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THE ZERO BOUND IN AN OPEN ECONOMY: A FOOLPROOF WAY OF ESCAPING FROM A LIQUIDITY TRAP

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ABSTRACT

The paper examines the transmission mechanism of monetary policy in an open economy with and without a binding zero bound on nominal interest rates. In particular, a foolproof way of escaping from a liquidity trap is presented, consisting of a price-level target path, a devaluation of the currency and a temporary exchange rate peg, which is later abandoned in favor of price-level or inflation targeting when the price-level target has been reached. This will jump-start the economy and escape deflation by a real depreciation of the domestic currency, a lower long real interest rate, and increased inflation expectations. The abandonment of the exchange-rate peg and the shift to price-level or inflation targeting will avoid the risk of overheating. Some conclusions for Japan are included.

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1. Introduction

For several decades, high inflation has been the main threat to monetary stability. The successful disinflation and resulting low inflation rate in many countries, together with the problematic situation in Japan, has brought the potential threat of deflation and a binding zero bound on nominal interest rates (a liquidity trap) into focus. The zero bound on the central bank's instrument rate would seem to prevent expansionary monetary policy in situations when it would be mostly needed. Many papers have recently discussed the consequences of the zero bound and a liquidity trap, how to avoid these and how to escape if trapped, often with specific references to Japan, where the threat of deflation and a binding zero bound has been a reality for several years.[1]

There seems to be considerable agreement on how to *avoid* the zero bound and a liquidity trap. Many papers recommend an explicit positive symmetric inflation target (say 2 percent per year). Many central banks already implement such inflation targets. Another possibility is an upward-sloping price-level target path (say rising at 2 percent per year), although there is yet no central bank that implements explicit price-level targeting (with either a flat or an upward-sloping price-level target path).[2] Svensson [63] also suggests that prudent central banks should prepare a set of emergency measures, to be used at preannounced indications of an immanent liquidity trap. These emergency measures would include unorthodox open-market operations in long government bonds and corporate bonds, direct lending to the private sector, foreign-exchange interventions and fiscal and monetary cooperation including a money-financed fiscal expansion involving government expenditure complementary to private consumption.

There seems to be less agreement on how to *escape* from a liquidity trap if already trapped. Krugman [33] has suggested that the central bank should make a commitment to future monetary expansion and has proposed an inflation target for Japan of 4 percent per year for 15 years. The idea is that this would induce inflation expectations that would reduce the real interest rate (even if the nominal interest rate is at the zero bound) and thereby stimulate the economy

[1] These include Bernanke [8], Blinder [11], Bryant [13], Buiter and Panigirtzoglou [14], BIS [2, section IV], Clouse, Henderson, Orphanides, Small and Tinsley [17], Christiano [16], Feldstein [21], Freedman [22], Goodfriend [26], Hetzel [28], IMF [29], Ito [31], Johnson, Small and Tryon [35], King [32], Krugman [33] and [34], Lebow [36], McCallum [39], McKinnon [41] and [42], Meyer [38], Meltzer [43]-[46], Mussa [47], Okina [50]-[52], Orphanides and Wieland [53] and [54], Posen [55], Reifschneider and Williams [56], Smets [59], Svensson [63, section 5 and appendix B], Ueda [69] and [70], Uhlig [71], Wolman [74] and [75], and Woodford [76]. An early contribution is Brunner and Meltzer [12].

[2] An inflation target allows base drift in the price level and makes the latter nonstationary, whereas a price-level target (path) does not allow base drift in the price level but makes it (trend-)stationary. The only real-world example of explicit price-level targeting is Sweden during part of the 1930s, see Berg and Jonung [7].

