the end of period t by household j is $M_t^j \geq 0$. A unit of currency held at the end of period t pays a risk-free amount $1 + i_{t+1,t}^m$ of currency in period $t+1$. A unit of currency serves as the numéraire in all price contracts. Households are subject to a cash-in-advance constraint on their purchases of market goods: a fraction $\alpha_t(j)$, $0 \leq \alpha_t(j) \leq 1$ of consumer goods purchased in period t by other households from household j must be paid in cash; the remainder is financed with 'trade credit'. The government is assumed not to be subject to a cash-in-advance constraint. Leisure is not traded; it has to be consumed by the owner of the endowment of potential leisure time. As regards the cash-in-advance constraint, leisure therefore plays a role equivalent to a credit good. The nominal value of household $j's$ portfolio of all non-monetary financial claims held at the end of period t is F_t^j.[12]

I adopt the Lucas [43], [44] version of the timing of transactions. The unit period, t, is partitioned into three distinct sub-periods, each of which contains one trading session. All realisations of random variables during period t are known to the households and the government before they take any period t actions. During the first sub-period, household j trades securities, pays taxes, obtains (extends) trade credit to finance the shares $1-\alpha_t(i),\ i \neq j$ of purchases $(1-\alpha_t(j)$ of sales) of market goods not financed with cash. Household j brings total nominal financial wealth (monetary and non-monetary) W_t^j to the first sub-period. During this securities trading session, trades that require cash-in-advance cannot be made.

Supplier j can economise on the amount of money he needs to carry over to the next period from the sale of his cash goods by expending real resources s_t^j. The shoe-leather technology possesses the property that for period t sales of $\tilde{p}_t(j)y_t^j$, household j has to accept $\alpha(s_t^j)\tilde{p}_t(j)(y_t^j - g_t^j)$ in cash yielding $1+i_{t+1,t}^m$, while $\tilde{p}_t(j)\left[\left(1-\alpha(s_t^j)\right)\left(y_t^j - g_t^j\right) + g_t^j\right]$ is paid for with credit instruments yielding $1+i_{t+1,t}$. I assume that α is twice continuously differentiable with $0 \leq \alpha \leq 1;\ \alpha(0) = 1;\ \alpha' \leq 0;\ \alpha'' \geq 0$. When $\alpha'(s_t^j) = 0,\ 0 \leq s_t^j \leq e_t^j$, then $\alpha \equiv 1$ and we have the pure cash-in-advance model with cash and credit goods (leisure) but without shoe-leather costs.[13]

The government announces its taxes, public spending, money issuance and debt issuance for period t at the beginning of the period, before the securities markets open, and pays interest and principal due on its outstanding stocks of debt instruments. In sub-period one, when the financial markets are open, each household acquires at least the money balances it needs to pay the cash component of period t's planned purchases of market goods.

[12]This does not include the one-period risk-free nominally denominated trade credit extended by producers or the one-period risk-free nominally denominated consumption loans taken out by households to finance the shares of their sales or purchases of consumption goods that are not subject to the cash-in-advance constraint.

[13]One interpretation of s_t^j is shopping time (see e.g. Brock [7], and McCallum and Goodfriend [46]), but the interpretation of s_t^j as representing the real resource cost of active cash management by the producer, that is, shoe-leather costs in the spirit of Allais, Baumol and Tobin seems more apt here.

Letting μ_t^j denote the money balances acquired by household j during the first trading sub-period, the cash-in-advance constraint for household $j's$ shopper is $\mu_t^j \geq \int_0^1 \alpha_t(i)\tilde{p}_t(i)c_t^j(i)di$. Household j treats $\alpha_t(i)$, $i \in [0,1]$, $i \neq j$ as given. As shown in (9), during the first trading sub-period of period t, total financial wealth, W_t^j, is allocated to non-monetary financial claims, F_t^j, money, μ_t^j, direct taxes, $T_t^j + \frac{\theta_t(j)}{1+\theta_t(j)}p_t(j)y_t^j$, and the financing of the non-cash component of its purchases of market goods, $\int_0^1 [1-\alpha_t(i)]\,\tilde{p}_t(i)c_t^j(i)di$, net of the non-cash component of its sales revenue: $-\tilde{p}_t(j)\left[[1-\alpha_t(j)]\left(y_t^j - g_t^j\right) + g_t^j\right]$, where $g_t^j \geq 0$ is the amount of good j purchased by the government.

$$\begin{aligned} W_t^j \quad &\geq \quad F_t^j + \mu_t^j + T_t^j + \frac{\theta_t(j)}{1+\theta_t(j)}p_t(j)y_t^j \\ &\quad + \int_0^1 [1-\alpha_t(i)]\,\tilde{p}_t(i)c_t^j(i)di - \tilde{p}_t(j)\left[[1-\alpha_t(j)]\left(y_t^j - g_t^j\right) + g_t^j\right]. \end{aligned} \tag{9}$$

In sub-period two, the financial markets are closed. Each household's shopper purchases consumption goods with the money acquired in sub-period one. The government has made its consumption purchases with credit in sub-period one. The supplier in each household j sells $\tilde{p}_t(j)y_t^j$, the part of its perishable period t endowment that it does not itself consume as leisure or use up as shoe leather costs, to the shoppers of the other households or to the government. It sets the factor cost price of good j and chooses its shoe-leather input to maximise its objective function (1).[14] It has paid a fraction $\frac{\theta_t(j)}{1+\theta_t(j)}$ of its period t revenues as production taxes to the government in the first sub-period. A fraction $\alpha_t(j)$ of its sales to other households is received in the form of cash balances.

Beginning-of-period total (monetary plus non-monetary) financial wealth in period t, W_t^j consists of the gross returns on the non-monetary financial portfolio purchased in

[14] If the production activities were uncoupled from the 'normal' household activities (consumption, saving and portfolio allocation and labour supply) by having firms as distinct economic entitities owned by the households, the same equilibrium will be supported in a complete markets setting if the firms maximise profits.

period $t-1$, A_t^j, plus the gross earnings on the money balances carried over from period $t-1$: $(1+i_{t,t-1}^m)M_{t-1}^j$. The end-of-period $t-1$ stock of money held by household j, M_{t-1}^j is the sum of the money received by the household j producer $\alpha_t(j)\tilde{p}_{t-1}(j)(y_{t-1}^j - g_{t-1}^j)$, plus the 'excess' money balances carried over from period $t-1$ by the household j shopper, $\mu_{t-1}^j - \int_0^1 \alpha_t(i)\tilde{p}_{t-1}(i)c_{t-1}^j(i)di$. Therefore,

$$W_t^j \equiv A_t^j + (1+i_{t,t-1}^m)M_{t-1}^j, \tag{10}$$

where

$$M_{t-1}^j = \alpha_{t-1}(j)\tilde{p}_{t-1}(j)(y_{t-1}^j - g_{t-1}^j) + \mu_{t-1}^j - \int_0^1 \alpha_{t-1}(i)\tilde{p}_{t-1}(i)c_{t-1}^j(i)di \tag{11}$$

The set containing all possible values of the state of the economy at time t, $t = 0, 1, 2, ...$ is denoted S. The state vector is assumed to evolve according to a Markov process with density $f(\sigma', \sigma)$ defined by.

$$\text{Prob}(\sigma_{t+1} \leq \sigma' | \sigma_t = \sigma) = \int_{-\infty}^{\sigma'} f(u,\sigma)du = F(\sigma', \sigma).$$

The initial state, σ_0, is assumed given and known to all private agents and the government at time $t=0$. Until further notice, the period-t state vector σ_t contains the following elements: (1) all potential sources of exogenous randomness in period t: household endowments, $\{e_t^j;\ j \in [0,1].\}$, real aggregate public spending, G_t and all tax rates, ζ_t and $\theta_t(j),\ j \in [0,1]$; (2) the value of household stocks of money and non-monetary financial claims carried over from period $t-1$, $\{(1+i_{t,t-1}^m)M_{t-1}^j \geq 0,\ A_t^j;\ j \in [0,1]\}$; and (3) the period t value of the stock of risk-free one-period nominal bonds issued in period $t-1$ by the government, $(1+i_{t,t-1})B_{t-1}$, where B_{t-1} is the nominal stock of one-period risk-free bonds issued by the government in period $t-1$. The $k-t$ - step-ahead transition function $f^{k-t}(\sigma_k, \sigma_t)$ is defined from the one-period ahead transition functions $f(\sigma', \sigma)$ using the recursion:

$$\begin{aligned} f^{k-t}(\sigma_k, \sigma_t) &= \int_{\sigma_k \in S} f(\sigma_k, \sigma_{k-1}) f^{k-t-1}(\sigma_{k-1}, \sigma_t) d\sigma_{k-1}, \;\; k > t \\ &= 1, \;\; k = t. \end{aligned}$$

A key requirement of equilibrium is that there be no arbitrage opportunities. In every period t, there exists a one-period ahead stochastic nominal discount factor or one-step-ahead pricing kernel $I(\sigma_{t+1}, \sigma_t)$, which has the property that, if in period t the economy is in state σ_t, the period-t price in terms of money of 1 unit of period $t+1$ money contingent on the event that σ_{t+1} belongs to the set $\Omega \subseteq S$ in period $t+1$, is given by:

$$E_{\sigma_{t+1} \in \Omega} I(\sigma_{t+1,} \sigma_t) = \int_{\sigma_{t+1} \in \Omega} I(\sigma_{t+1}, \sigma_t) f(\sigma_{t+1}, \sigma_t) d\sigma_{t+1}.$$

I will refer to $I(\sigma_{t+1}, \sigma_t)$ as the period t nominal one-period forward price of money - forward price of money for short. It follows that the price in period-t currency, if the period-t state is σ_t, of $Z(\sigma_{t+1})$ units of period $t+1$ money contingent on σ_{t+1} belonging to the set Ω in period $t+1$, is

$$E_{\sigma_{t+1} \in \Omega} \left[Z(\sigma_{t+1}) I(\sigma_{t+1,} \sigma_t) \right] = \int_{\sigma_{t+1} \in \Omega} Z(\sigma_{t+1}) I(\sigma_{t+1}, \sigma_t) f(\sigma_{t+1}, \sigma_t) d\sigma_{t+1}.$$

In particular, the price in period-t currency, if the period-t state is σ_t, of $\tilde{P}_{t+1}(\sigma_{t+1})$ units of money contingent on σ_{t+1} belonging to the set Ω in period $t+1$, is $\tilde{P}_{t+1} I(\sigma_{t+1}, \sigma_t)$. We can then define the period-t single-period stochastic real discount factor $\tilde{R}(\sigma_{t+1}, \sigma_t)$ - the period t real one-period forward price of the composite consumption good

$$\tilde{R}(\sigma_{t+1}, \sigma_t) \equiv I(\sigma_{t+1}, \sigma_t) \tilde{\Pi}_{t+1,t}.^{15} \tag{12}$$

[15] That is, the period t price in terms of the period t composite consumption good of a unit of the period $t+1$ consumption good.

In what follows, for any random variable X_{t+1} the notation $E_t X_{t+1}$ is used to define the expectation conditional on the entire state space, S, that is,

$E_t X_{t+1} \equiv \int_{\sigma_{t+1} \in S} X(\sigma_{t+1}) f(\sigma_{t+1}, \sigma_t) d\sigma_{t+1}$. Also, $I_{t+1,t} \equiv I(\sigma_{t+1},\sigma_t)$ and $\tilde{R}_{t+1,t} \equiv \tilde{R}(\sigma_{t+1}, \sigma_t)$. Multi-period stochastic nominal discount factors can be obtained recursively from the single period stochastic nominal discount factors as follows:

$$\begin{aligned} I_{t_1,t_0} &\equiv \prod_{k=t_0+1}^{t_1} I_{k,k-1}; \quad t_1 > t_0 \\ &\equiv 1 \qquad\qquad\qquad t_1 = t_0. \end{aligned} \tag{13}$$

Equation (13) and the law of iterated projections imply that (as long as the information set conditioning expectations at time $t' \geq t$ contains the information set conditioning expectations at the earlier time t)

$$E_{t_0}\left[I(t_1, t_0) E_{t_1} I(t_2, t_1)\right] = E_{t_0} I\left(t_2, t_0\right), \; t_2 \geq t_1 \geq t_0. \tag{14}$$

Multi-period stochastic real discount factors can be obtained recursively from the single period stochastic real discount factors as follows:

$$\begin{aligned} \tilde{R}_{t_1,t_0} &\equiv \prod_{k=t_0+1}^{t_1} \tilde{R}_{k,k-1}; \quad t_1 > t_0 \\ &\equiv 1 \qquad\qquad\qquad t_1 = t_0. \end{aligned} \tag{15}$$

Therefore:

$$E_{t_0}\left[\tilde{R}(t_1, t_0) E_{t_1} \tilde{R}(t_2, t_1)\right] = E_{t_0} \tilde{R}\left(t_2, t_0\right), \; t_2 \geq t_1 \geq t_0. \tag{16}$$

