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Prices, Exchange Rates and Risk Premia

M.Udara Peiris & Herakles Polemarchakis

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CRETA
Centre for Research in Economic Theory and its Applications

Department of Economics
University of Warwick, Coventry,
CV4 7AL, United Kingdom

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Quantitative easing in an open economy: prices, exchange rates and risk premia [1]

M. Udara Peiris [2] Herakles Polemarchakis [3]

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[2] International College of Economics and Finance, National Research University-Higher School of Economics, Moscow, Russia and Department of Economics, University of Warwick; upeiris@hse.ru

[3] Department of Economics, University of Warwick; h.polemarchakis@warwick.ac.uk

Abstract

Explicit targets for the composition of assets traded by governments are necessary for fiscal-monetary policy to determine the stochastic paths of inflation or exchange rates; this is the case even if fiscal policy is non-Ricardian. Targets obtain with the traditional conduct of monetary policy and Credit Easing, but not with unconventional policy and Quantitative Easing. The composition of the portfolios traded by monetary-fiscal authorities determines premia in asset and currency markets.

Key words: quantitative easing; exchange rates

JEL classification numbers: E50; F41.

1 Introduction

Unconventional monetary-fiscal policy take many forms, but a general distinction can be made between quantitative policies, that focus on the expansion of the balance sheet of the central bank and the related creation of reserves, but, importantly, do not restrict the mix of assets in the balance sheet, and credit policies, that target the allocation of credit across assets on the balance sheet; Bernanke et al. (2004) make the point. The contrast is highlighted by the recent policies of the Federal Reserve with those of the Bank of Japan and the Bank of England. Indeed, at the Stamp Lecture at the London School of Economics, Bernanke (2009) explained that the unconventional policies of the Fed are distinct from those of the Bank of Japan in 2001-2006 in that the composition of assets held by the Fed are central to the achievement of its policy objectives, and named it "Credit Easing" (CE).[1] This contrasts with the first round of quantitative easing undertaken by the Bank of Japan between 2001 and 2006, that he labelled "Quantitative Easing" (QE), as they had focused on the quantities of bank reserves.[2] The "Asset Purchase Facility" of the Bank of England has features of both CE and QE. First established in January 2009, it was designed to increase the monetary base by £200 billion by purchasing various assets at market determined rates and quantities. Although the emphasis of the scheme was the amount of assets purchased, in effect the APF was restricted to medium and long-term gilts.

In practice, unconventional policies in practice display features of both pure QE and pure CE regimes. Nevertheless, it is instructive to understand the implications of each regime separately. Here, we examine the effects of pure QE and pure CE policies on the path of inflation and exchange rates. We show that QE, unlike CE, prevents Central Banks from using short-term nominal interest rates to determine the path of inflation and exchange rates. The path of short-term interest rates determines the expected rate of inflation and expected exchange rate, but not their distribution. We consider a large open, dynamic stochastic, cash-in-advance economy with flexible prices and a perfect, in particular complete, asset market in each country (currency). We assume a non-Ricardian seigniorage policy for the central bank so as to remain in an environment that typically yields a determinate price

[1] The "Maturity Extension Program," that extended the average maturity of Treasury holdings was a version of "Operation Twist," implemented in the early 1960's, that sought to "twist" the yield curve by lowering longer-term yields while keeping the short rates at existing levels.

[2] Ugai (2007) discusses the experience of the Bank of Japan with Quantitative Easing, and Maeda et al. (2005) the monetary operations employed.

level, in spite of the evident criticisms of the fiscal theory of the price level, such as those in Buiter (2002) and Drèze and Polemarchakis (2000). We also assume that only domestic currency be used for transactions in each country (else the indeterminacy result in Kareken and Wallace (1981) obtains) and that the budget constraints of the monetary-fiscal authority in each country are satisfied independently in each country (else the indeterminacy in Dupor (2000) obtains). We show that the stochastic distributions of inflation and exchange rates are a consequence of the manner in which monetary authorities adjust their portfolios over time. The absence of adequate targets for the composition of assets under pure QE regimes, in contrast to pure CE and conventional policy, proliferates indeterminacy.[3] Curdia and Woodford (2011) similarly define QE as lending to the private sector restricted only by a target quantity of reserves while credit easing refers to the purchases of government bonds. Note that a managed exchange rate does not resolve the indeterminacy, but transmits foreign fluctuations in inflation to the domestic economy. Evidently, indeterminacy is nominal only as long as prices are flexible, monetary policy sets nominal rates of interest, and the asset market is complete; otherwise, there are, generically, real effects.

Expositions of the fiscal theory of the price level, as in Woodford (1994) and Dubey and Geanakoplos (2003) in a closed economy, and Dupor (2000) in an open economy, typically assume that monetary authorities trade exclusively in short term, nominally risk free bonds. Woodford (1994) and Dupor (2000) highlights the importance of the present value of the monetary-fiscal authority budget constraint in the determination of the price level, while Dubey and Geanakoplos (2003) highlight the importance, state-by-state, of the monetary authority budget constraint. However, by implicitly restricting attention to conventional policy, all fail to highlight the importance of the portfolio composition assumption for the claim of determinacy of the path of prices and exchange rates. In a closed economy, McMahon et al. (2014) develop the argument and draw implications of the conduct of unconventional policies on the path of inflation. This is consistent with the need for "comprehensive monetary policy", of Drèze and Polemarchakis (2000), that restricts the stochastic path of the term structure of interest rates in order to determine the path of inflation. This theme was later developed in Adao et al. (2014), and Magill and Quinzii (2014a) in a closed economy setting though they did not make the connection with quantitative easing.[4] These

[3]Conventional monetary policy sets a target for the short-term (here, one period) interest rate, and it conducts open market operations or repo transactions that conform to an ex ante determined overall portfolio composition; in particular, one that has an exclusive focus on Treasuries of short maturity.