out of the liquidity trap. A problem with this suggestion is that a mere announcement of a future monetary expansion or an inflation target need not be credible with the private sector and therefore not affect inflation expectations, in the absence of any commitment mechanism or any action supporting the announcement. Furthermore, the high inflation target for Japan for 15 years may not be credible, since the Bank of Japan might be tempted to reduce the inflation target to a more conventional level (say 2 percent) once the economy has escaped from the liquidity trap. Posen [55], analyzing the economic situation of Japan, suggests a fiscal expansion and a more moderate inflation target of 3 percent that is reduced to 2 percent after a few years, but he recommends avoiding a yen depreciation. Meltzer [46] and [43] recommends increasing the monetary base, with reference to a real-balance effect on aggregate demand and that increased supply of money will affect a number of other asset prices and interest rates in an expansionary direction, even if short nominal interest rates are zero, especially depreciating the domestic currency. A problem with a real-balance effect on aggregate demand in a liquidity trap is that if the private sector is already satiated with liquidity, increasing liquidity is unlikely to affect consumption.[3] Furthermore, in a liquidity trap, short nominal government bonds and money are (close to) perfect substitutes, and open-market operations increasing private holdings of money and reducing private holdings of short government bonds would have little effect. Accordingly, Meltzer recommends open-market operations in other assets than short government bonds, for instance, long government bonds or foreign-currency government bonds, to reduce long bond rates and depreciate the domestic currency, relying on the assumption of imperfect substitutability between these assets and money/short bonds, but without any discussion of the degree of imperfect substitutability and how large open-market operations would be needed.

The reason why nominal interest rates cannot fall below zero is that an alternative to investing in short government bonds is simply to hold cash at zero interest rates. Buiter and Panigirtzoglou [14] and Goodfriend [26] discuss a more exotic way of eliminating the zero bound by introducing a carry tax, a tax on holding reserves and currency. This would allow negative nominal interest rates in equilibrium, and allow the central bank to achieve the desired stimulating negative interest rate. Although it seems technically feasible to introduce a carry tax for commercial-bank reserves in the central bank, introducing a carry tax on currency re-

[3] As discussed by Woodford [76], Nelson [48] and McCallum [39], a direct money effect would enter if real balances enter the representative agent's utility function and this utility function is not additively separable in consumption and real balances but has a positive cross-derivative. However, reasonable parameter values make any such effect so small that it can safely be disregarded, also outside a liquidity trap.

quires technological innovations (electronic chips in the notes, for instance) and also implies the inconvenience of notes circulating with the same nomination but trading at different discounts.

McCallum [39] has recommended foreign-exchange interventions to depreciate the currency and, in this way, stimulate the economy when the interest rate is zero. His argument either ignores uncovered interest parity or relies on a portfolio-balance effect, whereby the relative supply of domestic- and foreign-currency denominated assets affects the foreign-exchange risk premium and thereby the exchange rate. Although huge foreign-exchange interventions are likely to affect the exchange rate (if not because of a portfolio-balance effect, at least because of the expectations of future depreciation they may induce), a problem with this argument is that the size of the portfolio-balance effect is controversial and most empirical work on the effect of sterilized foreign-exchange interventions indicates that the portfolio effect is small or even negligible. McCallum does not provide any calculations of the magnitude of the foreign-exchange interventions that would be needed to significantly depreciate the yen.

Bernanke [8], analyzing the situation in Japan, discusses several potential remedies, especially a relatively high inflation target in the 3–4 percent range for a number of years to undo the "price-level gap" created by several years of zero or negative inflation, aggressive foreign-exchange interventions to depreciate the yen, and money-financed fiscal transfers.

At the Jackson-Hole Symposium in August 1999, Svensson [63] suggested that all the emergency measures prepared in advance by prudent central banks (see above) should be used, in the hope that some of these would work. In particular, a temporary exchange-rate peg was discussed [63, Section 5.3]:

> Could the central bank peg the exchange rate and this way escape the liquidity trap? Such pegging would involve a commitment to arbitrarily large nonsterilized foreign-exchange interventions, buying foreign exchange and selling domestic currency at the pegged rate. Again, for such pegging to succeed, market expectations of future appreciation would have to change. If they do not change, huge foreign-exchange interventions could be absorbed by the foreign-exchange market. The question is then, in such a game of attrition, who will blink first, the market or the central bank? Compared to the usual speculative attack on a pegged exchange rate to force a devaluation, the central bank does not risk running out of foreign-exchange reserves; instead it just has to create more domestic currency. The fact that a commitment to a pegged exchange rate is immediately verifiable and the technical possibility to always create more domestic currency may make the commitment more credible in the short run than a commitment to an inflation target when interest rates have reached zero. It cannot be excluded that an exchange-rate peg can serve as a temporary emergency measure, an intermediate step towards fulfilling an inflation target.