Let $A^j_{t+1} = A^j(\sigma_{t+1})$ be the net amount purchased by household j at time t of the security paying one unit of money if the economy is in state σ_{t+1} at time $t+1$. The value, at time t, of the portfolio of non-monetary financial instruments held by household j, F^j_t is given by:

$$F_t^j = \int_{\sigma_{t+1}\in S} I_{t+1,t} A^j(\sigma_{t+1}) f(\sigma_{t+1}, \sigma_t) d\sigma_{t+1} = E_t \left(I_{t+1,t} A_{t+1}^j \right) \tag{17}$$

Two financial portfolios are of special interest. The first is a portfolio paying one unit of money in period $t+1$, regardless of which state of the world σ_{t+1} is realised (that is, $A^j(\sigma_{t+1}) = 1$ for all $\sigma_{t+1} \in S$). This defines the one-period risk-free nominal interest rate $i_{t,t+1}$:

$$\frac{1}{1+i_{t+1,t}} \equiv \int_{\sigma_{t+1}\in S} I_{t+1,t} f(\sigma_{t+1}, \sigma_t) d\sigma_{t+1} = E_t I_{t+1,t} \tag{18}$$

The second is a portfolio paying one unit of the composite consumption good in period $t+1$, that is, $A^j(\sigma_{t+1}) = \tilde{P}_{t+1}(\sigma_{t+1})$ units of money, in every state of the world σ_{t+1}. This defines the one-period risk-free real interest rate on non-monetary financial instruments, $\tilde{r}_{t,t+1}$:

$$\begin{aligned} \frac{1}{1+\tilde{r}_{t+1,t}} &\equiv \tilde{P}_t^{-1} \int_{\sigma_{t+1}\in S} I_{t+1,t} \tilde{P}_{t+1} f(\sigma_{t+1}, \sigma_t) d\sigma_{t+1} \\ &= \tilde{P}_t^{-1} E_t \left(I_{t+1,t} \tilde{P}_{t+1} \right) = E_t \left(I_{t+1,t} \tilde{\Pi}_{t+1,t} \right). \end{aligned} \tag{19}$$

If (9) holds with equality (as it will when the household chooses an optimal programme), (9) and (10) can be combined to yield:

$$\begin{aligned} E_t \left(I_{t+1,t} W_{t+1}^j \right) &\equiv W_t^j + p_t(j)[1+\theta_t(j)]^{-1} y_t^j - T_t^j - \int_0^1 \tilde{p}_t(i) c_t^j(i) di \\ &+ E_t \left[I_{t+1,t}(1+i_{t+1,t}^m) - 1 \right] \left(\alpha_t(j) \tilde{p}_t(j)(y_t^j - g_t^j) + \mu_t^j - \int_0^1 \alpha_t(i) \tilde{p}_t(i) c_t^j(i) di \right). \end{aligned} \tag{20}$$

Because of (18) and the assumption that the interest rate on money is risk-free, (20) can be written as:

$$E_t\left(I_{t+1,t}W_{t+1}^j\right) \equiv W_t^j + p_t(j)[1+\theta_t(j)]^{-1}y_t^j - T_t^j - \int_0^1 \tilde{p}_t(i)c_t^j(i)di \qquad (21)$$
$$-\lambda_{t+1,t}\left(\alpha_t(j)\tilde{p}_t(j)(y_t^j - g_t^j) + \mu_t^j - \int_0^1 \alpha_t(i)\tilde{p}_t(i)c_t^j(i)di\right).$$

where

$$\lambda_{t+1,t} \equiv \left(\frac{i_{t+1,t} - i_{t+1,t}^m}{1+i_{t+1,t}}\right).$$

The household solvency constraint is the no-Ponzi requirement that the expected present discounted value of its terminal net financial wealth be non-negative, that is

$$\lim_{k\to\infty} E_t I_{k,t} W_k^j \geq 0. \qquad (22)$$

Equations (21), (12), (14) and (22) imply the period t intertemporal budget constraint of household j :

$$\frac{W_t^j}{\tilde{P}_t} \geq E_t \sum_{k=t}^{\infty} \tilde{R}_{k,t} \left(\begin{array}{c} \int_0^1 \frac{p_k(i)}{P_k}c_k^j(i)di + \frac{T_k^j}{\tilde{P}_k} - \frac{p_k(j)}{P_k}\frac{1}{(1+\zeta_k)[1+\theta_k(j)]}y_k^j \\ +\lambda_{k+1,k}\left(\alpha_k(j)\frac{p_k(j)}{P_k}(y_k^j - g_k^j) + \frac{\mu_k^j}{\tilde{P}_k} - \int_0^1 \alpha_k(i)\frac{p_k(i)}{P_k}c_k^j(i)di\right) \end{array}\right) \qquad (23)$$

I assume that $i_{t,t+1} \geq i_{t,t+1}^m$ for all t. If not, the simplest possible arbitrage argument would show that infinite risk-free profits could be made by households borrowing at the rate $i_{t,t+1}$ and investing the proceeds in money earning a rate $i_{t,t+1}^m$.

In addition to the transactions role attributed to the monetary financial instrument, money is also assumed to be the numéraire. With fully flexible prices, the choice of numéraire has no implications for the behaviour of equilibrium real variables. When there are nominal rigidities in price setting, that is, rigidities of prices in terms of the numéraire, the (bold) assumptions that (1) the monetary authorities determine the numéraire; that (2) the monetary authorities have a monopoly of the supply of the financial instrument a unit of which serves as numéraire; and that (3) this financial instrument is irredeemable and that therefore the authorities can freely set the interest rate in terms of that numéraire, are of great significance for the real economy.[16]

Prices are set according to Calvo's overlapping staggered price setting model, as developed in Woodford [58]. Each period a randomly selected constant fraction $1-\varpi$, $0 < \varpi < 1$ of all household-suppliers has the opportunity to freely set the nominal price of their product. The optimal price set by the '*free*' suppliers in period t is denoted $\hat{p}_t(j)$. The remaining share ϖ of household-suppliers (the *'constrained'* suppliers) sets its price according to a simple indexation rule.[17] When $\varpi = 0$, the Calvo model reduces to the flexible price model.

The generic indexation rule for the nominal producer price of good j can be written as:

$$p_t(j) = p_{t-1}(j)\Omega^j_{t,t-1} \tag{24}$$

or, equivalently,

$$\frac{p_t(j)}{P_t} = \frac{p_{t-1}(j)}{P_{t-1}}\Pi_{t-1,t}\Omega^j_{t,t-1} \tag{25}$$

I will refer to $\Omega^j_{t,t-1}$ as household-producer $j's$ *core inflation* in period t. The only restrictions imposed on core producer price inflation, $\Omega^j_{t,t-1}$ are: (1) independence from individual characteristics (26a); (2) recursiveness (26b); (3) symmetry (26c); (4) a natural identity transformation (26d); (5) Positivity (26e); and (6) equality between core producer

[16]The more common set of assumptions is that (1) the numéraire for price and wage contracts happens to be the unit of the unique financial instrument that fulfills the means of payment/medium of exchange function (money) and (2) the state has the monopoly of the issuance of money and can fix the risk-free interest rate in terms of money. The assumptions in the main text create a role for 'monetary policy' or rather, nominal interest rate policy, also in an economy without a distinct monetary financial instrument - a 'cashless' economy, (see Woodford [58]).

[17]It is here that the interpretation, mentioned in footnote 2.1, of j as indexing household types, $j \in [0,1]$ and there being a continuum of identical household-suppliers indexed by l^j of each type j, with $l^j \in [0,1]$ is helpful in rationalising the expressions for the general price levels in equations (49) and (50) below. A randomly chosen fraction $1-\omega$ of households of each type j is able to set prices freely each period.

price inflation in the deterministic steady state, $\bar{\Omega}$, and actual producer price inflation in the deterministic steady-state, $\bar{\Pi}$ (26f):

$$\begin{aligned}
\Omega^j_{t_1,t_0} &= \Omega_{t_1,t_0} \quad j \in [0,1] && (26a)\\
\Omega_{t_2,t_1}\Omega_{t_1,t_0} &= \Omega_{t_2,t_0} && (26b)\\
\Omega_{t_1,t_0} &= \Omega^{-1}_{t_0,t_1} && (26c)\\
\Omega_{t,t} &= 1 && (26d)\\
\Omega_{t_1,t_0} &> 0. && (26e)\\
\bar{\Omega} &= \bar{\Pi} && (26f)
\end{aligned}$$

Assumption 26f is a very weak, minimal long-run consistency or 'eventual learning' assumption. Assumption (1) is for expositional simplicity only.

Under the indexation rule (24) the expected value, in period t, of the relative price set in period $t+1$ by household j is

$$E_t \frac{p_{t+1}(j)}{P_{t+1}} = \varpi \frac{p_t(j)}{P_t} \Pi_{t,t+1} E_t \Omega_{t+1,t} + (1-\varpi) E_t \frac{\hat{p}_{t+1}(j)}{P_{t+1}}$$

Therefore, when household-supplier j can freely choose its optimal price in period t, that is, when $p_t(j) = \hat{p}_t(j)$, the expected value of its relative price in period $k > t$ is:

$$E_t \frac{p_k(j)}{P_k} = \varpi^{k-t} \frac{\hat{p}_t(j)}{P_t} E_t \left(\Pi_{t,k}\Omega_{k,t}\right) + (1-\varpi) \sum_{n=t+1}^{k} \varpi^{k-n} E_t \left(\frac{\hat{p}_n(j)}{P_n} \Pi_{n,k} \Omega_{k,n} \right). \tag{27}$$

The optimisation problem for a household that can set its price freely in period t involves choosing $\hat{p}_t(j)$ allowing for the effect of this choice on future expected prices, as given by (27), and allowing for its monopoly power in period t and beyond. Current and future expected values of the general producer and consumer price levels and the monetary and fiscal policy instruments are taken as given.

When $p_t(j)$ can be set freely by supplier j in period t, the optimality conditions for household j's consumption, leisure, shoe-leather and pricing decisions are as follows for all $t \geq 0$:

$$c_t^j(i) = C_t^j \left(\frac{p_t(i)}{P_t}\right)^{-\eta} \ , \ i \in [0,1] \tag{28}$$

$$\begin{aligned} v'\left(\ell_t^j\right) &= -\alpha'(s_t^j)u'\left(C_t^j\right)\frac{p_t(j)}{P_t}(y_t^j - g_t^j) \text{ if } \alpha' < 0 \text{ and } i_{t+1,t} > i_{t+1,t}^m & \text{(29a)} \\ s_t^j &= 0, \ \alpha = 1 \text{ if } \alpha'(s_t^j) = 0 \ , \ 0 \leq s_t^j \leq e_t^j \text{ or if } i_{t+1,t} = i_{t+1,t}^m & \text{(29b)} \end{aligned}$$

$$\left(\frac{\hat{p}_t(j)}{P_t}\right)^{-(1+\eta)} \left\{v'\left(\ell_t^j\right) - u'\left(C_t^j\right)\frac{\hat{p}_t(j)}{P_t}\left(\frac{\eta-1}{\eta}\right)\left[\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} - \alpha(s_t^j)\lambda_{t+1,t}\frac{C_t}{Y_t}\right]\right\} \tag{30}$$

$$+\sum_{k=t+1}^{\infty}(\varpi\beta)^{k-t}E_t\left(\begin{array}{c} \frac{Y_k}{Y_t}\Pi_{t,k}\Omega_{k,t}\left(\frac{p_k(j)}{P_k}\right)^{-(1+\eta)} \\ \left\{v'\left(\ell_k^j\right) - u'\left(C_k^j\right)\frac{p_k(j)}{P_k}\left(\frac{\eta-1}{\eta}\right)\left[\frac{1}{(1+\zeta_t)[1+\theta_t(j)]} - \alpha(s_k^j)\lambda_{k+1,k}\frac{C_k}{Y_k}\right]\right\}\end{array}\right) = 0.$$

$$e_t^j = \ell_t^j + s_t^j + y_t^j \tag{31}$$

$$u'(C_{t+1}^j) = \beta^{-1}I_{t+1,t}\tilde{\Pi}_{t+1,t}u'(C_t^j) = \beta^{-1}\tilde{R}_{t+1,t}u'(C_t^j) \tag{32}$$

$$\begin{aligned} \mu_t^j &\geq \int_0^1 \alpha(s_t^i)\tilde{p}_t(i)c_t^j(i)di \\ &= \int_0^1 \alpha(s_t^i)\tilde{p}_t(i)c_t^j(i)di \text{ if } \ i_{t+1,t} > i_{t+1,t}^m \end{aligned} \tag{33}$$

The household solvency constraint and the Standard Transversality Condition imply that (22) holds with equality:[18]

$$\lim_{k\to\infty} E_t I_{k,t} W_k^j = 0 \tag{34}$$

The Euler equation (32) has to hold for all $t \geq 0$ and for all possible states at each date. From the one-period risk-free nominal interest rate definition (18) it then follows that :

$$1 + i_{t+1,t} = \frac{\beta^{-1} u'(C_t^j)}{E_t \left(u'(C_{t+1}^j) \tilde{\Pi}_{t,t+1} \right)} \tag{35}$$