[4]There is a vast and important literature on indeterminacy of monetary equilibria:

papers obtain determinacy by targeting or restricting the return on assets. Our point here is that the instrument of immediate policy relevance is the composition of the balance sheet of the monetary authority and adequate attention to it permits (under CE) or prevents (under QE) the targeting of a desired path of prices and exchange rates.

One of the objectives of unconventional monetary policies has been to affect long-term interest rates and asset prices by altering the portfolio of securities held. In the last few years, the Federal Reserve and the Bank of England purchased similar quantities of bonds, relative to both the size of their economies and to the stocks of outstanding government debt. Their effects have also been similar.[5] However there is debate in the literature about whether the effects are due to changes in expectations of future interest rates (the signalling channel), or changes in risk premia (the portfolio balance channel).[6]

The portfolio balance channel operates when bonds of different maturities are not perfect substitutes and traders have have maturity-specific bond demands. In this setting, the maturity structure of outstanding debt can affect term premia. Theoretical models describing the portfolio balance channel such as Vayanos and Vila (2009) and Hamilton and Wu (2012) neglect the consequences of variations in the composition of the monetary authority portfolio on the stochastic path of inflation. We show that as the composition of the portfolios of monetary-fiscal authorities determine the stochastic path of prices, they also determine the nominal stochastic discount factor. Indepen-

Sargent and Wallace (1975) pointed out the indeterminacy of the initial price level under interest rate policy; Lucas and Stokey (1987) derived the condition for the uniqueness of a recursive equilibrium with money supply policy; Woodford (1994) analysed the dynamic paths of equilibria associated with the indeterminacy of the initial price level under money supply policy. In this paper, we give the exact characterisation of recursive equilibria under quantitative easing with interest rate policy. The possible multiplicity of stochastic inflation paths at equilibrium was clear in Bloise et al. (2005) and Nakajima and Polemarchakis (2005); there, in a Ricardian specification, the indeterminacy in a monetary economy was parametrised by the price level and a nominal martingale measure. Magill and Quinzii (2014b) emphasised an equivalent role for inflationary expectations.

[5] A cumulative decline of 91 basis points in the 10-year US Treasury yield following eight key announcements about the Feds first programme of large-scale asset purchases (LSAP) was reported by Gagnon et al. (2011). In the UK, Joyce et al. (2011) report that six key quantitative easing announcements led to a fall of about 100 basis points in long-term UK government bond (gild) yields.

[6] Gagnon et al. (2011) and Joyce et al. (2011) suggest that the portfolio balance channel dominated in the US and UK. On the other hand Christensen and Rudebusch (2012) finds evidence of the signaling channel in the US and the portfolio balance channel in the UK. Krishnamurthy and Vissing-Jorgensen (2011) find evidence on both safe and risky assets for the signalling channel by considering changes in money-market futures rates.

dent of changes in expectations about the path of short-term interest rates, the correlation between the discount factor and asset prices, and nominal exchange rates, then generates risk premia and biases whose size and direction corresponds to the chosen portfolio composition.

Since the global financial crisis of 2007, there is an emerging view that variations in the capital account should be examined if not managed, and that these variations may stem from the monetary policy of trading partners (see, for example, Rey (2013)). Our results contributes to this view by highlighting that QE proliferates indeterminacy in central bank portfolios and consequently the path of exchange rates, and, if markets were incomplete within each country, then fluctuations in central bank portfolios would resonate abroad not only by affecting the nominal exchange rate, but also directly to asset prices and premia globally. Furthermore, if central banks set interest rates according to a Taylor-type rule that accounts for changes in the nominal exchange rate[7], and trading partners conducted QE, then they would not be able to guarantee the desired outcomes can be implemented. In other words, QE by trading partners would manifest itself as indeterminacy of both nominal and real risk-premia, globally, and more importantly, even in countries that conducted traditional monetary policy or CE.

The analytical argument

Monetary policy involves *Quantitative Easing* (QE) if open market operations extend to unrestricted portfolios of government bonds of different maturities or bonds (or assets) issued by the private sector. It involves *Credit Easing* (CE) if open market operations extend beyond treasuries, but still target a specific composition for the balance sheet of the monetary-fiscal authority; as a limit case, monetary policy is *conventional* when open market operations are restricted to short term, nominally risk-free assets (treasury bills).

Fiscal policy is *Ricardian* if it is restricted to satisfy an intertemporal budget constraint or transversality condition; equivalently, if public debt vanishes for all possible, equilibrium or non-equilibrium, values of prices and interest rates. It is *non-Ricardian*, if it is not restricted to satisfy an intertemporal budget constraint; in particular, outside money or initial liabilities of the public towards the private sector are not taxed back.

QE generates indeterminacy indexed by a *nominal pricing measure* over states of the world. This measure determines the distribution of rates of inflation, up to a moment that is determined by the risk-free rate and non-arbitrage, and the distribution of exchange rates, up to a moment that is

[7] For a discussion on such rules see Taylor (2001).

determined by the ratio of risk-free rates across countries and no arbitrage. Ricardian policy leaves the initial price level and nominal exchange rate indeterminate as well. Determinacy and, by extension, monetary and financial stability, obtain under CE or monetary policy that is conventional and, require, possibly, fiscal policy that is non-Ricardian.