Thus, this argument relies on a commitment by the central bank to buy and sell unlimited amounts of foreign exchange at the given pegged exchange rate. In particular, it does not rely on any portfolio-balance effects; instead it relies on the change in private-sector expectations of future exchange rates brought about by the commitment to unlimited interventions at the pegged exchange rate. This paper expands on this idea and argues that there is indeed a safe and foolproof way of escaping from a liquidity trap in an open economy, namely (1) announcing an upward-sloping price-level target path (that is, corresponding to a positive long-run inflation target) above the current price level, (2) announcing that (a) the currency will be devalued and the exchange rate pegged at a level corresponding to a real depreciation relative to a steady-state level, and (b) the peg will be abandoned in favor of price-level targeting (or inflation targeting) once the price-level target path has been reached, and (3) just doing it.[4] [5]

It is argued that this "foolproof way" will jump-start the economy by (a) a real depreciation of the domestic currency relative to a long-run equilibrium level, (b) a lower long real interest rate (since there must eventually be a real appreciation of the domestic currency, and expected real appreciation of the currency is associated with relatively low short and long domestic real interest rates), and (c) increased inflation expectations (since, with the exchange-rate peg, expected real appreciation is associated with expected domestic inflation). The output gap will increase because of (a) and (b), and deflation will turn into inflation because of (a), (c) and the increased output gap. The economy will find itself out of the liquidity trap (a credible peg will be associated with a positive short nominal interest rate). The price-level will rise and eventually reach the price-level target path, after which the peg will be abandoned.

The foolproof way acknowledges the crucial role of private-sector inflation expectations and includes a concrete way for the central bank of affecting those expectations. It handles the credibility problem associated with Krugman's proposal, in that it specifies what the central bank should do and not just what it should say, and by giving the central bank an arena, the foreign-exchange market, where it can quickly demonstrate its resolve to the market by success in pegging the exchange rate. In particular, a price-level target path is a more precise way of

[4] In September 1999, Feldstein [21] similarly suggested an exchange rate depreciation, although followed by a gradual appreciation: "Japan could simply announce that it wants an exchange rate of, say, 140 yen per dollar and is prepared to buy dollars for yen until it achieves that goal. Once markets saw that the Japanese were serious, the exchange rate would adjust and further dollar purchases would be largely unnecessary. The Japanese government could add that it recognizes that such an exchange rate cannot last indefinitely and that it expects to permit the yen to rise at, say, 8% a year, reaching 129 after one year, 119 after two years and so on until the currency reaches a level at which intervention is no longer needed."

[5] In October 1999, Dale Hendersen, in an intervention from the floor at the conference "Monetary Policy in a Low Inflation Environment," similarly suggested a temporary peg of the yen and that such a peg would be credible (see Blinder [11]).

undoing the "price-level gap" caused by several years of zero or negative inflation than the high inflation target suggested by Krugman [33] and Bernanke [8]. The price-level target path allows inflation to be higher first and lower later, thereby providing an "anchored expansion," indeed better anchored than the variable inflation target suggested by Posen [55].

By including the price-level target path, the foolproof way makes the temporary peg consistent with desirable long-run inflation expectations. It differs from McKinnon's [41] and [42] proposal of a bilateral agreement between U.S. and Japan to stabilize the yen/dollar exchange rate, by the initial real depreciation and the temporary use of the peg (and by being unilateral). The foolproof way is consistent with Meltzer's [46] and McCallum's [39] proposals to depreciate the currency, but it does not rely on the somewhat controversial magnitude of a portfolio-balance effect. Instead, it relies on affecting exchange-rate expectations via a commitment to the exchange-rate peg, regardless of the magnitude of any portfolio-balance effect; in case there is no portfolio-balance effect it is consistent with uncovered interest parity.[6] Furthermore, in contrast to these proposals, the foolproof way provides a precise framework, the peg, for the depreciation, and for abandoning the peg in favor of the long-run inflation or price-level target.[7] Indeed, it appears to be a foolproof way for an open economy in general, and Japan in particular, of escaping from a liquidity trap.