Likewise, from the definition of the one-period risk-free real interest rate (19), it then follows that:

$$1 + \tilde{r}_{t+1,t} = \frac{\beta^{-1} u'(C_t^j)}{E_t u'(C_{t+1}^j)} \tag{36}$$

When there are no nominal price rigidities, that is, when $\varpi = 0$, we have $p_t(j) = \hat{p}_t(j)$ for all households, and equation (30) is replaced by the static optimality condition:

$$v'\left(\ell_t^j\right) = u'\left(C_t^j\right) \frac{p_t(j)}{P_t} \left(\frac{\eta - 1}{\eta}\right) \left[\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} - \alpha(s_t^j)\lambda_{t+1,t}\frac{C_t}{Y_t}\right]. \tag{37}$$

2.2 The public sector

In period t, the government spends $\tilde{P}_t G_t$ on consumption goods, levies lump-sum taxes $T_t = \int_0^1 T_t^j dj$, production taxes $\int_0^1 \frac{\theta_t(j)}{1+\theta_t(j)} p_j(t) y_t^j dj$ and sales tax $\zeta_t P_t Y_t$ and finances any budget deficit by issuing money or one-period risk-free nominal bonds. The aggregate stocks of money and nominal bonds outstanding at the end of period t are M_t and B_t respectively. The government period budget constraint is:

[18] The Standard Transversality Condition for the consumer's optimisation problem is $u'(C_t^j) \frac{\lim_{k\to\infty} E_t I_{k,t} W_k^j}{\tilde{P}_t} = 0$.

$$M_t + B_t \equiv (1+i^m_{t,t-1})M_t + (1+i_{t,t-1})B_{t-1} + \tilde{P}_t G_t - T_t - \int_0^1 \frac{\theta_t(j)}{1+\theta_t(j)} p_t(j) y_t^j dj - \zeta_t P_t Y_t. \quad (38)$$

Real aggregate public spending in terms of the composite commodity, G_t, is distributed across the individual public consumption goods, $g_t(i)$, $i \in [0,1]$ in the same manner as private consumption, that is,

$$g_t^j = G_t \left(\frac{p_t(j)}{P_t} \right)^{-\eta}$$

$$G = \left(\int_0^1 \left(g^i\right)^{\frac{\eta-1}{\eta}} di \right)^{\frac{\eta}{\eta-1}}.$$

$$e^i > g^i \geq 0$$

The government's solvency constraint requires the present discounted value of its terminal *non-monetary* debt to be non-positive, that is,

$$\lim_{k \to \infty} E_t I_{k,t}(1+i_{k,k-1})B_{k-1} \leq 0. \quad (39)$$

Equations (38) and (39)imply the government's intertemporal budget constraint:

$$(1+i_{t,t-1})B_{t-1} \leq \quad (40)$$

$$E_t \sum_{k=t}^{\infty} I_{k,t} \left[T_k + \int_0^1 p_k(j) \left(\frac{\theta_k(j)}{1+\theta_k(j)} \right) y_k^j dj + \zeta_k P_k Y_k - \tilde{P}_k G_k + M_k - (1+i^m_{k,k-1})M_{k-1} \right].$$

Aggregate real government spending G is exogenous and aggregate lump-sum taxes adjust endogenously to keep constant the real value of the stock of non-monetary public debt at its initial value $\tilde{b}_0$, that is,

$$\tilde{\tau}_t = \tilde{r}_{t+1,t}\tilde{b}_0 + G_t - \int_0^1 \left(\frac{\theta_t(j)}{1+\theta_t(j)}\right)\frac{p_t(j)}{(1+\zeta_t)P_t}y_t^j dj - \frac{\zeta_t}{1+\zeta_t}Y_t - \tilde{\vartheta}_t \tag{41}$$

where real taxes, $\tilde{\tau}$, real non-monetary debt $\tilde{b}$ and real seigniorage $\tilde{\vartheta}$, are defined, respectively, as $\tilde{\tau}_t \equiv T_t/\tilde{P}_t$; $\tilde{b}_0 \equiv B_0/\tilde{P}_0$ and $\tilde{\vartheta}_t \equiv \frac{M_t-(1+i^m_{t,t-1})M_{t-1}}{\tilde{P}_t}$.[19]

The optimal determination of the production tax rates $\theta_t(j)$, the sales tax rate ζ_t and the two short nominal interest rates $i_{t+1,t}$ and $i^m_{t+1,t}$ is deferred till Section 3. All policy instruments are treated as exogenous here, with $i_{t+1,t} \geq i^m_{t+1,t}$. Like G_t and the individual and aggregate lump-sum taxes, all monetary and fiscal policy instruments can, in principle, be state-contingent.[20]

The nominal money stock is endogenous when $i_{t+1,t} > i^m_{t+1,t}$. However, when $i_{t+1,t} = i^m_{t+1,t}$, the authorities can determine the path of the nominal money stock. In that case, I assume that the nominal money stock grows at a proportional rate less than the nominal interest rate on money. This ensures that the boundary condition implied by the household's 'standard transversality condition' (34) and the government's solvency constraint (40) and fiscal rule (41) can be satisfied when monetary policy implements the OQM rule:

$$\text{If } i_{t+1,t} = i^m_{t+1,t} \text{ then } M_{t+1} = (1+\nu)M_t;\ \nu < i^m_{t+1,t} \tag{42}$$

2.3 Aggregation and equilibrium

With identical tastes and complete financial markets for risk-trading, differences among individual household behaviour occur only because of differences in the present value of

[19] The fiscal rule (41) only determines *aggregate* lump-sum taxes. Lump-sum taxes on individuals T_t^j, $j \in [0,1]$ can be chosen by the policy authorities to achieve any distributional objectives they may have, subject only to the constraint that $\int_0^1 T_t^j dj = \tilde{P}_t\tilde{\tau}_t$. Any rule for aggregate lump-sum taxes that ensures that the government's intertemporal budget constraint is satisfied will support the same equilibrium, holding constant all distortionary tax rates, public spending and nominal interest rates.

[20] For instance, as regards the nominal interest rate, the authorities have the capacity, in period t and state σ_t, to set the period t price of a unit of money in any state σ_{t+1} in period $t+1$, that is, they can set $I_{t+1,t} \equiv I(\sigma_{t+1},\sigma_t)$ for each state σ_{t+1}, and not just the risk-free one-period nominal interest rate $E_t I_{t+1,t} \equiv (1+i_{t+1,t})^{-1}$.

lifetime resources and different realisations of the random endowment e_t^j. Leisure (a non-market good) is separable in the period utility function from the consumption of market goods. Shoe-leather inputs s_t^j are likewise 'effectively' separable from the consumption of market goods. Therefore, different realisations of e_t^j will not result in differences among households j in their consumption of individual market goods, i, $c_t^j(i),\ i \in [0,1]$ or in aggregate consumption of market goods, C_t^j , provided the present value of net lifetime resources, defined by the left-hand-side of equation (43), is the same for all agents.

$$W_t^j + E_t \sum_{k=t}^{\infty} I_{k,t} \left[p_k(j) \frac{1}{1+\theta_k(j)} y_k^j - T_k^j - \lambda_{k+1,k} M_k^j \right] = E_t \sum_{k=t}^{\infty} I_{k,t} \tilde{P}_k C_k^j \tag{43}$$

For aggregate consumption of market goods to be representable as the choice of a representative agent, it suffices to assume that the *initial* value of the financial endowment plus the present value of lump-sum taxes, $W_0^j + E_0 \sum_{k=0}^{\infty} I_{k,0} T_k^j$ of each agent offsets any differences in $E_0 \sum_{k=0}^{\infty} I_{k,0} \left[p_k(j) \frac{1}{1+\theta_k(j)} y_k^j - \lambda_{k+1,k} M_k^j \right]$. The left-hand-side of (43) will be the same for all agents in periods $t > 0$ if it is the same for $t = 0$.

Given these assumptions aggregate consumption of all goods, C_t is given by $\int_0^1 C_t^j dj = C_t = C_t^j,\ j \in [0,1]$. Aggregate consumption of good i is denoted $c_t(i)$, that is, $c_t(i) \equiv \int_0^1 c^j(i) dj$. The consumption of good $i,\ i \in [0,1]$ is the same for all consumers: $c_t^j(i) = c_t(i),\ j \in [0,1]$.

Equilibrium in the market for consumption good i is given by:

$$c_t(i) + g_t(i) = y_t(i). \tag{44}$$

Monetary equilibrium is given by:

$$\int_0^1 M_t^j dj = M_t. \tag{45}$$

Aggregate real GDP is given by:

$$Y_t \equiv \left(\int_0^1 \left(y_t^j\right)^{\frac{\eta-1}{\eta}} dj \right)^{\frac{\eta}{\eta-1}}. \tag{46}$$

The aggregate demand for consumption good i is given by:

$$y_t^j = Y_t \left(\frac{p_t(j)}{P_t} \right)^{-\eta}, \tag{47}$$

which confirms the conjecture of the monopolistic price setter for consumption good i in equation (8).

Equilibrium in the market for non-monetary financial claims is given by:

$$\int_0^1 F_t^j dj = B_t. \tag{48}$$

The aggregate producer price level is[21]

$$P_t \equiv \left(\int_0^1 p_t(j)^{1-\eta} dj \right)^{\frac{1}{1-\eta}} = \left((1-\varpi) \int_0^1 \hat{p}_t(j)^{1-\eta} dj + \varpi \left(\Omega_{t,t-1} P_{t-1} \right)^{1-\eta} \right)^{\frac{1}{1-\eta}}. \tag{49}$$

The general price level at market prices $\tilde{P}$ is given by:[22]

$$\tilde{P}_t \equiv \left(\int_0^1 \tilde{p}_t(j)^{1-\eta} dj \right)^{\frac{1}{1-\eta}} = \left(\int_0^1 \left\{ p_t(j) \left(1+\zeta_t\right) \right\}^{1-\eta} dj \right)^{\frac{1}{1-\eta}} = \left(1+\zeta_t\right) P_t \tag{50}$$

From equation (49), actual producer price inflation $\Pi_{t,t-1}$ is related to *core* producer price inflation $\Omega_{t,t-1}$ as follows:

[21] The selection of those who are free to set their period t price is random, and the probability that the price of any randomly selected good j will be freely adjustable rather than constrained by the indexing rule in any given period t is assumed to be equal to $1-\omega$.

[22] Because markets for risk-trading are complete and because the period utility function is separable in the consumption of market goods and leisure, an appropriate distribution of initial financial wealth (either by chance or through the appropriate use of lump-sum taxes) ensures that all households have the same consumption of market goods: $C_t^j = C_t$, even if different households have different endowment realisations. Different realisations of e_t^j will, however, be associated with different equilibrium values for $p_t(j)$ (and different values of ℓ_t^j).

$$\Pi_{t,t-1} = \left(\frac{\varpi}{1-(1-\varpi)\int_0^1 \left[\hat{p}_t(j)/P_t\right]^{1-\eta} dj} \right)^{\frac{1}{1-\eta}} \Omega_{t,t-1}. \tag{51}$$

Given exogenous $i_{t+1,t},\ i^m_{t+1,t},\ G_t,\ \zeta_t$ and $\theta_t(j)$, equilibrium is characterised by equations (52) to (65) which hold for all $t \geq 0$ and for $j, i \in [0,1]$:

$$\begin{aligned} \frac{M_t}{\tilde{P}_t} &\geq C_t \int_0^1 \alpha(s^i_t) di \\ &= C_t \int_0^1 \alpha(s^i_t) di \text{ if } i_{t+1,t} > i^m_{t+1,t} \end{aligned} \tag{52}$$

If $\varpi > 0$:

$$\left(\frac{\hat{p}_t(j)}{P_t}\right)^{-(1+\eta)} \left\{ v'\left(\ell^j_t\right) - u'\left(C_t\right) \frac{\hat{p}_t(j)}{P_t} \left(\frac{\eta-1}{\eta}\right) \left[\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} - \alpha(s^j_t)\lambda_{t+1,t}\frac{C_t}{Y_t}\right]\right\} \tag{53}$$

$$+ \sum_{k=t+1}^{\infty} (\varpi\beta)^{k-t} E_t \left(\begin{array}{c} \frac{Y_k}{Y_t}\Pi_{t,k}\Omega_{k,t}\left(\frac{p_k(j)}{P_k}\right)^{-(1+\eta)} \\ \left\{ v'\left(\ell^j_k\right) - u'\left(C_k\right)\frac{p_k(j)}{P_k}\left(\frac{\eta-1}{\eta}\right)\left[\frac{1}{(1+\zeta_t)[1+\theta_t(j)]} - \alpha(s^j_k)\lambda_{k+1,k}\frac{C_k}{Y_k}\right]\right\} \end{array} \right) = 0.$$