A stochastic dynamic economy [8]

Time, t, is discrete, and it extends into the infinite future. Events, s^t, at each date, are finitely many. An immediate successor of a date-event is $s^{t+1}|s^t$, and, inductively, a successor is $s^{t+k}|s^t$. Conditional on s^t, probabilities of successors are $f(s^{t+1}|s^t)$ and, inductively, $f(s^{t+k}|s^t) = f(s^{t+k}|s^{t+k-1})f(s^{t+k-1}|s^t)$.

There are two countries in the world, home and foreign, each inhabited by a representative agent. Foreign variables, both macro and those relating to foreign agents, will be denoted with an asterisk (*). The transactions of agents in the home and foreign country will be denoted with a subscript "h" and "f," respectively. It suffices to specify explicitly mostly only the constraints and variables relevant for the home agent and country.

At a date-event, a perishable non-tradable input, labor, $l(s^t)$, is employed to produce a perishable domestic tradable output, consumption, $y(s^t)$, according to a linear technology:

$$y(s^t) = a(s^t)l(s^t), \quad a(s^t) > 0.$$

The representative home individual is endowed with 1 unit of leisure at every date-event. He supplies non-tradable labor and demands the tradeable consumption good, and he derives utility according to the cardinal utility index $u(c(s^t), 1 - l(s^t))$ that satisfies standard monotonicity, curvature and boundary conditions. The preferences of the individual over consumption-employment paths commencing at s^t are described by the separable, von Neumann-Morgenstern, intertemporal utility function

$$u(c(s^t), 1 - l(s^t)) + \mathrm{E}_{s^t} \sum_{k>0} \beta^k u(c(s^{t+k}|s^t), 1 - l(s^{t+k}|s^t)), \quad 0 < \beta < 1.$$

Balances, $m_h(s^t)$ and $m_f(s^t)$ provide liquidity services in the home and foreign country respectively. Elementary securities, $\theta(s^{t+1}|s^t)$, serve to transfer wealth to and from immediate successor date-events. The price level is $p(s^t)$, and the wage rate is $w(s^t) = a(s_t)p(s^t)$, as profit maximisation requires.

[8] The specification is an extension of McMahon, Peiris, and Polemarchakis (2014) and Nakajima and Polemarchakis (2005), similar in spirit to Lucas (1982) and Geanakoplos and Tsomocos (2002).

The nominal, risk-free interest rate is $r(s^t)$. As the goods produced in each country are perfect substitutes, the law-of-one-price holds and determines the exchange rate $e^*(s^t) = p(s^t)/p^*(s^t)$.

At each date-event, the asset market opens after the uncertainty, s^t, has realized, and, as a consequence, purchases and sales in the markets for labor and the consumption good are subject to standard cash-in-advance constraints; the effective cash-in-advance constraint is[9]

$$a(s^t)p(s^t)l(s^t) \leq m_h(s^t), \quad 0 \leq m_f^*(s^t).$$

Prices of elementary securities are

$$q(s^{t+1}|s^t) = \frac{\nu(s^{t+1}|s^t)}{1 + r(s^t)},$$

with $\nu(\cdot|s^t)$ a "nominal pricing measure," which guarantees the non-arbitrage relation

$$\sum_{s^{t+1}|s^t} q(s^{t+1}|s^t) = \frac{1}{1 + r(s^t)}.$$

Inductively,

$$\nu(s^{t+k}|s^t) = \nu(s^{t+k}|s^{t+k-1})\nu(s^{t+k-1}|s^t), \quad k > 1,$$

and the implicit price of revenue at successor date-events is

$$q(s^{t+k}|s^t) = \frac{\nu(s^{t+k}|s^{t+k-1})}{1 + r(s^{t+k-1})} q(s^{t+k-1}|s^t), \quad k > 1.$$

Note that the nominal prices of elementary securities and the "nominal pricing measure" are unique to the currency in which they are denominated. As there are a complete set of state-contingent bonds in each currency, the prices of securities which deliver currency in the same state are related by the following no-arbitrage condition

$$\frac{\nu^*(s^{t+1}|s^t)}{\nu(s^{t+1}|s^t)} \left\{ \frac{1 + r(s^t)}{1 + r^*(s^t)} \right\} = \frac{e^*(s^{t+1}|s^t)}{e^*(s^t)}.$$

In other words, the path of nominal exchange rates depends on the ratio of the "nominal pricing measure" across countries and implies the uncovered interest parity condition

$$\frac{1 + r(s^t)}{1 + r^*(s^t)} e^*(s^t) = \sum_{s^{t+1}|s^t} \nu(s^{t+1}|s^t) e^*(s^{t+1}|s^t).$$

[9] Nakajima and Polemarchakis (2005) provide an explicit derivation.

This gives the risk-neutral expected exchange rate. As markets are complete, variations in the nominal equivalent martingale measure in each country only have nominal effects on the implicit premium in the exchange rate[10]. If there were nominal rigidities or frictions which prevented the law of one price from holding, then the covariance between the nominal equivalent martingale measure and nominal exchange rate, and hence the premium in expected exchange rates, would imply different allocations of (real) resources.

The individual has initial nominal wealth $\tau_h(s^t)$ and $\tau_f(s^t)$ in each country. Initial wealth constitutes a claim against the respective monetary-fiscal authority; alternatively, it can be interpreted as outside money. It is exogenous in a non-Ricardian specification. In a Ricardian specification, it is set endogenously so as to satisfy the transversality condition imposed on monetary-fiscal policy.