Section 2 discusses the transmission mechanism of monetary policy in an open economy, with and without the zero bound, as a background. Section 3 presents the foolproof way of escaping from a liquidity trap in some detail. Section 4 contains some conclusions for Japan. The appendix contains some technical details.

2. The transmission mechanism in an open economy

In order to discuss the effect of monetary policy actions when the zero bound is binding, we need to specify the transmission mechanism of monetary policy in general, and with the zero bound in particular. Several similar models of monetary policy in an open economy have been

[6] Thus, no portfolio-balance effect is assumed in the model used below. However, as discussed in appendix B, one interpretation of the equilibrium resulting from the temporary peg is that the corresponding commitment to unlimited foreign exchange interventions poses a threat of huge interventions in support of the peg. At such huge interventions, a portfolio-balance effect would realistically appear and affect the exchange rate. This threat then affects exchange-rate expectations and supports the temporary peg, and a portfolio-balance effect need not be observed at the moderate interventions that occur in equilibrium.

[7] The foolproof way differs from Feldstein's [21] proposal (see footnote 4) by maintaining the peg until the price-level target paths is reached and hence let domestic inflation achieve the real appreciation after the initial depreciation, instead of Feldstein's gradual appreciation of the nominal exchange rate. Maintaining the peg is essential for the foolproof way in generating inflation and inflation expectations.

presented.[8] Here, I use a simplified variant of a model derived and discussed in detail in Svensson [65] and [61, appendix].[9] The main characteristic of the transmission mechanism in this and similar models are:

- Domestic inflation (increases in the general price level of domestically produced goods and services) depends positively on expected future domestic inflation (the inflation-expectations channel to domestic inflation) and marginal cost of the production. Marginal cost, in turn, depends positively on the output gap (the aggregate-demand channel to domestic inflation) and the exchange rate (via imported intermediate inputs; the exchange-rate channel to domestic inflation).

- Consumer-Price-Index (CPI) inflation depends positively on domestic inflation and inflation in imported final goods and services. The latter depends positively on the rate of domestic-currency depreciation (the direct exchange-rate channel to CPI inflation).

- The output gap (the difference between output and potential output) depends, via domestic aggregate demand, negatively on the long real interest rate (the real-interest rate channel to aggregate demand) and, via the relative price between domestic and foreign goods, positively on the real exchange rate (the exchange-rate channel to aggregate demand).

- The long real interest rate depends positively on expected future short nominal rates (the central bank's instrument rate) and negatively on expected future domestic inflation.

The main property used in the development of the foolproof way of escaping from a liquidity trap in section 3 is that, everything else equal, the output gap increases from (a) a real depreciation of the domestic currency and (b) a reduction in the long real interest rate. Domestic inflation increases from an increase in the output gap, (a), and (c) an increase in private-sector expectations of future domestic inflation. Thus, any open-economy model with the above rather uncontroversial characteristics will do.

The model of Svensson [65] also introduces somewhat realistic relative lags in the effects of monetary-policy actions on output and inflation as well as additional inertia in these variables.

[8] See Batini and Haldane [4], Benigno [6], Galí and Monacelli [24], Leitemo [37], McCallum and Nelson [40], Obstfeld and Rogoff [49], Svensson [65] and Weerapana [73].

[9] The model differs from that in Svensson [65] and [61, appendix] in that the nominal variables and some of the real variables are not measured only as deviations from a steady-state or trend level and in that the zero bound is made explicit.

These lags imply that expectations play an even more important role: Current domestic inflation and output are predetermined, and only future domestic inflation and output can be affected by monetary-policy actions. Furthermore, it is not the current real exchange rate and current long real rate but the expected future real exchange rate and the expected future real interest rate that are of importance for private-sector decisions.