If $\varpi = 0$:

$$v'\left(\ell^j_t\right) = u'\left(C_t\right) \frac{p_t(j)}{P_t} \left(\frac{\eta-1}{\eta}\right) \left[\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} - \alpha(s^j_t)\lambda_{t+1,t}\frac{C_t}{Y_t}\right]. \tag{54}$$

$$v'\left(\ell^j_t\right) = -u'\left(C_t\right)\alpha'(s^j_t)\lambda_{t+1,t}C_t\left(\frac{p_t(j)}{P_t}\right)^{1-\eta} \text{ if } \alpha'\left(s^j_t\right) < 0 \ \&\ i_{t+1,t} > i^m_{t+1,t} \tag{55a}$$

$$s^j_t = 0,\ \alpha = 1 \text{ if } \alpha'(s^j_t) = 0\ ,\ 0 \leq s^j_t \leq e^j_t \text{ or if } i_{t+1,t} = i^m_{t+1,t} \tag{55b}$$

$$\lambda_{t+1,t} \equiv \frac{i_{t+1,t} - i^m_{t+1,t}}{1+i_{t+1,t}} \tag{56}$$

$$\ell_t^j = e_t^j - s_t^j - \left(\frac{p_t(j)}{P_t}\right)^{-\eta} Y_t \tag{57}$$

$$P_t \equiv \left(\int_0^1 p_t(j)^{1-\eta} dj\right)^{\frac{1}{1-\eta}} = \left((1-\varpi)\int_0^1 \hat{p}_t(j)^{1-\eta} dj + \varpi\left(\Omega_{t,t-1}P_{t-1}\right)^{1-\eta}\right)^{\frac{1}{1-\eta}}. \tag{58}$$

$$c_t^j(i) = \left(\frac{p_t(j)}{P_t}\right)^{-\eta} C_t \tag{59}$$

$$C_t + G_t = Y_t \tag{60}$$

$$u'(C_{t+1}) = \beta^{-1} I_{t+1,t}\tilde{\Pi}_{t+1,t} u'(C_t) \ = \beta^{-1}\tilde{R}_{t+1,t} u'(C_t) \tag{61}$$

Equation (61) implies the following Euler-equation based equilibrium conditions for the risk-free nominal and real interest rates:

$$1 + i_{t+1,t} = \frac{\beta^{-1} u'(C_t)}{E_t\left[u'(C_{t+1})\tilde{\Pi}_{t,t+1}\right]} \tag{62}$$

$$1 + \tilde{r}_{t+1,t} = \frac{\beta^{-1} u'(C_t)}{E_t u'(C_{t+1})} \tag{63}$$

$$\tilde{\Pi}_{t+1,t} = \left(\frac{1+\zeta_{t+1}}{1+\zeta_t}\right)\Pi_{t+1,t} = \left(\frac{1+\zeta_{t+1}}{1+\zeta_t}\right)\frac{P_{t+1}}{P_t} \tag{64}$$

$$\lim_{k\to\infty} E_t I_{k,t}\left(1 + i^m_{k,k-1}\right) M_{k-1} = \tilde{P}_t \lim_{k\to\infty} E_t \tilde{R}_{k,t}\left(1 + i^m_{k,k-1}\right)\frac{M_{k-1}}{\tilde{P}_{k-1}} = 0 \tag{65}$$

The boundary condition (65) is derived from equation (34), the financial market equilibrium condition (48) and the government's tax rule (41), provided the long-run expected real interest rate is positive, that is, provided $\lim_{k\to\infty} E_t \tilde{R}_{k-1,t} = 0$.[23]

Consider the behaviour of the economy starting from any period $t = 0$. Equations (52), to (64) determine for $t \geq 0$ and for $j, i \in [0,1]$, $M_t/\tilde{P}_t$, Y_t, C_t, $\tilde{\Pi}_{t+1,t}$, $\Pi_{t+1,t}$, $p_t(j)/P_t$, ℓ_t^j, $s_t^j, c_t^j(i)$. The boundary condition (65) places restrictions on the long-run behaviour of the real stock of money balances. These restrictions will rule out most deflationary bubble solutions and liquidity trap solutions except those, like the OQM equilibrium, where the nominal money stock goes to zero in the long run (see Buiter [10], [13] and Buiter and Sibert [18]).

With exogenous risk-free nominal interest rates (or with any rules for the two nominal interest rates that depend on real variables only) the model with full price flexibility ($\varpi = 0$) exhibits nominal indeterminacy: only real output, real consumption, leisure, shoe leather inputs, real interest rates, real money balances $M_t/\tilde{P}_t$, relative prices $p_t(j)/P_t$ and the inflation rates $\tilde{\Pi}_{t+1,t}$ and $\Pi_{t+1,t}$ are determinate. The nominal money stock, the general consumer and producer price levels and the nominal prices of the individual goods are indeterminate: there is no nominal anchor. When there are nominal rigidities ($\varpi > 0$), the period t general price level will depend on the predetermined value of the period $t-1$ general price level, unless $\Pi_{t,t-1} = \Omega_{t,t-1}$ (see equation (58)).

3 Optimal monetary and tax policy

A utilitarian government capable of credible precommitment maximises the sum of the utilities of all households, that is, it chooses $\{I_{t+1,t},\ i^m_{t+1,t},\ \theta_t(j),\ \zeta_t,\ T^j_t;\ j \in [0,1],\ t = 0,1,2,...\}$ to maximise (66) subject to the equilibrium conditions of the model, given in equations (52) to (65) and $\int_0^1 T_t^j dj = \tilde{P}_t \tau_t$.[24].

[23]Equations (34), (48) and (41) imply (defining $W_k \equiv \int_0^1 W_k^j dj$) that $\lim_{k\to\infty} E_t I_{k,t} W_k = \lim_{k\to\infty} E_t I_{k,t}\left[\left(1 + i^m_{k,k-1}\right) M_{k-1} + (1 + i_{k,k-1}) B_{k-1}\right] = 0$.

Because of the government's tax rule (41). $\lim_{k\to\infty} E_t I_{k,t} (1 + i_{k,k-1}) B_{k-1} = \tilde{P}_t \lim_{k\to\infty} E_t \tilde{R}_{k-1,t} \tilde{b}_{k-1} = \tilde{b}_0 \tilde{P}_t \lim_{k\to\infty} E_t \tilde{R}_{k-1,t}$. It follows that (65) has to hold in equilibrium whenever $\lim_{k\to\infty} E_t \tilde{R}_{k-1,t} = 0$.

[24]Because is sets $I_{t,t-1}$ for every state σ_t, it also sets $i_{t,t-1}$.

$$W_t = \int_0^1 E_t U_t^j dj \equiv u(C_t) + \int_0^1 v[\ell_t(j)]dj + \sum_{k=t+1}^{\infty} \beta^{k-t} E_t \left[u(C_k) + \int_0^1 v[\ell_k(j)]dj \right] \quad (66)$$

3.1 Optimal monetary and tax policy with flexible prices

Consider first the case of perfect price flexibility, with $\varpi = 0$ and with equation (54) instead of equation (30). Since the government has access to unrestricted lump-sum taxes, it just needs either the uniform consumption tax or a uniform production tax to implement a Pareto-efficient equilibrium. By setting the pecuniary opportunity cost of holding money equal to zero, it reduces to zero the real resources used up as shoe-leather costs. It can then use either of the two taxes (or both in combination) to eliminate the distortion that drives a wedge between the private opportunity cost of leisure and its social opportunity cost. The private marginal cost of leisure is below the social marginal cost for two reasons. First, sales of the consumption good are partly paid for in cash which earns the nominal risk-free interest rate on money, $i^m_{t+1,t}$, rather than the nominal risk-free interest rate on bonds, $i_{t+1,t}$. It follows that, if $i_{t+t,t} > i^m_{t+1,t}$, the implicit private opportunity cost of consumption goods produced for the market by the household is below the social marginal cost. This 'Austrian' distortion exists even in the pure cash goods and credit goods cash-in-advance model which does not have shoe-leather costs $(\alpha'(s^j_t) = 0\ ,\ 0 \leq s^j_t \leq e^j_t$, so $s^j_t = 0,\ \alpha = 1)$. Second, the household has monopoly power (if $\eta < \infty$) in the market for the consumption good it produces. The following two propositions can be verified by inspection of the equilibrium conditions (52) to (65):

Proposition 1 *In the model with perfect price flexibility ($\varpi = 0$) and an operative shoe-leather mechanism ($\alpha'(s^j_t) < 0$) , a Pareto-efficient equilibrium is supported by the following policies:*

$$i_{t+1,t} = i^m_{t+1,t}\ ,\ t \geq 0 \quad (67)$$

$$\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} = \frac{\eta}{\eta - 1},\ j \in [0,1],\ t \geq 0 \quad (68)$$

Proposition 2 *In the model of Proposition 1, there is 'superneutrality of money' or inflation neutrality: any sequence of consumer and producer price inflation rates can be optimal if the nominal interest rate on money can be chosen freely.*

Because the price elasticity of demand for each consumption good is the same and is also constant over time, the optimal subsidy rate is uniform across commodities and constant over time.

There is no optimal rate of inflation in the flexible price model; the optimal monetary and fiscal policies (those that support the command optimum) can be achieved with any sequence of inflation rates - not just with any constant rate of inflation - and with any level of the risk-free nominal interest rate on bonds. The Bailey-Friedman Optimal Quantity of Money (OQM) rule (67) requires a zero pecuniary opportunity cost of holding money. This is achieved by equating the short risk-free nominal interest rate on money and the short risk-free nominal interest rate on bonds. From equation (61), a unique equilibrium rate of consumer price inflation $\tilde{\Pi}_{t+1,t}$ is determined for each state, given any choice of $I_{t+1,t}$ with $(E_t I_{t+1,t})^{-1} = 1 + i_{t+1,t} = 1 + i^m_{t+1,t}$. Specifically, a unique optimal rate of inflation is defined when $i^m_{t+1,t} = 0$. This requires $i_{t+1,t} = 0$ to support the command optimum, so the inflation rate under the optimal policy is determined by equations (61) and (62) with $i_{t+1,t} = 0$.

Under the optimal monetary and fiscal policy, the labour market and shoe leather equilibrium conditions become

$$v'\left[e^j_t - Y_t\left(\frac{p_t(j)}{P_t}\right)^{-\eta}\right] = \frac{p_t(j)}{P_t}u'\left(Y_t - G_t\right)$$

and

$$s^j_t = 0.$$

It is clear that $C_{t+1} = Y_{t+1} - G_{t+1}$ depends only on the exogenous random variables e^j_{t+1} and G_{t+1}. Its value in any state σ_{t+1} is independent of $i_{t+1,t}$. Likewise, $C_t \equiv Y_t - G_t$

depends only on e_t^j and G_t. If then follows from (63) that the period t risk-free real interest rate, $\tilde{r}_{t+1,t}$ is independent of the period t risk-free nominal interest rate $i_{t+1,t}$. From (62) it then follows that the Fisher condition holds:

$$\frac{dE_t(\tilde{\Pi}_{t,t+1})}{d(1+i_{t+1,t})} = (1+\tilde{r}_{t+1,t})^{-1} \tag{69}$$

In fact, the consumer price inflation rate $\tilde{\Pi}_{t,t+1}$ in every state σ_{t+1} satisfies the Fisher condition for that state:

$$\frac{d\left[\tilde{\Pi}_{t,t+1}(\sigma_{t+1})\right]}{dI_{t+1,t}} = \tilde{R}_{t+1,t}^{-1}, \;\; \sigma_{t+1} \in S. \tag{70}$$

Proposition 3 *In the model with perfect price flexibility but without an operative shoe-leather mechanism ($\alpha'(s_t) = 0, \;\; 0 \leq s_t \leq e_t$, so $\alpha \equiv 1$ and $s_t = 0$), a Pareto-efficient equilibrium is supported by any values of the policy instruments $\zeta_t, \;\; \theta_t(j), \;\; i_{t+1,t}$ and $i_{t+1,t}^m$ that satisfy (71) and $i_{t+1,t} \geq i_{t+1,t}^m$:*

$$\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} - \left(\frac{i_{t+1,t} - i_{t+1,t}^m}{1+i_{t+1,t}}\right)\frac{C_t}{Y_t} = \frac{\eta}{\eta - 1} \tag{71}$$

It follows that in the pure 'cash goods and credit goods' cash-in-advance model, the command optimum can be implemented solely through the use of either the sales tax or the production tax (or by the two in combination), with the two short nominal interest rates i and i^m set at arbitrary levels, subject only to $i_{t+1,t} \geq i_{t+1,t}^m$. The opposite is not true: it is not possible to undo the effect of monopoly simply by using the two nominal interest rates. Since $i \geq i^m$, the lowest value of the opportunity cost for money balances is zero. While this eliminates the relative price distortion due to a positive opportunity cost of holding money, even maximal use of the two nominal interest rates cannot overcome the effect of monopoly power.

When prices are fully flexible, both the net effective subsidy and the interest rates supporting the first-best are constant over time, across states and (in the case of the net effective subsidy) also across commodities.