The flow budget constraint is[11]

$$
\begin{aligned}
&p(s^t)c_h(s^t) + e^*(s^t)p^*(s^t)c_f(s^t) + m(s^t)\\
&\quad + \sum_{s^{t+1}|s^t} \left\{ q(s^{t+1}|s^t)\theta_h(s^{t+1}|s^t) + e^*(s^t)q^*(s^{t+1}|s^t)\theta_f(s^{t+1}|s^t) \right\}\\
&\qquad \leq p(s^t)a(s^t)l(s^t) + \tau_h(s^t) + e^*(s^t)\tau_f(s^t).
\end{aligned}
$$

Debt limit constraints are

$$
\tau_h(s^t) + e^*(s^t)\tau_f(s^t) \geq -\sum_{k>0}\sum_{s^{t+k}|s^t} q(s^{t+k}|s^t)\frac{1}{1+r(s^t)}a(s^{t+k})
$$

or, equivalently,

$$
\lim_{k\to\infty}\sum_{s^{t+k}|s^t} q(s^{t+k}|s^t)\left\{\tau_h(s^{t+k}|s^t) + e^*(s^{t+k}|s^t)\tau_f(s^{t+k}|s^t)\right\} \geq 0.
$$

Wealth at successor date-events is

$$
\tau_h(s^{t+1}|s^t) = \theta(s^{t+1}|s^t) + m(s^t) \quad \text{and} \quad \tau_f(s^{t+1}|s^t) = \theta_f(s^{t+1}|s^t),
$$

and, after elimination of the trade in assets and using the law-of-one-price, the flow budget constraint reduces to

$$
p(s^t)z(s^t) + \frac{r(s^t)}{1+r(s^t)}a(s^t)p(s^t)l(s^t) + \sum_{s_{t+1}} q(s_{t+1}|s^t)\tau(s_{t+1}|s^t) \leq \tau(s^t),
$$

[10] The difference between the risk neutral and objective expected exchange rate.

[11] Foreign money balances are dominated by foreign bonds and are zero in equilibrium, while the effective cash-in-advance constraint guarantees that domestic money balances are positive.

where $z(s^t) = c(s^t) - a(s^t)l(s^t)$ is the effective excess demand for consumption, $c(s^t)$ is the sum of consumption at home and abroad and $\tau(s^t) = \tau_h(s^t) + e^*(s^t)\tau_f(s^t)$.

Alternatively, $\tilde{m}(s^t) = (1/p(s^t))m(s^t)$ are real balances, $\tilde{\tau}(s^t) = (1/p(s^t))$ $\tau(s^t)$ is real wealth, $\pi(s^{t+1}|s^t) = (p(s^{t+1})/(p(s^t)) - 1$ is the rate of inflation, and

$$\tilde{q}(s^{t+1}|s^t) = q(s^{t+1}|s^t)(1 + \pi(s^{t+1}|s^t)) = \frac{\nu(s^{t+1}|s^t)(1 + \pi(s^{t+1}|s^t))}{1 + r(s^t)}$$

are prices of indexed elementary securities[12].

Real wealth at successor date-events is

$$\tilde{\tau}(s^{t+1}|s^t) = \left(\frac{\theta(s^{t+1}|s^t) + m(s^t) + e^*(s^{t+1}|s^t)\theta(s^{t+1}|s^t)}{p(s^t)}\right)\frac{1}{1 + \pi(s^{t+1}|s^t)},$$

and the flow budget constraint reduces to

$$z(s^t) + \frac{r(s^t)}{1 + r(s^t)}a(s^t)l(s^t) + \sum_{s_{t+1}} \tilde{q}(s_{t+1}|s^t)\tilde{\tau}(s_{t+1}|s^t) \leq \tilde{\tau}(s^t).$$

First order conditions for an optimum are

$$\frac{\partial u(c(s^t), 1 - l(s^t))}{\partial c(s^t)} = \frac{\partial u(c(s^t), 1 - l(s^t))}{\partial l(s^t)}\left(\frac{a(s^t)}{1 + r(s^t)}\right)^{-1},$$

$$\beta f(s^{t+1}|s^t)\frac{\partial u(c(s^{t+1}), 1 - l(s^{t+1}))}{\partial c(s^{t+1})}\tilde{q}(s^{t+1}|s^t)^{-1} = \frac{\partial u(c(s^t), 1 - l(s^t))}{\partial c(s^t)},$$

and the transversality condition is

$$\lim_{k\to\infty} \sum_{s^{t+k}|s^t} \tilde{q}(s^{t+k}|s^t)\tilde{\tau}(s^{t+k}|s^t) = 0.$$

The monetary-fiscal authority in each country sets domestic one period rates of interest and accommodates the demand for domestic balances. It supplies domestic balances, $M(s^t)$, and trades in elementary securities subject to a flow budget constraint that, after elimination of the trade in assets, reduces to

$$T(s^t) \leq \frac{r(s^t)}{1 + r(s^t)}M(s^t) + \sum_{s^{t+1}|s^t} q(s^{t+1}|s^t)T(s^{t+1}|s^t),$$

[12] From the no-arbitrage condition for assets, this is also the same in the foreign country.

where $T(s^t)$ and, similarly, $T(s^{t+1}|s^t)$ are obligations towards the private sector. They are decomposed as $T(s^{t+1}|s^t) = M(s^t) + \Theta(s^{t+1}|s^t)$ where $\Theta(s^{t+1}|s^t)$ are trades in elementary securities at home[13].