The model above does not explicitly model a credit channel (see, for instance, Bernanke, Gertler and Gilchrist [10]) and the more controversial transmission channels involving direct aggregate-demand effects of money (see Meltzer [46], Woodford [76] and Nelson [48]), the effect of foreign-exchange interventions on the foreign-exchange risk premium (see McCallum [39]), and the price-gap or real-money-gap effects on inflation in P^* models (see Hallman, Porter and Small [27], Tödter and Reimers [68], Svensson [64] and Gerlach and Svensson [25]). Indeed, the foolproof way of escaping a liquidity trap presented in section 3 does not depend on the presence (or the absence) of those transmission channels.[10]

Readers not interested in the more detailed description of the model and discussion of the transmission mechanism may prefer to skim the next few subsections or even jump directly to section 3.

2.1. An illustrative model of an open economy

The model has an aggregate-supply equation (Phillips curve) of the form

$$\pi_{t+1} = \alpha_\pi \pi_t + (1-\alpha_\pi)\pi_{t+2|t} + \alpha_y y_{t+1|t} + \alpha_q (q_{t+1|t} - q) + \varepsilon_{t+1}. \tag{2.1}$$

Here, for any variable x, $x_{t+\tau|t}$ denotes $\mathrm{E}_t x_{t+\tau}$, that is, the rational expectation of $x_{t+\tau}$ in period $t+\tau$, conditional on the information available in period t. Furthermore,

$$\pi_t \equiv p_t - p_{t-1} \tag{2.2}$$

denotes (log) domestic inflation in period t, where p_t is the (log) prices of domestic(ally produced) goods. The variable y_t is the output gap, defined as

$$y_t \equiv y_t^d - y_t^n, \tag{2.3}$$

where y_t^d is (log) aggregate demand (output) and y_t^n is (log) potential output (for simplicity, both are measured as deviations from a constant steady-state level, although the model could also be

[10] Except possibly, as discussed in appendix B, that the temporary peg is supported by a threat of huge foreign-exchange interventions that do not materialize in equilibrium but would affect the foreign-exchange risk premium and depreciate the domestic currency if they were to materialize.

formulated in terms of deviations from a steady-state trend). Potential output is assumed to be exogenous and stochastic and follows

$$y^n_{t+1} = \gamma^n_y y^n_t + \eta^n_{t+1}, \tag{2.4}$$

where the coefficient γ^n_y fulfills $0 \leq \gamma^n_y < 1$ and η^n_{t+1} is a serially uncorrelated zero-mean shock to potential output (a "productivity" shock). The variable q_t is the (log) real exchange rate, defined as

$$q_t \equiv s_t + p^*_t - p_t, \tag{2.5}$$

where p^*_t the (log) foreign price level, s_t denotes the (log) exchange rate (in units of domestic currency per unit foreign currency), and q is the steady-state level of the real exchange rate.[11] Finally, ε_{t+1} is a serially correlated zero-mean "cost-push" shock. Thus, we have two distinct "supply" shocks, namely a productivity shock and a cost-push shock. The coefficients α_π, α_y, β_y and α_q are constant and positive; furthermore α_π and β_y are smaller than unity.

This supply function is derived in Svensson [61, appendix] (along the lines of Rotemberg and Woodford [57]), from the first-order condition of an optimization problem and hence, with some microfoundations. Inflation depends on lagged inflation and previous expectations of the output gap and future inflation. It is similar to a Calvo-type [15] Phillips curve in that inflation depends upon expectations of future inflation. It is similar to the Fuhrer and Moore [23] Phillips curve in that inflation depends on both lagged inflation and expected future inflation (see also Estrella and Fuhrer [19]). Domestic inflation is assumed to be predetermined one period.[12] The term including $q_{t+1|t}$ in (2.1) represents the effect of expected costs of imported intermediate inputs (or resulting wage compensation).