3.2 Optimal monetary policy with Calvo contracts under unrestricted optimal fiscal policy

If the authorities can freely set state-contingent and commodity-specific production tax rates and state-dependent aggregate consumption tax rates, the first-best, Pareto-efficient equilibrium can be supported when there are nominal price rigidities ($\varpi > 0$) - the same command optimum that is supported when prices are fully flexible ($\varpi = 0$). Calvo's staggered, overlapping price contracts are neutralised by commodity-specific production taxes that equate $p_k(j)$, the price charged by the j^{th} supplier in period k to $\hat{p}_k(j)$ - the price he would have charged had he been able to set his price freely in period k. To achieve the first-best, the production taxes and the consumption tax must also correct the monopoly distortion that is present even when prices are fully flexible. Either the risk-free nominal interest rate on bonds or the consumption tax rate can then be used to ensure that the relative prices faced by consumers are undistorted. Monetary policy implements the OQM rule. By inspection of the equilibrium conditions, including (30), the following proposition can be shown to hold:

Proposition 4 *With Calvo staggered, overlapping price contracts and for all indexation functions $\Omega_{t,t-1}$, the first-best, Pareto-efficient equilibrium can be supported with the OQM rule (67), fiscal policies satisfying (72) and (73) and nominal interest rate policy satisfying (74):*

$$\frac{1}{(1+\zeta_t)\,[1+\theta_t(j)]} = \left(\frac{\eta}{\eta-1}\right)\frac{\hat{p}_t(j)}{p_t(j)} \tag{72}$$

$$\frac{1+\zeta_{t-1}}{1+\zeta_t}\tilde{\Pi}_{t,t-1} \equiv \Pi_{t,t-1} = \Omega_{t,t-1}. \tag{73}$$

$$u'(C_{t+1}) = \beta^{-1} I_{t+1,t} \tilde{\Pi}_{t+1,t} u'(C_t) \tag{74}$$

For a household-supplier j free to set his price in period t, the tax rule (72) implies $\frac{1}{(1+\zeta_t)[1+\theta_t(j)]} = \frac{\eta}{\eta-1}$. Since $\frac{\eta}{1-\eta} < 1$, equation (72) determines the optimal net effective *subsidy* to the consumption or production of market goods whose price is unconstrained. For a constrained supplier in period t the tax rule implies $\frac{1}{(1+\zeta_t)[1+\theta_t(j)]} = \left(\frac{\eta}{\eta-1}\right) \frac{\hat{p}_t(j)}{P_t} \frac{P_{t-1}}{p_{t-1}(j)} \frac{\Pi_{t,t-1}}{\Omega_{t,t-1}}$.

Equation (73) specifies that the optimal rate of producer price inflation in every period and in each state equals the rate of core inflation generated by the indexation rule of the constrained price setters that period. I refer to this as the optimal producer price inflation rate *validating* (confirming or fully accommodating) the core rate of producer price inflation. The consumption tax rate ζ_t permits, if it is necessary, the uncoupling of the consumer and producer price inflation rates.

Given $I_{t+1,t}$, the rate of inflation of consumer prices in each state, $\tilde{\Pi}_{t,t-1}$, is determined from the consumption Euler equation (74). Under the optimal policies, all real variables, including aggregate consumption and the relative prices faced by producers, $\frac{1}{(1+\zeta_t)[1+\theta_t(j)]} \frac{p_t(j)}{P_t} = \left(\frac{\eta}{\eta-1}\right) \frac{\hat{p}_t(j)}{p_t(j)}$ and consumers, $\frac{p_t(j)}{P_t}$, are independent of the rates of inflation of consumer and producer prices. Because period t consumption will in general be a function of the period t state, σ_t, equation (74) or (61) determines for each state the rate of consumer price inflation, $\tilde{\Pi}_{t,t-1}$, which varies with the risk-free price of money for that state according to the Fisher condition (70).

The full range of commodity-specific and state-contingent production tax rates will in general be needed to implement (72), since $\hat{p}_t(j)$ depends on e_t^j and on the other elements of the state vector σ_t. The uniform (across commodities) sales tax is redundant for meeting the production efficiency conditions (72). The sales tax is therefore available, together with or instead of the state-specific prices of one-period-ahead money, $I_{t+1,t}$ (and therefore the risk-free nominal interest rate $i_{t+1,t} = (E_t I_{t+1,t})^{-1} - 1$), to eliminate any distortionary effects of the indexation rule (that is, of core inflation) on relative prices faced by consumers. Any combination of inflation policy and indexation rule that does not ensure $\Omega_{t,t-1} = \Pi_{t,t-1}$ distorts the relative prices faced by consumers. It is worth stating this as a separate proposition:

Proposition 5 *In the Calvo model, the (unconstrained) optimal rate of producer price inflation equals the core rate of producer price inflation in every state:*

$$\Pi_{t,t-1} = \Omega_{t,t-1}. \tag{75}$$

The optimal rate of producer price inflation can be achieved through either of two mechanisms. First, the adoption by constrained price setters of full, current indexation with complete contemporaneous information, that is, $p_t(j) = \Pi_{t,t-1}p_{t-1}(j)$ or $\Omega_{t,t-1} = \Pi_{t,t-1}$ for all constrained price setters j. In that case any sequence of producer price inflation rates can be optimal: there is no inertia in the core inflation process.

The second mechanism relies on specific combinations of nominal interest rate and consumption tax policies to support the first-best for *any* indexation rule of constrained price setters. For any indexation rule and associated core inflation process, including partial and/or lagged indexation or other arbitrary indexation rules, the authorities can use the state-specific one-period forward price of money $I_{t+1,t}$ and/or the indirect tax rate ζ_t to validate that core inflation process. Equations (73) and (74) characterise the sequences of indirect tax rates ζ_t, ζ_{t+1} and/or forward prices of money $I_{t+1,t}$ that support the optimum rate of producer price inflation. The optimal rate of producer price inflation, $\Pi_{t+1,t} = \Omega_{t+1,t}$ can, since $I_{t+1,t} = \tilde{\Pi}_{t,t+1}\beta u'(C_{t+1})/^{-1}u'(C_t) = \frac{1+\zeta_t}{1+\zeta_{t+1}}\Omega_{t,t+1}\beta u'(C_{t+1})/^{-1}u'(C_t)$, be achieved with any constant value of the indirect tax rate, $\zeta_t = \zeta$, by varying the forward price of money, $I_{t+1,t}$, over time and across states of nature, or with any constant value of the forward price of money, $I_{t+1,t} = I$, by varying the indirect tax rate ζ_t over time and across states of nature. Since period t consumption is state-dependent, the optimal period t indirect tax rate and/or the optimal forward price of money $I_{t+1,t}$ will depend on

σ_t. If the indexation rule is based on past aggregate information only, the optimal rate of producer price inflation in period t depends on past aggregate information only and is independent of σ_t. Since the rate of consumer price inflation that supports the OQM rule is, in general, state-dependent, either the indirect tax rate or the forward price of money will have to be state-dependent to support the first best. I summarise this discussion in two corollaries:

Corollary 6 *Under full current indexation with complete contemporaneous information, any producer price inflation sequence can be optimal.*

Corollary 7 *With an arbitrary indexation rule, the optimal rate of producer price inflation - the rate that validates the core inflation rate - will not be constant unless the arbitrary core inflation happens to be constant.*

When the nominal interest rate on money is constrained to be constant, say $i^M_{t+1,t} = 0$, the OQM rule requires that $i_{t+1,t} = 0$, and the first-best can be achieved only with time-varying tax rates, unless $1 = \frac{\beta^{-1}u'(C_t)}{E_t[u'(C_{t+1})\Omega_{t,t+1}]}$ for all t.[25]

With $i_{t+1,t} = i^m_{t+1,t}$ for all $t \geq 0$ we have $s^j_t = 0$ and $\alpha = 1$ for all $t \geq 0$ and for all $j \in [0,1]$. The price setting equilibrium condition (53) becomes

$$\left(\frac{\hat{p}_t(j)}{P_t}\right)^{-(1+\eta)}\left\{v'\left(\ell^j_t\right) - \frac{\hat{p}_t(j)}{P_t}u'\left(C_t\right)\right\} + \sum_{k=t+1}^{\infty}\left(\varpi\beta\right)^{k-t}E_t\left\{\frac{Y_k}{Y_t}\left(\frac{p_k(j)}{P_k}\right)^{-(1+\eta)}\left[v'\left(\ell^j_k\right) - \frac{\hat{p}_k(j)}{P_k}u'\left(C_k\right)\right]\right\} \tag{76}$$

This will be satisfied by $v'\left(\ell^j_t\right) - \frac{\hat{p}_t(j)}{P_t}u'\left(C_t\right) = 0$ for all $t \geq 0$ and for all $j \in [0,1]$. The OQM rule, the flexible commodity-specific production subsidy rule and the aggregate consumption tax rule together support the first-best equilibrium.

[25] Proposition 4 also holds if, rather unreasonably, the producer price indexation rule is a function of current, past and anticipated future rates of *consumer price* inflation only. Consider, e.g. the case where $\Omega_{t,t-1} = \tilde{\Pi}_{t,t-1}$. Equation (73) then implies that the optimal rates of producer and consumer price inflation are the same, that is, $\Pi_{t,t-1} = \tilde{\Pi}_{t,t-1}$, or $\zeta_t = \zeta_{t-1}$.

As with flexible prices there is no unique optimal inflation rate associated with the first-best equilibrium if the nominal interest rate on money can be chosen freely.[26] If the risk-free nominal interest rate on money is constrained to equal zero, the optimal consumer price inflation rate is that associated with a zero risk-free nominal interest rate on bonds. Unless there is full current indexation, the indirect tax rate will have to be assigned to achieving the optimal producer price inflation rate.

Under the unrestricted optimal tax policy (72), the real after-tax prices received by the suppliers satisfy:

$$\int_0^1 \left(\frac{p_t(j)}{P_t} \frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} \right)^{1-\eta} dj = \frac{\eta}{\eta-1} \left[\int_0^1 \left(\frac{\hat{p}_t(j)}{P_t} \right)^{1-\eta} dj \right]^{\frac{1}{1-\eta}} \tag{77}$$

Real consumer prices satisfy:

$$\int_0^1 \left(\frac{p_t(j)}{P_t} \right)^{1-\eta} dj = 1 = (1-\varpi) \int_0^1 \left(\frac{\hat{p}_t(j)}{P_t} \right)^{1-\eta} dj + \varpi \left(\Pi_{t-1,t} \Omega_{t,t-1} \right)^{1-\eta} dj \tag{78}$$

Given the optimal indirect tax rates policy given in (73), we have $\Pi_{t-1,t} = \Omega_{t,t-1}$ and

$$\int_0^1 \left(\frac{\hat{p}_t(j)}{P_t} \right)^{1-\eta} dj = 1. \tag{79}$$

The mean of the cross-sectional distribution of relative prices set by free price setters is therefore the same as in the model with fully flexible prices.

3.3 Optimal monetary policy with restricted monetary and fiscal rules

I now consider optimal monetary policy, and the inflation rates associated with it, when monetary and fiscal policy cannot make use of information on current or past prices and endowments of individual suppliers but is restricted to feedback from past aggregate

[26]The same holds true when prices are set one-period-in-advance (see Buiter [12]).

prices or quantities. With such restricted fiscal rules the terms

$$\Psi_t^j \equiv \left\{ v'\left(\ell_k^j\right) - u'\left(C_k\right) \frac{p_k(j)}{P_k} \left(\frac{\eta-1}{\eta}\right) \left[\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} - \alpha(s_k^j)\lambda_{k+1,k}\frac{C_k}{Y_k} \right] \right\}$$

in equation (30) will not, in general, all be equal to zero. However, the equilibrium values of the real variables $\frac{p_t(j)}{P_t}$, Y_t and C_t will be independent of the rates of inflation of consumer prices and producer prices, if there exist restricted fiscal rules that ensure that both the discount factors $(\varpi\beta)^{k-t} E_t \frac{Y_k}{Y_t} \Pi_{t,k} \Omega_{k,t} \left(\frac{p_k(j)}{P_k}\right)^{-(1+\eta)}$ and the Ψ_t^j terms do not depend on either rate of inflation. The reason such inflation-neutral equilibria are interesting is that, provided the deterministic steady state level of output is efficient, constrained-optimal equilibria must be inflation-neutral.[27] It is also easily shown that an inflation-neutral equilibrium that satisfies the OQM condition and the condition that the deterministic steady state level of output is efficient, is constrained-optimal.

I therefore consider first the details of a number of alternative indexation rules $\Omega_{k,t}$ and the arguments that support or detract from their plausibility, to determine whether the private price setting mechanism is itself 'producer-price-inflation-neutral' (given constant production and consumption tax rates and constant risk-free nominal interest rates). Second, I check whether there are simple monetary and fiscal feedback rules that can neutralise any inflation non-neutralities that may be present in the private price setting mechanism.

In what follows, I establish the two following propositions and offer arguments in support of the view that the long-run equilibrium distribution of relative prices ought not to depend on the indexation rule even for constant values of the nominal and fiscal policy instruments.

Proposition 8 *Regardless of the specification of the private indexation rule and the associated core inflation process, the authorities can always use either the indirect tax rate*

[27] Constrained-optimal equilibria are equilibria that are optimal given the constraint that fiscal and monetary instruments can only respond to aggregate variables.

ζ_t or the nominal interest rate on bonds $i_{t+1,t}$ according to the simple rules given by (73) and (62) or (61), to eliminate any influence of producer and consumer price inflation rates on the real equilibrium. The uniform production subsidy given in (80) addresses efficiency losses due to monopoly power.

$$\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} = \frac{\eta}{\eta-1} \text{ for all } j \tag{80}$$

Optimal monetary policy is then again defined by the OQM rule (67), even if the fiscal policy rules are not flexible enough to support the first-best equilibrium.