Ricardian policy imposes on monetary-fiscal policy the transversality condition

$$\lim_{k\to\infty} \sum_{s^{t+k}|s^t} q(s^{t+k}|s^t)T(s^{t+k}|s^t) = 0$$

or, equivalently, as prices vary, it sets the initial claims of the private sector as

$$T(s^t) = \frac{r(s^t)}{1+r(s^t)}M(s^t) + \sum_{k>0} \sum_{s^{t+k}|s^t} \frac{r(s^{t+k}|s^t)}{1+r(s^{t+k}|s^t)} q(s^{t+k}|s^t)M(s^{t+k}|s^t).$$

For equilibrium, it is necessary and sufficient that the excess demand for output vanishes:

$$z(s^t) + z^*(s^t) = c(s^t) + c^*(s^t) - a(s^t)l(s^t) - a^*(s^t)l^*(s^t) = 0,$$

which determines the path of employment and consumption for each household:

$$\frac{\partial u(c(s^t), 1-l(s^t))}{\partial c(s^t)} = \frac{\partial u(c(s^t), 1-l(s^t))}{\partial l(s^t)} \left(\frac{a(s^t)}{1+r(s^t)}\right)^{-1};$$

in turn, this determines the prices of indexed elementary securities:

$$\beta f(s^{t+1}|s^t) \frac{\partial u(c(s^{t+1}), 1-l(s^{t+1}))}{\partial c(s^{t+1})} \tilde{q}(s^{t+1}|s^t)^{-1} = \frac{\partial u(c(s^t), 1-l(s^t))}{\partial c(s^t)}.$$

The initial price level serves to guarantee that, at equilibrium, the transversality condition of the monetary-fiscal authority holds. If monetary-fiscal policy is Ricardian, the price level remains indeterminate.

More importantly, without further restrictions, as is the case under QE, the decomposition of equilibrium asset prices into an inflation process, $\pi(\cdot|s^t)$, and a nominal pricing measure, $\nu(\cdot|s^t)$, remains indeterminate: if the nominal pricing measure, $\nu(\cdot|s^t)$, is specified arbitrarily, the inflation process, $\pi(\cdot|s^t)$, adjusts to implement the equilibrium; that is, to satisfy

$$\tilde{q}(s^{t+1}|s^t) = \frac{\nu(s^{t+1}|s^t)(1+\pi(s^{t+1}|s^t))}{1+r(s^t)}.$$

[13] For ease of exposition we restrict each monetary-fiscal authority to only trade domestic assets.

Furthermore, the path of the nominal exchange rate remains indeterminate. Arbitrary nominal pricing measures in each country determine the stochastic future exchange rate to satisfy

$$\frac{\nu^*(s^{t+1}|s^t)}{\nu(s^{t+1}|s^t)}\left\{\frac{1+r(s^t)}{1+r^*(s^t)}\right\}e^*(s^t)=e^*(s^{t+1}|s^t).$$

Under CE or under conventional monetary-fiscal policy, determinacy obtains; we postpone the argument to the stationary case to avoid repetition. Concerning the indeterminacy that obtains, further remarks are in order:

1. Our results under unconventional quantitative policies remain valid if the law of one price failed to hold, as in Corsetti and Pesenti (2005), or if there were pricing rigidities. However, in these cases the indeterminacy may have real effects.

2. The indeterminacy under QE obtained is not a consequence of deviations from steady-state equilibria and will not be eliminated by an interest rate feed-back rule, such as a "Taylor rule". This will be discussed at the end of the following section to avoid repetition. The non-stationary equilibria results presented above allow for extreme paths inflation and exchange rates. As the Fisher equation only guarantees an expected rate of inflation, it is entirely possible that there are paths of ever increasing inflation and a path of ever decreasing inflation (deflation), and consequently large stochastic changes in nominal exchange rates, and is reminiscent of the literature on speculative hyperinflation such as Obstfeld and Rogoff (1983).

3. Our requirement that the present-value budget constraints of the monetary-fiscal authority in each country be satisfied individually is not innocuous. Equilibrium only requires that the individual household budget constraints are satisfied, and as a consequence, only the joint budget constraint of the two government budget constraints will be satisfied. In that case the non-Ricardian assumption only guarantees that the present value of the monetary liabilities of both central banks, weighted by the exchange rate, equals the initial nominal wealth, also weighted by the exchange rate. As a consequence, neither the price levels in each country nor the exchange rate is determinate. This is the point of Dupor (2000). Here, the non-Ricardian assumption in each country results in the price-level in each country to be uniquely determined. The subsequent indeterminacy is then restricted to the indeterminacy of the stochastic path of inflation, and is convenient to identify the role that QE plays in generating this indeterminacy.

4. A managed exchange rate, satisfying uncovered interest parity, will either transmit or eliminate the indeterminacy. If, for arguments sake, the home country conducts traditional monetary policy (and has a determinate path of inflation), then the foreign country may partake in quantitative easing and provided that they also target a path of the exchange rate, then the law-of-one-price guarantees that foreign prices are also determinate. If, however, the home country also conducts quantitative easing, then management of the path of the exchange rate leaves the rates of inflation in each country indeterminate. This is because the law-of-one-price only determines the ratio of prices across countries to equal the nominal exchange rate, but the (stochastic) levels are left free.