Let ω be the share of imported goods in the CPI.[13] Then CPI inflation, π^c_t, fulfills[14]

$$\pi^c_t = (1-\omega)\pi_t + \omega\pi^f_t = \pi_t + \omega(q_t - q_{t-1}). \tag{2.6}$$

Here, π^f_t denotes domestic-currency inflation of imported foreign goods, which fulfills

$$\pi^f_t \equiv p^f_t - p^f_{t-1} \equiv \pi^*_t + s_t - s_{t-1} = \pi_t + q_t - q_{t-1},$$

[11] Since there are no nontraded goods, the real exchange rate also constitutes the terms of trade.

[12] In Svensson [65] domestic inflation is assumed to be predetermined two periods in advance, in order to have a two-period lag in the effect of monetary policy on domestic inflation (and hence, a longer lag than for the output gap, see below).

[13] The share of imported goods in the CPI is approximately constant for small deviations around a steady state. It is exactly constant if the utility function over domestic and imported goods has a constant elatisticity of substitution equal to unity (that is, is a Cobb-Douglas utility function), as is actually assumed in Svensson [65].

[14] Since there is no interest-rate component in the CPI, it is best interpreted as CPIX; that is, CPI inflation (and domestic inflation) are exclusive of any credit service costs.

where

$$p_t^f \equiv p_t^* + s_t \tag{2.7}$$

is the (log) domestic-currency price of imported foreign goods, and

$$\pi_t^* \equiv p_t^* - p_{t-1}^* \tag{2.8}$$

is foreign inflation. That is, for simplicity, I assume that there is no lag in the pass-through of import costs to domestic prices of imported goods.[15]

Aggregate demand for domestically produced goods is given by the aggregate-demand equation (expressed in terms of the output gap, (2.3)),

$$y_{t+1} = \beta_y y_t - \beta_\rho \rho_{t+1|t} + \beta_y^* y_{t+1|t}^* + \beta_q (q_{t+1|t} - q) - (\gamma_y^n - \beta_y) y_t^n + \eta_{t+1}^d - \eta_{t+1}^n, \tag{2.9}$$

where y_t^* is (log) foreign output (measured as a deviation from a constant steady-state level), all coefficients are constant and nonnegative, with $0 \leq \beta_y < 1$, and η_{t+1}^d is a serially uncorrelated zero-mean "demand" shock. The variable ρ_t is defined as

$$\rho_t \equiv \sum_{\tau=0}^{\infty} (r_{t+\tau|t} - r), \tag{2.10}$$

where r_t, the (short domestic-good) real interest rate, fulfills

$$r_t \equiv i_t - \pi_{t+1|t}, \tag{2.11}$$

where i_t is the (short) nominal interest rate. The constant steady-state level of the real interest rate is denoted $r > 0$. The zero bound on the nominal interest rate implies that it fulfills

$$i_t \geq 0. \tag{2.12}$$

The nominal interest rate is (normally) the instrument of the central bank.[16]

Thus, the variable ρ_t is the sum of current and expected future deviations of the real interest rates from the steady-state level of the real rate. The sum enters in the aggregate demand, since the latter is the forward solution of an Euler condition involving the short real interest rate, cf. Svensson [61]. The sum always converges in the equilibria examined below. The variable ρ_t is (under the expectations hypothesis) related to the deviations from the steady-state level

[15] There are obviously more realistic and less simplistic ways of modelling the pass-through of exchange-rate movements to domestic prices of imported final goods.

[16] The variable ρ_t fulfills $\rho_t = \sum_{\tau=0}^{\infty} r_{t+\tau|t}^c - \omega q_t - r$, where $r_t^c \equiv i_t - \pi_{t+1|t}^c = r_t - \omega(q_{t+1|t} - q_t)$ is the CPI real interest rate. Hence, we can express ρ_t in terms of r_t^c rather than r_t (the derivation in Svensson [61, appendix] actually starts from an Euler condition in terms of r_t^c).