Proposition 9 *If the nominal interest rate on money is constrained to equal zero, the OQM rule requires $i_{t+1,t} = 0$ and the optimal rate of producer price inflation $\Pi_{t,t-1} = \Omega_{t,t-1}$ can, in general[28] only be achieved using a time-varying indirect tax rate. If the period t indexation rule depends on σ_t, the indirect tax rate also has to depend on σ_t.*

Under the fiscal rules (73) and (80),

$$\begin{aligned}\frac{p_t(j)}{P_t}\frac{1}{(1+\zeta_t)\left[1+\theta_t(j)\right]} &= \left(\frac{\eta}{\eta-1}\right)\frac{\hat{p}_t(j)}{P_t} \text{ for free price setters} &(81)\\ &= \left(\frac{\eta}{\eta-1}\right)\frac{p_{t-1}(j)}{P_{t-1}} \text{ for constrained price setters.} &(82)\end{aligned}$$

The fiscal rule (73) requires either that the constrained price setters always use the full current indexation rule with complete contemporaneous information ($\Omega_{t,t-1} \equiv \Pi_{t,t-1}$), or that the authorities know the private sector's indexation rule $\Omega_{t,t-1}$ and are able to observe the variables included in the private sector's indexation rule. It is not necessary for the authorities to know, when they make the credible announcement (in period t or earlier) of the tax rule (73) for period t, the values of all the variables (dated period t or earlier) required to *implement* the period t tax rule (that is, to send out the tax bill or

[28] Unless $1 = \frac{\beta^{-1}u'(C_t^j)}{E_t\left(u'(C_{t+1}^j)\Omega_{t,t+1}\right)}$ for all t

the subsidy refund). It is only necessary that the authorities have this information in period t *or at some later date*. Any payments from the private sector to the public sector (or vice versa) associated with the tax rule can be delayed until the required information (the realisations of the arguments in the rule) has become known to and verifiable by both parties involved in the tax or subsidy payment. As long as the present values of the payments do not depend on their timing (and they will not in the complete markets framework assumed here), the tax rules will have their intended effect even if the public sector were to observe aggregate variables later than the private sector - itself probably an unlikely scenario.

Under optimal monetary policy and constrained optimal fiscal policy, the free price setter's optimality condition is again given by (76). With constrained fiscal policy, however, this condition cannot be satisfied by achieving $v'\left(\ell_k^j\right) - u'\left(C_k\right)\frac{p_k(j)}{P_k} = 0$ for all $k \geq t \geq 0$. Instead, conditions (80) will, given the core inflation validation rule (73) and the OQM rule (67), achieve $v'\left(\ell_k^j\right) - u'\left(C_k\right)\frac{p_k(j)}{P_k} = 0$ 'on average'.

The after-tax real prices received by the producer satisfy

$$\frac{1}{(1+\zeta_t)}\left\{\int_0^1\left[\frac{p_t(j)}{P_t}\left(\frac{1}{1+\theta_t(j)}\right)\right]^{1-\eta}dj\right\}^{\frac{1}{1-\eta}} = \left(\frac{\eta}{\eta-1}\right)\left[(1-\varpi)\int_0^1\left(\frac{\hat{p}_t(j)}{P_t}\right)^{1-\eta}dj+\varpi\right]^{\frac{1}{1-\eta}}. \tag{83}$$

As before, real consumer prices (and real prices at factor cost) satisfy:

$$1 = (1-\varpi)\int_0^1\left(\frac{\hat{p}_t(j)}{P_t}\right)^{1-\eta}dj + \varpi\left(\Pi_{t-1,t}\Omega_{t,t-1}\right)^{1-\eta}dj$$

Given the interest rate policy (if $i_{t,t-1}^m$ can be set freely) and/or the indirect tax rate policy given in (73), we have $\Pi_{t-1,t} = \Omega_{t,t-1}$ and

$$1 = \int_0^1\left(\frac{\hat{p}_t(j)}{P_t}\right)^{1-\eta}dj \tag{84}$$

Equations (83) and (84) imply that

$$\frac{1}{(1+\zeta_t)}\left\{\int_0^1\left[\frac{p_t(j)}{P_t}\left(\frac{1}{1+\theta_t(j)}\right)\right]^{1-\eta}dj\right\}^{\frac{1}{1-\eta}}=\frac{\eta}{\eta-1}$$

$>$From (83) it is clear that the tax rule cannot achieve full productive efficiency, since a fraction ϖ of producers is locked into last period's relative prices. However, the mean of the distribution of the relative prices set by free price setters is the same as in the unconstrained optimal equilibrium.

Under this optimal monetary policy and constrained optimal fiscal policy combination, which can be implemented for *any* indexation rule, the rate of inflation of the consumer price index is again indeterminate if the nominal interest rate on money can be chosen freely, because in that case the common risk-free nominal interest rates on bonds and money can be chosen freely.

3.4 What indexation rule?

The indexation rules $\Omega_{k,t}$ considered in what follows (and indeed the entire Calvo-class of price setting models) are *ad-hoc*, in the sense of not being derived as decision rules of purposefully acting agents starting from acceptable primitive assumptions (tastes, technology, endowments, information, contract enforcement institutions). Nevertheless, certain restrictions on permissible indexation rules can reasonably be imposed. One way to 'stress test' an *ad-hoc* indexation rule is to evaluate its performance in very simple, well-understood environments. As this paper investigates which inflation target (not necessarily constant) would be justifiable on utilitarian welfare-economic grounds, the indexation rule should be able to support more than one constant rate of inflation (indeed a non-trivial range of inflation rates) in a deterministic steady state. In this deterministic steady-state benchmark, all sources of uncertainty, other than the random allocation of suppliers to the free and constrained groups, are abstracted from and government spending G_t , individual endowments e_t^j, the consumption tax rate ζ_t and output tax rates θ_t^j are constant.[29]

3.4.1 Woodford's indexation rule

The indexation rule proposed by Woodford [58], which plays a central role in his argument for price stability (zero inflation) as the appropriate target for monetary policy, is given in equation (85).[30] It applies to all suppliers that are not free to choose their optimal price $\hat{p}_t$:

$$p_t(j) = p_{t-1}(j)\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma}. \tag{85}$$

Using the notation of (24),

$$\Omega_{t,t-1} = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma} = \Pi^{\gamma}_{t-1,t-2}.$$

Under this indexation rule, the relative price of good j for constrained suppliers evolves according to:

$$\frac{p_t(j)}{P_t} = \frac{p_{t-1}(j)}{P_{t-1}}\Pi_{t-1,t}\Pi^{\gamma}_{t-1,t-2}$$

It is clear that this indexation rule (85), although it respects the 'homogeneity postulate', is a most unfortunate choice as the maintained hypothesis in an analysis of the welfare consequences of alternative inflation targets. Unless $\gamma = 1$ or $\Pi_{t,\,t-1} = \Pi^{\gamma}_{t-1,t-2}$, the rule (85) introduces an arbitrary source of permanent inflation non-neutrality into the price setting behaviour of firms. When $\gamma = 1$, $\frac{p_t(j)}{P_t} = \frac{p_{t-1}(j)}{P_{t-1}}\frac{\Pi_{t-1,t-2}}{\Pi_{t,t-1}}$ and the real equilibrium is invariant under alternative *constant* rates of inflation. When $0 \leq \gamma < 1$, under any constant non-zero rate of inflation, ever-widening relative price distortions result, mechanically, from the application of the indexation rule (85): (85) only satisfies (26f) when steady state producer price inflation is zero.

[29] This can easily be extended to steady states with a constant growth rate of the endowments and of GDP.

[30] Woodford's model has a uniform production subsidy that eliminates inefficiencies due to the existence of monopoly power.

Cross-sectional real commodity prices satisfy the following relationship under Woodford's indexation rule:

$$1 - \varpi \left(\Pi_{t-1,t}\Pi_{t-1,t-2}^{\gamma}\right)^{1-\eta} = (1-\varpi)\int_0^1 \left(\frac{\hat{p}_t(j)}{P_t}\right)^{1-\eta} dj. \tag{86}$$

If $\Pi_{t,t-1} = \Pi_{t-1,t-2}^{\gamma}$ (actual inflation validates the core inflation process), which includes as a special case the zero inflation case $\Pi_{t,t-1} = \Pi_{t-1,t-2} = 1$), then, under the Woodford indexation rule, the relative prices of those suppliers that are free to set their prices in period t satisfy $\int_0^1 \left(\frac{\hat{p}_t(j)}{P_t}\right)^{1-\eta} dj = 1$, which is a property shared by the equilibrium relative prices under full price flexibility. The prices set by the constrained price setters under the Woodford indexation rule would be $\frac{p_t(j)}{P_t} = \frac{p_{t-1}(j)}{P_{t-1}}$. However, if $\Pi_{t,t-1} \neq \Pi_{t-1,t-2}^{\gamma}$, a constant aggregate rate of factor cost inflation Π would imply:

$$\int_0^1 \left(\frac{\hat{p}_t(j)}{P_t}\right)^{1-\eta} dj = \frac{1-\varpi\Pi^{(\gamma-1)(1-\eta)}}{1-\varpi} \tag{87}$$

If the inflation rate is positive ($\Pi > 1$), then, since $\eta > 1$, $\int_0^1 \left(\frac{\hat{p}_t(j)}{P_t}\right)^{1-\eta} dj \lesseqqgtr 1$ if $\gamma \gtreqqless 1$. For instance, with a positive, constant rate of inflation and over-indexing ($\gamma > 1$), a constrained price setter's relative price will be rising over time for as long as he remains constrained. It will also be above-average cross-sectionally, forcing the relative prices of the free price setters to be below-average. If $\gamma < 1$, the price setter would be systematically and persistently 'under-indexed', with his relative price declining exponentially to zero for as long as he is not free to set his price.

The indexation rule (85) therefore ought to be rejected because it implies unreasonable, indeed irrational, behaviour by constrained price setters in simple, well-understood environments in which over-indexing or under-indexing cannot be rationalised with an appeal to signal extraction, risk sharing or impaired learning ability. Even the mildest version of the Lucas critique would imply that the indexation rule in (85) would not survive (unless $\gamma = 1$) if the firm that adopted it were operating in an environment with a constant but non-zero rate of inflation. If the firm stuck to the indexation rule, the firm would be unlikely to survive.

Of course, even when $\gamma \neq 1$, the implementation of simple policy rules for the nominal interest rate and/or the indirect tax rate (73) will make the price setting mechanism inflation-neutral. Under (73), it will always be the case that producer price inflation satisfies $\Pi_{t,\,t-1} = \Pi^{\gamma}_{t-1,t-2}$. Consumer price inflation is then given by $\tilde{\Pi}_{t,t-1} \equiv \frac{1+\zeta_t}{1+\zeta_{t-1}}\Pi^{\gamma}_{t-1,t-2}$. Thus, regardless of whether Woodford's indexation rule is dropped and replaced by something more sensible or kept and neutralised/validated by a simple indirect tax rule or nominal interest rate rule, price stability (of either the consumer price level or the producer price level) is neither necessary nor sufficient for monetary policy to be optimal. When the nominal interest rate on money is constrained to be zero, consumer price stability is inconsistent with optimal monetary policy, except in a cashless economy.

3.4.2 Ad-hoc indexation rules that permit steady states with non-zero inflation rates

Consider slight generalisation of Woodford's indexation rule given in equation (88):[31]

$$p_t(j) = p_{t-1}(j)\left(\frac{P_t}{P_{t-1}}\right)^{\delta}\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma}, \quad 0 \leq \delta, \gamma \leq 1. \tag{88}$$

or

$$\frac{p_t(j)}{P_t} = \Pi^{\delta-1}_{t,t-1}\Pi^{\gamma}_{t-1,t-2}$$

In terms of our generic indexation rule (24) this implies:

$$\Omega_{t,t-1} = \Pi^{\delta}_{t,t-1}\Pi^{\gamma}_{t-1,t-2}$$

[31] This can easily be generalised to an autoregressive-moving average process like $A(L)\pi_{t,t-1} = B(L)\Pi_{t,t-1}$ where $A(L)$ and $B(L)$ are polynominal distributed lag functions with $A(1)^{-1}B(1) = 1$.

This formulation includes as special cases both Calvo's original model, where a constant nominal price is maintained by the constrained suppliers ($\delta = \gamma = 0$) and Woodford's formulation ($\delta = 0$). As I am only interested in economic systems that can support, in the deterministic special case, steady states with more than one constant rate of inflation, I will concentrate on the case where $\delta = 1 - \gamma$.