5. Our argument allows monetary-fiscal authorities to arbitrarily select the composition of initial assets, and independently of the initial quantity of money and price level, which are determined by the initial fiscal liabilities. Our argument is valid when the monetary-fiscal authority attempts to affect the initial quantity of money by purchasing assets with newly printed money: this would be analagus to increasing the outstanding liabilities that need to be returned through seignorage profits

6. The argument holds for the policies of unwinding of quantitive easing that are dependent on realized rates of inflation. This will be made more explicit in the following section, but intuitively, the monetary-fiscal authority here are faced with a new portfolio every period, due to the one-period contracts we focus on. This implies that the degrees of indeterminacy are $S - 1$ in each country and state. Hence, even if the initial portfolio composition is fixed, the consequent evolution of the portfolio (ie the unwinding phase) is not and indeterminacy will result.

A stationary economy

The argument extends to stationary economies and stationary equilibria or steady states.

The resolution of uncertainty follows a stationary stochastic process. Elementary states of the world are s, finitely many, and transition probabilities are $f(s'|s)$.

Rates of interest, $(r(s), r^*(s))$ determine the path of consumption, $(c(s), c^*(s))$ and employment, $(l(s), l^*(s))$ at equilibrium, which, in turn, determine the prices of indexed elementary securities:

$$\beta f(s'|s)\frac{\partial u(c(s'),1-l(s'))}{\partial c(s')}\tilde{q}(s'|s)^{-1} = \frac{\partial u(c(s),1-l(s))}{\partial c(s)}$$

or

$$\tilde{Q} = \beta Du(s)^{-1}FDu(s').$$

Note that the prices of indexed elementary securities is independent of the country. The nominal elementary securities, and hence martingale measures, across countries differ in their stochastic rates of inflation (and consequently the no-arbitrage condition).

Here,

$$Du(s) = diag(\ldots,\frac{\partial u(c(s),1-l(s))}{\partial c(s)},\ldots)$$

is the diagonal matrix of marginal utilities of consumption, and

$$F = (f(s'|s)) \quad \text{and} \quad \tilde{Q} = (\tilde{q}(s'|s))$$

are, respectively, the matrices of transition probabilities and of prices of indexed elementary securities.

For the home household,

$$\tilde{m} = (\ldots \frac{r(s)}{1+r(s)}a(s)l(s)\ldots)$$

is the vector of net, real balances at equilibrium,

$$\tilde{z} = (\ldots z(s)\ldots)$$

is the vector of excess demands and the real wealth at the steady state is given by

$$\tilde{\tau} = (\ldots \tau(s),\ldots).$$

$\tilde{\tau}$ is determined by by the equations

$$\tilde{z} + \tilde{m} + \tilde{Q}\tilde{\tau} = \tilde{\tau} \quad \text{or} \quad \tilde{\tau} = (I-\tilde{Q})^{-1}\left[\tilde{z}+\tilde{m}\right].$$

$$\tilde{z}^* + \tilde{m}^* + \tilde{Q}\tilde{\tau}^* = \tilde{\tau}^* \quad \text{or} \quad \tilde{\tau}^* = (I-\tilde{Q})^{-1}\left[\tilde{z}^*+\tilde{m}^*\right].$$

The real wealth of the monetary-fiscal authorities in the home country, $\tilde{T}$, is determined by

$$\tilde{M} + \tilde{Q}\tilde{T} = \tilde{T} \quad \text{or} \quad \tilde{T} = (I-\tilde{Q})^{-1}\tilde{M},$$

where $\tilde{M} = (\dots \frac{r(s)}{1+r(s)} a(s)l(s) \dots)$ and, since F is a Markov transition matrix, while $\tilde{M} \gg 0$, the real claims against the monetary-fiscal authority at the steady state are strictly positive:

$$\tilde{T} \gg 0.$$

Note that the real claims against the monetary-fiscal authorities can only be jointly determined, $\tilde{T} + \tilde{T}^* = \tilde{\tau} + \tilde{\tau}^*$.

As we have solved the entire real economy without nominal variables, the initial price level in each country remains indeterminate. More importantly, the decomposition of equilibrium asset prices into an inflation process, $\pi(\cdot|s)$, and a nominal pricing measure, $\nu(\cdot|s)$, remain indeterminate in each country. For the home country:

$$\tilde{Q} = R^{-1} N \otimes \Pi.$$

Here,

$$R = diag(\dots, (1 + r(s)), \dots)$$

is the diagonal matrix of interest factors, and

$$N = (\nu(s'|s)), \qquad \Pi = ((1 + \pi(s'|s))), \quad \text{and} \quad E = (e^*(s'|s)/e^*(s))$$

are, respectively, the matrices of "nominal pricing transition probabilities", inflation factors and exchange rate factors. The stochastic growth rates of nominal exchange rates are given by[14]

$$E = \Pi \oslash \Pi^*$$

In the absence of restrictions on the balance sheet of the monetary fiscal authority, which is the case under QE, the set of steady state equilibria is indexed by the nominal pricing transition probabilities, $\nu(\cdot|s)$, that can be set arbitrarily; the inflation factors, $\pi(\cdot|s)$, and exchange rate factors, $e(s'|s)/e(s)$, then adjust to implement the equilibrium.

In each country, the composition of the balance sheet of the monetary-fiscal authority can be described by portfolio weights, $\delta(s'|s)$ (that is, $0 < \delta(s'|s) \leq 1$, and $\sum_{s'} \delta(s'|s) = 1$), and scale factors $h(s)$, such that

$$h(s)\delta(s'|s) = \tilde{T}(s')(1 + \pi(s'|s));$$

this is the case since the inflation factor is the rate of exchange of output between a date-event and an immediate successor.