of a long real zero-coupon bond rate: Consider the real rate r_t^T with maturity T. Under the expectations hypothesis, it fulfills

$$r_t^T = \frac{1}{T}\sum_{\tau=0}^{T} r_{t+\tau|t}.$$

Hence, for a long (but finite) maturity T, the variable ρ_t is approximately the product of the long real rate and its maturity,

$$\rho_t \approx T(r_t^T - r). \tag{2.13}$$

The aggregate demand is predetermined one period in advance. It depends on lagged expectations of accumulated future real interest rates, foreign output and the real exchange rate. The aggregate-demand equation is derived, from a first-order condition consistent with optimization and hence with some microfoundations, and discussed in further detail in Svensson [61, appendix]. A crucial assumption is that the output gap, the current account and the real exchange rate are all stationary.[17] [18]

The exchange rate fulfills the interest parity condition

$$i_t - i_t^* = s_{t+1|t} - s_t + \varphi_t, \tag{2.14}$$

where i_t^* is the foreign nominal interest rate and φ_t is the foreign-exchange risk premium. The foreign-exchange risk premium incorporates any exogenous residual disturbances to the exchange rate, including changes in portfolio preferences, credibility effects, etc. In order to eliminate the potentially non-stationary exchange rate, I use (2.5) to rewrite this as the real interest parity condition in terms of the stationary real exchange rate,[19]

$$q_{t+1|t} = q_t + (i_t - \pi_{t+1|t}) - (i_t^* - \pi_{t+1|t}^*) - \varphi_t. \tag{2.15}$$

Note that q_t and ρ_t are closely related. Solving q_t forward and exploiting that q_T approaches q when $T \to \infty$, we have

$$\begin{aligned} q_t - q &= -\sum_{\tau=0}^{\infty}(r_{t+\tau|t} - r) + \sum_{\tau=0}^{\infty}(r_{t+\tau|t}^* - r^*) + \sum_{\tau=0}^{\infty}(\varphi_{t+\tau|t} - \varphi) \\ &\equiv -(\rho_t - \rho_t^*) + \frac{1}{1-\gamma_\varphi}(\varphi_t - \varphi), \end{aligned} \tag{2.16}$$

[17] There is an obvious similarity to the closed-economy aggregate demand function of Fuhrer and Moore [23], except that a *lagged* long real coupon-bond rate enters in their function.

[18] The natural output level enters in (2.9), because the equation is first derived for the level of aggregate demand. It is then expressed in terms of the output gap by subtraction of the natural output level.

[19] Equation (2.15) may give the impression that the real exchange rate will have a unit root. This is not the case in equilibrium, however. All real variables, inflation rates and interest rates are then stationary. The nominal price level and exchange rate are nonstationary under inflation targeting with base-drift in the price level.

where the $r_t^* \equiv i_t^* - \pi_{t+1|t}^*$ is the foreign real interest rate, r^* is the foreign steady-state real interest rate, ρ_t^* is defined in analogy with (2.10), and I use (2.20) below as well as the fact that the steady-state domestic and foreign real interest rate will be related the steady-state foreign-exchange risk premium, φ, according to

$$r - r^* = \varphi. \tag{2.17}$$

Thus, the real exchange rate is related to the negative difference between the domestic and foreign expected future deviations of the real interest rate from the steady-state real interest rate.

For simplicity, I assume that foreign inflation, foreign output and the foreign-exchange risk premium follow stationary univariate AR(1) processes,

$$\pi_{t+1}^* = \pi^* + \gamma_\pi^*(\pi_t^* - \pi^*) + \varepsilon_{t+1}^* \tag{2.18}$$

$$y_{t+1}^* = \gamma_y^* y_t^* + \eta_{t+1}^* \tag{2.19}$$

$$\varphi_{t+1} = \varphi + \gamma_\varphi(\varphi_t - \varphi) + \xi_{\varphi,t+1}, \tag{2.20}$$

where the coefficients are nonnegative and less than unity, the shocks are serially uncorrelated and zero-mean, and π^* and φ are the constant steady-state levels of foreign inflation and the foreign-exchange risk premium, respectively. Furthermore, for simplicity, I assume that the foreign interest rate follows a Taylor-type instrument rule; that is, it is a linear function of foreign inflation and output,

$$i_t^* = i^* + f_\pi^*(\pi_t^* - \pi^*) + f_y^* y_t^* + \xi_{it}^*, \tag{2.21}$$

where $i^* \equiv r^* + \pi^*$ (where r^* is the constant steady-state foreign real interest rate) is a constant steady-state level of the foreign interest rate, the coefficients are constant and positive, and ξ_{it}^* is a serially uncorrelated zero-mean shock. These specifications of the exogenous variables are chosen for simplicity; obviously the exogenous variables may be cross-correlated in more general ways without causing any difficulties, and additional variables can be introduced to represent the state of the rest of the world.[20]