The indexation rule given in (88) is also subject to the Lucas critique. Unless either the core inflation process is validated ($\Pi_{t,t-1} = (\Pi_{t-1,t-2})^{\frac{\gamma}{1-\delta}}$), or $\delta = 1$ and $\gamma = 0$, the relative price of good j, $p_t(j)/P_t$ will be subject to inefficient cross-sectional and time-series variation. Any constant aggregate rate of inflation would keep the relative price of good j constant. For instance, when $\delta = 1 - \gamma$, equation (88) can be written as $\frac{\pi_{t,t-1}(j)}{\Pi_{t,t-1}} = \left(\frac{\Pi_{t-1,t-2}}{\Pi_{t,t-1}}\right)^{\gamma}$. This implies a systematic and persistent decline in the relative price of constrained suppliers if the economy-wide rate of inflation were rising systematically and persistently, if $\gamma > 0$. The indexation rule (88) therefore only makes sense if there is no significant trend (positive or negative) in the rate of inflation.

A possible attractive generalisation of (88) would be along the lines of John Flemming's 'gearing hypothesis' (see Flemming [29]). Flemming's hypothesis, proposed as a theory of inflation expectation formation rather than as a theory of indexation rules, held that as long as the price *level* was stationary, a simple, ad-hoc forecasting rule (indexation rule for our purposes) relating the predicted price level to past realisations of the price level (subject to a homogeneity constraint) would be adopted. For indexation rules that only use aggregate information from the current and most recent past period, we would, when the aggregate price level is stationary, have a rule like:

$$p_t(j) = P_t^{1-\gamma} P_{t-1}^{\gamma}.$$

If a trend were to appear in the price level but not in the rate of inflation (if the price level were to become non-stationary but the rate of inflation remained stationary), forecasts would 'shift up a gear' (because learning takes place) and a forecasting rule relating the forecast of the inflation rate to the past behaviour of the inflation rate would be adopted. The indexation rule (88) is an example. If the inflation rate became non-stationary but the change in the rate of inflation remained stationary, the forecasting rule would again shift up a gear. The indexation rule would become:

$$\frac{\pi_{t,t-1}(j)}{\pi_{t-1,t-2}(j)} = \left(\frac{\Pi_{t,t-1}}{\Pi_{t-1,t-2}}\right)^{1-\gamma} \left(\frac{\Pi_{t-1,t-2}}{\Pi_{t-2,t-3}}\right)^{\gamma}$$

A statistical description of Flemming's gearing hypothesis as applied to indexation rules would be that the economy-wide inflation rate and the supplier's core inflation rate generated by the indexation rule are 'co-integrated'. The indexation rule (or the inflation expectation formation process), without meeting the full-fledged model-consistency requirement of the Lucas critique, does meet the less demanding, but possibly more relevant, requirement that it should not be 'off' by an order of integration or more.

With constant indirect tax rates, the indexation rule (88) makes the real equilibrium invariant to any constant inflation rate of producer prices if $\delta = 1 - \gamma$. It makes the real equilibrium invariant to any rate of inflation, constant or not, if in addition $\delta = 1$ - the case of full current indexation. Regardless of the values of γ and δ, implementation of the fiscal rule (73) and/or appropriate use of the nominal interest rate will make the real equilibrium invariant under alternative inflation rates, by validating core inflation: $\Pi_{t,t-1} = \Pi_{t-1,t-2}^{\frac{\gamma}{1-\delta}}$.

3.4.3 Full current indexation

As noted in Woodford [58], pp. 214-215, all inflation inertia vanishes (with constant values of all policy instruments) in Calvo-type models with full current indexation. This corresponds to the case $\delta = 1$ and $\gamma = 0$ in equation (88).

With zero production and consumption tax rates, there remain three distortions when monetary policy is exogenous: (1) monopoly power; (2) insufficient relative price flexibility, which prevents constrained suppliers from responding with their prices to idiosyncratic shocks to their endowments; (3) a non-zero opportunity cost of holding money balances (when $i > i^m$). Since the real equilibrium under full current indexation is independent of the rate of inflation, optimal monetary can be dedicated to implementing the OQM rule.

3.4.4 Full current indexation as relative price contracting

The fact that, in period t, the price instrument of supplier j is the price of good j in terms of period t money, $p_t(j)$, does not mean that supplier j is unaware that it is the *relative* price of good j, $p_t(j)/P_t$, rather than its *nominal* price, that determines the demand for his product . Nominal price setting, and the nominal inertia that may result from it are not money illusion. Since it is the relative price of good j that matters to supplier j , a price indexation rule for supplier j could be plausibly argued to be a *relative price contracting rule*, that is, a rule that is motivated by a desire to achieve an acceptable or reasonable value for this relative price during the periods that supplier j is not free to set the relative price of his product. As a simple example consider the relative price contracting rule given in (89), which mimics the nominal price indexation rule in (88):

$$\frac{p_t(j)}{P_t} = \frac{p_{t-1}(j)}{P_{t-1}} \left(\frac{p_t(j)/P_t}{p_{t-1}(j)/P_{t-1}} \right)^{\bar{\delta}} \left(\frac{p_{t-1}(j)/P_{t-1}}{p_{t-2}(j)/P_{t-2}} \right)^{\bar{\gamma}}. \tag{89}$$

It can be rewritten as a nominal price indexation rule:

$$p_t(j) = p_{t-1}(j)\Omega_{t,t-1}(j)$$

where

$$= \Pi_{t,t-1} \left(\frac{\pi_{t,t-1}(j)}{\Pi_{t,t-1}} \right)^{\bar{\delta}} \left(\frac{\pi_{t-1,t-2}(j)}{\Pi_{t-1,t-2}} \right)^{\bar{\gamma}}.$$

The full current indexation rule for the nominal producer price is the special case of this relative price contracting rule (89) when $\bar{\delta} = \bar{\gamma} = 0$. It can be contrasted with

Calvo's original specification in which a nominal price freely set in period t has to be kept constant until the next random opportunity for changing that price ($\delta = \gamma = 0$ in equation (88)) - a model of staggered overlapping nominal price setting similar in spirit and in many of its key properties to Taylor's model of staggered, overlapping two-period nominal wage contracts (Taylor [57]).

The natural interpretation of Calvo's nominal price setting model with full indexation ($\delta = 1,\ \gamma = 0$ in equation (88)) is that household j, when it is among the randomly selected households whose price contracts can be altered in period t, sets a constant *relative* price for good j in terms of the composite consumption good, to remain in effect until the next random opportunity for changing this relative price comes along. This relative price setting model is in the spirit of Buiter and Jewitt [14], and Buiter and Miller [15]. Buiter and Jewitt [14] extended Taylor's [57] analysis of staggered overlapping *nominal* wage contracts (motivated with a concern by workers for relative money wages) by developing and analysing a model of staggered overlapping *real* wage contracts (motivated with a concern by workers for relative real wages). Buiter and Miller [15] developed a continuous time version of a Calvo-type model in which new contracts fix (until the next random opportunity for re-contracting) not the nominal value of the contract price but the proportional rate of change of the nominal contract price.

An even closer approximation to the key properties of the Buiter and Jewitt and Buiter and Miller models would be to take the $\bar{\delta} = \bar{\gamma} = 0$ version of equation (89) and to lag the relative price benchmark one period: $\frac{p_t(j)}{P_{t-1}} = \frac{p_{t-1}(j)}{P_{t-2}}$. This can be written as a nominal price indexation rule with full but one-period-lagged indexation: $p_t(j) = p_{t-1}(j)\Pi_{t-1,t-2}$, which is also the special case of (88) with $\delta = 0$ and $\gamma = 1$. The resulting model, like the Buiter-Miller model and the 2-period version of the Buiter-Jewitt model, is in all relevant respects the same as the Calvo model with full one-period lagged indexation considered by Christiano et. al.[22], Smets and Wouters [54] and Woodford [58].[32]. They

[32] See also Buiter [8] for an open economy version of the Buiter-Miller inflation inertia model and Buiter [9] for an analysis of optimal disinflation policies and the case for gradualism in the Buiter-Miller Model.

generate inflation inertia and not just price level inertia when the commodity tax rates are constant.[33] The real equilibrium of these models is invariant under alternative *constant* rates of inflation.

The full current indexation rule assumes that the period t constrained price setters index fully to the realisation of the period t aggregate price level. A slightly weaker variant assumes indexation to the expected value of the current aggregate price level:

$$\Omega_{t,t-1} = E_{t-1}\Pi_{t,t-1} \tag{90}$$

With (90), alternative deterministic inflation sequences would be associated with identical values of the model's real equilibrium variables. Unanticipated inflation would have real effects, unless the authorities validate the core inflation process by using their interest rate and/or indirect tax instruments to achieve $\Pi_{t,t-1} = E_{t-1}\Pi_{t,t-1}$.

4 Optimal monetary policy with a distorted natural level of output

Finally, consider the case where the authorities don't have the fiscal nous or ability to undo the effects of monopoly power in the deterministic steady state through an appropriate subsidy. For the model under consideration, we represent this by the restriction that the

[33] As pointed out in Buiter and Jewitt [14], the price level equation generated by the N-period staggered overlapping relative money wage contract is an ARIMA(N-1, N-1) process, while the price level generated by the N-period staggered, overlapping relative real wage process is an ARIMA (2N-2, 2N-2) process. When N=2, this means that the relative money wage model has price level inertia (an ARIMA (1,1) process) but not inflation inertia, while the relative real wage model has inflation persistence (an ARIMA (2,2) process. Of course, the relative money wage process with N=3 also generates an ARIMA (2,2) process for the price level. Unless one knows N a-priori, there is an observationally equivalent relative money wage model for every relative wage model. For some reason, the empirical literature seems to be stuck on the N-2 case. With yearly contracts this may make sense if the unit period of analysis and measurement is a year. However, if the true length of the typical (US) wage contract is 2 years, but contracts are negotiated every quarter and the distribution of contract renewals is uniform over the year, then, taking the quarter to be the unit period, N=8. The relative money wage model would imply an ARIMA(7,7) for the general price level (using quarterly data) and the relative real wage money an ARIMA(12,12) process. Plenty of inflation persistence therefore from both models and, I would think, a difficult task of discriminating between them using, say, 160 or 200 quarterly observations.

combined net production and consumption tax/subsidy is zero, that is,

$$\frac{1}{(1+\zeta_t)\,[1+\theta_t(j)]} = 1 \text{ for all } t, j. \tag{91}$$

This does not preclude the indirect tax rate ζ_t from being used to drive any required wedge between the rate of consumer price inflation required by the OQM rule and the optimal rate of producer price inflation. Benigno and Woodford [4],[5] refer to this as the case of a distorted (deterministic) steady state. When monopoly power is not neutralised, the natural level of output $\bar{Y}_t$ (the level of output that would be produced under full price flexibility) is below the efficient level of output Y_t^*. When the deterministic steady state natural level of output is inefficient (in our case, too low), the inflation-neutral rate of producer price inflation (the rate that validates core inflation) does not in general equal the optimal rate of producer price inflation if a steady-state gap between the actual and core rates of producer price inflation can influence the steady-state level of output. The weak consistency assumption (26f) made in this paper, that even the most intellectually challenged dunderhead price setter would, in a deterministic steady state, align his indexation rule with the (forever constant) actual rate of inflation, precludes the possibility that, from the 'supply side' of the economy, differences in steady-state inflation rates would be associated with different levels of steady-state output. However, Calvo, Benigno and Woodford do not impose (26f) or a similar minimal long-run consistency restriction on their indexation rules. Not surprisingly, rather Old-Keynesian implications follow.

As in the earlier papers by Woodford and in Woodford's book [58], the Benigno and Woodford papers [4] and [5] consider a (log) linear approximation at a deterministic steady state with zero inflation.[34] In Woodford ([58]), when core inflation is generated by partial, one-period-lagged indexation ($\Omega_{t,t-1} = \Pi^{\gamma}_{t-1,t-2}$; $\gamma < 1$), steady state core inflation equals steady state actual inflation (satisfies (26f)) only when both are zero (this happens to be

[34] The Benigno and Woodford [4],[5] papers include nominal wage rigidities as well as nominal price rigidities, but this does not affect the argument or the conclusions.

the case in the deterministic steady state at which the linear approximation is taken). In the Benigno and Woodford models, as in the original Calvo model, core inflation is always zero because the constrained price setters keep their nominal prices constant (that is, $\Omega_{t,t-1} = 1$). Again, 91 is satisfied only in a zero inflation deterministic steady state, and an inflation-neutral equilibrium requires $\Pi_{t,t-1} = \Omega_{t,t-1} = 1$.

With this steady-state distortion - a sub-optimal level of market goods production - the OQM rule has the desirable property, beyond eliminating shoe-leather costs, that it eliminates the second (Austrian) distortion making for a sub-optimal level of market goods production: a share α of market goods purchases is made with cash which earns a lower return, when $i^m < i$ than is available through the sale of credit goods or the retention for own use as leisure of the endowment of potential labour time.

However, with the natural level of output below the efficient level, rules for producer price inflation that cause actual producer price inflation to exceed core producer price inflation will systematically and persistently boost the actual and natural levels of output of market goods and bring them closer to the efficient level.