[14]Entry-by-entry multiplication is $\otimes$, while $\oslash$ is entry-by-entry division.

The equilibrium condition, then reduces to

$$\tilde{Q} = R^{-1}N \otimes H\Gamma = R^{-1}HN \otimes \Gamma.$$

Here,

$$H = diag(\ldots, h(s), \ldots)$$

is the diagonal matrix of scale factors, and

$$\Gamma = \left(\frac{\delta(s'|s)}{\tilde{T}(s')} \right)$$

is the matrix of portfolio weights relative to the payoff of the balance sheet.

Monetary-fiscal policy conducted as CE sets the composition of the balance sheet; that is, it sets positive portfolio weights, $\delta(s'|s) > 0$; claims against the monetary-fiscal authority in real terms, $\tilde{T}(s)$, are determined, at the steady-state, by fundamentals, and, as a consequence, under CE, the matrix Γ is determined.

Since

$$N\mathbf{1}_S = \mathbf{1}_S \quad \Leftrightarrow \quad H = (R\tilde{Q} \oslash \Gamma)\mathbf{1}_S,$$

the Markov tradition matrix, N, is well defined ($h \gg 0$) and determinate; it follows that the equilibrium is determinate as well.

Under conventional monetary-fiscal policy, the portfolio of the monetary-fiscal authority consists of treasury bills, nominally risk-free bonds of short maturity. Here, this corresponds to one-period nominally risk-free bonds: $\delta(s'|s) = 1/S$. □

The indeterminacy of stationary equilibria that we obtain is a significantly bigger problem than the non-stationary one shown in the previous section. This is because policy-oriented models often restrict their definition of equilibrium to a bounded space, and presume that this delivers determinacy under money-supply targeting or a Taylor-type rule. Our results under QE show that this is not enough to uniquely determine an equilibrium. If policy set the path of state-contingent money supply, rather than interest rates as we have, then the indeterminacy would appear in the path of interest rates and would be have real effects.

If interest rates in each country were not set exogenously, but as a function of $h(s)$, this is a "Taylor rule", and indeterminacy persists. This is because interest rates would then depend on the entire distribution of expected inflation without targeting one in particular. In other words, policy that specifies the path of nominal interest rates as a function of expected inflation, does not pin down the stochastic path of inflation.[15] Similarly, neither would adequate consideration of the interest-elasticity of money-demand resolve the indeterminacy.

Eggertsson and Woodford (2003) and Curdia and Woodford (2011) obtain determinacy in a closed economy conducting a policy of QE by setting the portfolio weights in the balance sheet of the monetary-fiscal authority to depend on realised variables. Similarly, if portfolio weights were chosen to target a specific path of nominal exchange rates (provided the other country targets domestic inflation or conducts traditional policy or CE) then determinacy would obtain and highlights the relationship between the composition of assets and the determination of asset prices, inflation and exchange rates[16]. Furthermore, this is consistent with our exposition of CE. On the other hand if the portfolio weights are chosen by policy to depend on endogenous nominal variables at s', such as exchange rate or foreign currency value of domestic wealth then indeterminacy obtains[17].

It is worth pointing out that the indeterminacy we obtain is not a consequence of the stochastic nature of our economy per se, but rather that, given the uncertainty, the non-colliniarity of assets traded by the monetary-fiscal authority. In a related note, McMahon et al. (2012), we examine the consequences of the recent European Central Bank (ECB) policy on purchasing the debt of member countries (Outright Monetary Transactions, or OMT). If the bonds purchased by the ECB are not expected to default, which such a policy is in fact designed to support, then the bonds of the member countries are collinear and there is no requirement to provide ex-ante restrictions on the composition of assets held by the ECB. If however such a policy cannot prevent default, then the bonds are no longer collinear and short-term interest rates may no longer be sufficient to determine the path of Eurozone inflation.

Unconvential Monetary Policy and Premia

In cash-in-advance specifications, liquidity costs generate a wedge between cash and credit goods, and consequently affect marginal utilities and equilibrium prices. This generates a positive correlation between the (real) stochas-

[15]That the Taylor rule does not depend on realized rates of inflation is appropriate for (stochastic) steady-state equilibria.

[16]See Magill and Quinzii (2014b) and Adao, Correia, and Teles (2014), where explicit targets for asset prices, independent of equilibrium, pin down portfolio weights.

[17]Suppose that the portfolio weights depended on expectations of the foreign value of real domestic wealth: $\delta(s'|s) = [\tilde{T}(s')(1+\pi^*(s'|s))]/[\sum_{s'} \tilde{T}(s')(1+\pi^*(s'|s))] \Rightarrow h(s) = e(s'|s)\sum_{s'} \tilde{T}(s')(1+\pi^*(s'|s))$.

tic discount factor and expected nominal interest rates, and, as a consequence, a real risk premium that causes the term structure of interest rates to lie above levels predicted by the pure expectation hypothesis. In a closed economy, Espinoza et al. (2009) show that the risk-premia generated by the non-neutrality of monetary policy exist in addition to the ones derived from the stochastic distribution of endowments as presented in Lucas (1978) and Breeden (1979). They provide a potential explanation for the Term Premium Puzzle[18]. In an open economy, the argument extends, whereby the path of nominal interest rates in each country can affect real risk-premia on the path of nominal exchange rates as in Peiris and Tsomocos (2015)[19]. This is in contrast to equilibrium models where monetary policy is neutral, as in Lucas (1982), where, as risk premia are constant, interest rate differentials move one-for-one with the expected change in the exchange rate. We extend this literature by showing how the composition of the monetary-fiscal authority balance sheet, in addition to policy setting the path of interest rates or money supplies, affects premia in the bond and currency markets. The premia that we obtain is purely nominal though our results extend to economies with incomplete markets and price rigidities, in which case the premia would also be real.

Term Premia:

Our analysis utilises the stationary equilibrium results obtained in the previous section.

Consider the price, in the home country, of a two-period nominally riskless

[18] There is a large literature on the difficulties of the uncovered interest parity holding empirically. The forward premium anomaly, as documented by Fama (1984), Hodrick (1987), and Backus et al. (1995) among others, states that when a currency's interest rate is high, that currency is expected to appreciate. Roughly speaking, the expected change in the exchange rate is constant and interest differentials move approximately one-for-one with risk premia.

[19] In that paper, there are two countries each inhabited by a representative agent and who must use domestic money for domestic trades, such as in the present paper. A cash-in-advance structure means that nominal interest rates affect the wedge between the marginal utilities of income and expenditure. Furthermore, markets are incomplete and agents may default upon their nominal obligtations. Monetary policy, by altering the wedge, affects the volume of real trade, and hence marginal utilities, default probabilities and implied risk neutral probabilities. Consequently, there is a covariance between nominal exchange rates, and real and nominal premia which affects the difference between the risk-neutral and objective expectation of future exchange rates. In the present paper, this difference is generated purely by altering the composition of assets traded by the monetary-fiscal authorities in each country.

bond, at state s:

$$q_2(s) = \sum_{s'} q(s'|s) \sum_{s''|s'} q(s''|s') = \frac{1}{1+r(s)} \sum_{s'|s} \frac{\nu(s'|s)}{1+r(s'|s)}$$

In other words, the forward rate gives the risk-neutral expectation of the future one-period interest rates:

$$q_2(s)(1+r(s)) = \sum_{s'|s} \frac{\nu(s'|s)}{1+r(s'|s)}.$$

The term premia are then described by

$$\sum_{s'|s} \frac{\nu(s'|s) - f(s'|s)}{1+r(s'|s)}.$$

The stationary distribution of the term premia is

$$N \otimes R - F \otimes R = [((R\tilde{Q} \oslash \Gamma)\mathbf{1}_S)^{-1} R\tilde{Q} \oslash \Gamma - F] \otimes R.$$

Recall that Γ is the matrix of portfolio weights relative to the payoff of the balance sheet of the monetary-fiscal authority. Hence, given the fundamentals of the economy, and a given path of one-period interest rates, the term premia depends on the composition of the monetary-fiscal authority balance sheet. More precisely, a correlation is generated between the nominal martingale measure and nominal interest rates which results in risk-neutral pricing being systematically biased (from subjective pricing alone).

Currency Premia:
Recall the Uncovered Interest Parity equation in state s

$$e^*(s)\frac{1+r(s)}{1+r^*(s)} = \sum_{s'|s} \nu(s'|s) e^*(s'|s),$$

where $\sum_{s'|s} \nu(s'|s)e^*(s'|s)$ is the risk neutral expectation of exchange rates. The realised distribution of exchange rates implies an (objective) expectation of $\sum_{s'|s} f(s'|s)e^*(s'|s)$. The difference between these two will be the currency premium. The stationary distribution of the premium is:

$$\begin{gathered} N \otimes E - F \otimes E = N \otimes \Pi \oslash \Pi^* - F \otimes \Pi \oslash \Pi^* = \\ R\tilde{Q} \oslash \Pi^* - F \otimes \Pi \oslash \Pi^* = (R\tilde{Q} - F \otimes \Pi) \oslash \Pi^* = \\ (R\tilde{Q} - F \otimes H\Gamma) \oslash (H^*\Gamma^*) = \\ (R\tilde{Q} - F \otimes (R\tilde{Q} \oslash \Gamma)\mathbf{1}_S\Gamma) \oslash ((R^*\tilde{Q}^* \oslash \Gamma^*)\mathbf{1}_S\Gamma^*). \end{gathered}$$

This is entirely in terms of real variables and nominal interest rates and portfolio weights set by policy. Furthermore there is a clear separation between home and foreign variables and policy parameters. It follows then that stationary portfolio weights chosen in each country correspond to varying premia in the currency markets. The sign and magnitude of the premium can be chosen arbitrarily by appropriate choices of nominal interest rates and portfolio weights. Note that varying the nominal interest rates results in the premium having a real (risk) component while varying the portfolio weights affects the stationary distribution of inflation and exchange rates which is purely nominal. From the equation, it is clear that the joint distribution of interest rates and inflation across countries matters in addition to the mean and variance of the inflation process in each country.

We have considered only interest rate targeting; the results do extend to policies that target the paths of money supplies. In that case, although the path of money is given by policy, fluctuations in demands for assets affect the path of interest rates and changes in the composition of monetary-fiscal authority portfolio has real effects. That is, in a money growth targeting regime, the path of real risk-premia depends on the composition of assets held by the monetary-fiscal authority.[20]

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[20] Nakajima and Polemarchakis (2005) show this in a closed economy. Alvarez et al. (2009) consider an open economy similar to ours, but with segmented participation in the asset market; in the the absence of a credit good, monetary policy is otherwise neutral. If the monetary-fiscal authority portfolio is left unrestricted, introducing a credit good may mean that the correlation between interest rates and risk premia depend both on the path of money and the evolution of the composition of the monetary-fiscal authority portfolio.

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