Let $\pi_{t,t-1} \equiv \ln \Pi_{t,t-1}, \omega_{t,t-1} = \ln \Omega_{t,t-1},\ y_t \equiv \ln Y_t,\ \bar{y}_t = \ln \bar{Y}_t$ and $y_t^* = \ln Y_t^*$. Given monopoly power and the suboptimal use of taxes and subsidies postulated in (91), $\bar{y}_t < y_t^*$. Woodford [58] shows that his pricing model (which is also the one in this paper) can, to a log-linear approximation, be written as follows:

$$\pi_{t,t-1} - \omega_{t,t-1} \approx \kappa(y_t - \bar{y}_t) + \beta E_t(\pi_{t+1,t} - \omega_{t+1,t}),\ \kappa > 0. \tag{92}$$

The same applies to the Benigno and Woodford models (where in addition $\omega_{t,t-1} = \omega_{t+1,t} = 0$). Welfare-reducing relative price distortions are created whenever $\pi_{t,t-1} \neq \omega_{t,t-1}$ for all t. However, if $\bar{y}_t < y_t^*$ because of the presence of uncorrected monopoly power, there will be welfare gains from keeping actual inflation ahead of core inflation. E.g. with $\pi_{t,t-1} - \omega_{t,t-1} = \nu > 0$, we have

$$y_t = \bar{y}_t + \kappa^{-1}(1-\beta)\nu > \bar{y}_t.$$

Actual output can be kept above the natural level of output and thus can be brought closer to (or set equal to) the efficient level of output. When $\omega_{t,t-1} \equiv 0$ (the special case considered by Benigno and Woodford), (92) implies:

$$y_t = \bar{y}_t + \kappa^{-1}(\pi_{t,t-1} - \beta E_t \pi_{t+1,t}).$$

Across deterministic steady states, $\pi = (1-\beta)^{-1}\kappa(y - \bar{y})$ - an upward-sloping long-run Phillips curve. The constant rate of inflation that supports the efficient level of output is given by

$$\pi = (1-\beta)^{-1}\kappa(y^* - \bar{y}). \tag{93}$$

The optimal rate of inflation in this case would be somewhere between zero (the core inflation validating rate that minimizes relative price distortions) and the positive inflation rate given in (93).

The reason why optimal inflation policy in the Benigno and Woodford models does not validate core producer price inflation is the presence of a long-run non-vertical Phillips curve and the associated permanent effect of fully anticipated inflation on output. This may have been an acceptable specification in 1926 (see Fisher [28]) or even in 1958 (see Phillips [52]), but not today, more than 30 years since the contributions of Phelps [48][49][50][51], Friedman [32], and Lucas [39][40][41][42] and the vast theoretical and empirical literature they spawned. A robust inflation target cannot be based on *ad-hoc* inflation non-neutralities resulting from price setters' arbitrary and implausible indexation rules.

Finally, the proposition that optimal inflation validates core inflation is also applicable to the "sticky information" or "inattentive price setters" version of the Phillips curve proposed by Mankiw and Reis [45] (see also [53] and [2]). Assume for simplicity that the deterministic steady state is efficient (that is, 68 holds). The log-linear approximation of the sticky information Phillips curve at the deterministic steady state can (see e.g. [2]) be written as:

$$
\begin{aligned}
\pi_t &= \frac{\varsigma(1-\varpi)}{\varpi}(y_t - \bar{y}_t) + \frac{1-\varpi}{\varpi}u_t + (1-\varpi)\sum_{j=0}^{\infty}\varpi^J E_{t-1-j}\left[\pi_t + \varsigma\Delta(y_t - \bar{y}_t) + \Delta u_t\right]. \\
\varsigma &> 0
\end{aligned}
$$

In this case ϖ is the fraction of wage setters that obtain new information about the state of the economy in any given period and incorporate this in their recomputed optimal plans; u_t is an increasing function of the gap between the actual period-t mark-up and the value of the mark-up in the deterministic steady state.[35] Defining core inflation in the sticky-information Phillips curve as $(1-\varpi)\sum_{j=0}^{\infty}\varpi^J E_{t-1-j}\left[\pi_t + \varsigma\Delta(y_t - \bar{y}_t) + \Delta u_t\right]$, the optimal inflation policy is once more to set actual inflation, π_t, equal to core inflation, thus ensuring that $y_t = \bar{y}_t - \varsigma u_t$.

5 Conclusion: Old Keynesian wine in New-Keynesian bottles

I have analysed the inflation rate associated with optimal monetary policy and either optimal or constrained but supportive tax policy in a model that is representative of the modern mainstream of dynamic stochastic (mostly) optimising macroeconomic general equilibrium tradition. The implications of the analysis are clear. The optimal rate of producer price inflation validates (confirms or fully accommodates) the core inflation process generated by constrained price setters - whatever that is. The optimal interest rate policy is given by the 'Optimal Quantity of Money' rule, that the financial opportunity

[35] >From 54, the mark-up is:
$\frac{p_t(j)u'(C_t)}{P_t v'\left(\ell_t^j\right)} = \left(\frac{\eta}{\eta-1}\right)\left[\frac{1}{(1+\zeta_t)[1+\theta_t(j)]} - \alpha(s_t^j)\lambda_{t+1,t}\frac{C_t}{Y_t}\right]^{-1}$. When the OQM rule is applied, the mark-up is given by $\frac{p_t(j)u'(C_t)}{P_t v'\left(\ell_t^j\right)} = \left(\frac{\eta}{\eta-1}\right)(1+\zeta_t)\left[1+\theta_t(j)\right]$.

cost of holding money must be equal to zero. If the nominal interest rate on money can be set freely by the authorities, there is no unique consumer price inflation rate associated with the optimal monetary rule. By varying the risk-free nominal interest rate on bonds (while keeping it equal to the risk-free nominal interest rate on money), any sequence of consumer price inflation rates, positive or negative, can be supported by an optimal monetary policy. With an exogenously given zero nominal interest rate on money, the consumer price inflation rate associated with the optimal monetary policy is the consumer price inflation rate supported by a zero risk-free nominal interest rate on bonds. In a deterministic steady state that would be a negative consumer price inflation rate equal to minus the rate of time preference.

Woodford ([58]) analysed models similar to those used in this paper. After considering the Calvo price setting model with a number of indexation rules, he reaches to following conclusion, which is starkly different from that of this paper: *"Thus aggregate price stability is a sufficient condition for the absence of price dispersion in the present simple framework"* (p. 405). *"At the same time, in most cases, it is also a necessary condition"* (p. 405); and: *"...in a model with staggered pricing and full indexation to a lagged price index, price stability is not necessary for the absence of price dispersion; it is simply necessary that the inflation rate be constant over time. But again this is a highly special case. If the indexation parameter γ takes any value other than one, only zero inflation is consistent with an absence of price dispersion"*. (p. 406).

To be correct, the last part of the last sentence of this quote should be "..., zero inflation is the only *constant* rate of inflation consistent with an absence of *suboptimal* price dispersion".

Woodford recognises further on (in Chapter 6 of Woodford [58]), that his analysis of the relationship between relative price dispersion and the aggregate inflation rate only implies that zero inflation should be the objective of monetary policy if there are no shoe-leather and no Austrian (cash-good vs. credit good) distortions in the economy. Even if monetary distortions are absent, the results of this paper are different from those of Woodford. There are two reasons for this, each of which is sufficient to invalidate the proposition that, in the class of models under consideration, price stability is necessary or sufficient for optimality. First, the lagged partial indexation rule for which Woodford establishes that zero inflation is necessary for optimality is implausible and inappropriate for an analysis of how the economy would perform under alternative non-zero constant inflation targets. With partial indexation and constant indirect taxes, there can be no constant inflation rate other than zero in a deterministic steady state. The relative price anomalies, cross-sectionally and over time, that result from this arbitrary indexation rule under any non-zero constant rate of inflation, would lead constrained price setters to abandon the Woodford indexation function as they learned about the relationship between their indexation rules and the behaviour of their relative prices and their profits.

The simplest plausible alternative to the Calvo pricing model with Woodford's indexation function is the natural modification of the pure Calvo model that assumes that free price setters choose not a fixed *nominal* price but a fixed *relative* price until their next random opportunity for setting the relative price freely. Individual money prices then adjust in line with the aggregate producer price level to maintain this relative price until the next free pricing opportunity. In this model, there is full current indexation and the real equilibrium is independent of the rate of inflation. Reasonable alternative relative price indexation rules result in the real equilibrium being invariant under alternative fully anticipated inflation sequences or under alternative constant inflation rates.

The second reason the results of this paper differ from those of Woodford hold for any price indexation rule, including Woodford's. I assume that the authorities are capable of implementing a very simple nominal interest rate rule and/or a very simple feedback rule for the indirect tax rate. Under these rules, the producer price core inflation process is validated by policy and any inflation non-neutralities in the private price setting mechanism are neutralised. The OQM rule is optimal under any price indexation rule if the nominal interest rate and/or the indirect tax rate can be used responsively in this way. Woodford implicitly assumes either that interest rate-setting and tax-setting authorities are completely unresponsive to aggregate information that is readily available or that they can only target a constant rate of inflation.

This paper does not argue that there are no valid arguments in favour of price stability (defined as zero inflation for some appropriate aggregate price or cost-of-living index) as an objective, or even the overriding objective, of monetary policy. All it says is that in the class of models considered in this paper, price stability is not a property of optimal monetary policy if either the private price setters are capable of learning or the tax authorities are capable of implementing a simple feedback rule for the nominal interest rate and/or the indirect tax rate. Woodford's argument that price stability is optimal when the natural output level is efficient and Benigno and Woodford's argument that a positive inflation rate is optimal when the natural output level is inefficiently low, are both examples of Old Keynesian wine in New Keynesian bottles: both depend on the existence and persistence of the same *ad-hoc* inflation-non-neutralities in wage and/or price setting that brought us the non-vertical long-run Phillips curve.

The key results of this paper, that optimal monetary policy should implement the Optimal Quantity of Money rule and that optimal producer price inflation validates (fully accommodates) core producer price inflation, are not robust to two important extensions. The first is the introduction of constraints on the ability of the authorities to impose lump-sum taxes or make lump-sum transfers. With such constraints, seigniorage revenues, that is, the real resources appropriated by the authorities through the issuance of base money, can become a valuable source of revenue for the authorities. When the interest rate on money is zero, this may raise the inflation rate associated with optimal monetary policy.[36]

The second extension is menu costs, that is, the explicit consideration of the real

[36] For seigniorage (or the anticipated inflation tax on base money) to matter, we also have to impose constraints on the ability of the authorities to raise distortionary tax rates. Without this, all the government's current and future revenue needs could be satisfied in the initial period through what amounts to a capital levy. If any non-monetary nominal debt is outstanding, it may also be necessary to impose a limit on the government's ability to inflict capital losses on the private owners of nominal public debt through an unanticipated jump in the initial price level.

resource costs associated with changing prices or renegotiating price contracts, as in the papers of Caplin and Spulber [20] and Caplin and Leahy [21]. Such menu costs should be interpreted broadly to include the time, effort and inconvenience of measuring, computing and calculating with an inconvenient yardstick whose length varies from period to period. The implications of menu costs for the optimal rate of inflation depend crucially on the details of how menu costs are modeled. It makes a difference whether a real sunk cost is incurred every time a nominal price is changed, or only when a new contract (which may involve indexation clauses) is negotiated. Nominal price changes that are the result of the mechanical implementation of an invariant indexation rule may have lower menu costs than those that are the result of bargaining between buyers and sellers or the outcome of an auction. If menu costs are assumed to be particularly important for the goods and services that make up the cost-of-living index, this would drive the optimal inflation rate of the cost of living index closer to zero. If, as seems more plausible, menu costs are especially important for money wages (negotiating and bargaining over wages, whether bilaterally or through organised labour unions and/or employers' associations is costly and time-consuming), a zero rate of money wage inflation would be a natural focal point of monetary policy. With positive labour productivity growth, zero wage inflation would imply a negative rate of inflation for the cost of living, consumer and producer price indices.

The marriage of conventional dynamic stochastic general equilibrium theory, characterised by homogeneity of degree zero of all real variables in nominal prices and nominal endowments with ad-hoc nominal wage and/or price rigidities (whether exemplified by the Calvo-style New-Keynesian Phillips curve explored in this paper, by the sticky-information Mankiw-Reis Phillips curve or by the earlier staggered overlapping nominal wage contracts models of Taylor or staggered overlapping real wage contracts of Buiter and Jewitt) was from the start a marriage of inconvenience. The distortions caused by nominal price rigidities are a sub-optimal degree of relative price dispersion; formal or informal price indexation rules that do not suffer from persistent, indeed permanent, inflation non-neutrality make these distortions disappear, perhaps gradually, if learning takes place. If the private price setting mechanism suffers from persistent inflation non-neutralities, simple policy rules involving only minor tinkering with the interest rate and/or the aggregate indirect tax rate will make these distortions disappear.

This paper demonstrates conclusively that the New-Keynesian approach it surveys does not contain the building blocks for welfare economic foundations of price stability as a target (let alone the overriding target) of monetary policy. This suggests that it may be time to stop hanging ever more small rigidities, frictions, ad-hoc behavioural regularities and other New-Keynesian ornaments on the old dynamic stochastic general equilibrium Christmas tree. The search for a welfare economic justification, grounded in solid microfoundations, for targeting price stability is back at square one.

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