Fiscal policy is not explicitly represented. It is implicitly assumed to be "Ricardian," so that the government's intertemporal budget constraint is an identity and the Fiscal Theory of the Price Level does not apply.

[20] Weerapana [73] extends this model to a two-country world with endogenous foreign variables.

2.2. The loss function, state-space form, and equilibrium

A possible loss function corresponds to "flexible (domestic) inflation targeting" with a constant inflation target $\hat{\pi}$ (thus, stars denote foreign variables and hats denote target levels). This can be represented as a period loss

$$L_t = (\pi_t - \hat{\pi})^2 + \lambda y_t^2, \tag{2.22}$$

where $\lambda > 0$ is the relative weight on output-gap stabilization, and an intertemporal loss function

$$\mathrm{E}_t(1-\delta)\sum_{\tau=0}^{\infty}\delta^{\tau}L_{t+\tau}, \tag{2.23}$$

where $0 < \delta < 1$ is a discount factor.[21]

As shown in Svensson [61], the model can be written in a convenient state-space form. Let X_t and Y_t denote the (column) vectors of predetermined state variables and goal variables, respectively, let x_t denote the (column) vector of forward-looking variables, and let v_t denote the (column) vector of innovations to the predetermined state variables,

$$\begin{aligned}
X_t &= (\pi_t, y_t, \pi_t^* - \pi^*, y_t^*, i_t^* - i^*, \varphi_t - \varphi, y_t^n, q_{t-1} - q)' \\
Y_t &= (\pi_t, y_t)' \\
x_t &= \left(q_t - q, \rho_t - r, \pi_{t+1|t}\right)' \\
v_t &= \left(\varepsilon_t, \eta_t^d - \eta_t^n, \varepsilon_t^*, \eta_t^*, f_\pi^*\varepsilon_t^* + f_y^*\eta_t^* + \xi_{it}^*, \xi_{\varphi t}, \eta_t^n, 0\right)',
\end{aligned}$$

where $'$ denotes the transpose.[22] Then the model can be written

$$\begin{bmatrix} X_{t+1} \\ x_{t+1|t} \end{bmatrix} = A\begin{bmatrix} X_t \\ x_t \end{bmatrix} + B(i_t - i) + \begin{bmatrix} v_{t+1} \\ 0 \end{bmatrix} \tag{2.24}$$

$$Y_t = C\begin{bmatrix} X_t \\ x_t \end{bmatrix} \tag{2.25}$$

$$L_t = (Y_t - \hat{Y})'W(Y_t - \hat{Y}), \tag{2.26}$$

where A, B and C are matrices or vectors of appropriate dimensions, W is a diagonal matrix with the diagonal $(1, \lambda)$, $i \equiv r + \hat{\pi}$ is the steady-state level of the nominal interest rate, and $\hat{Y} \equiv (\hat{\pi}, 0)'$ is the vector of target levels (see Svensson [61, appendix] for details[23]).

[21] Flexible CPI inflation targeting would have the period loss function $L_t = (\pi_t^c - \hat{\pi})^2 + \lambda y_t^2$. Svensson [65] and Aoki [1] compare domestic and CPI inflation targeting from different points of view.

[22] Intuitively, predetermined variables are determined by lagged variables and current exogenous shocks, whereas forward-looking variables (non-predetermined variables) are also affected by expectations of future forward-looking variables. More rigorously, predetermined and forward-looking variables have one-period-ahead prediction errors that are exogenous and endogenous, respectively.

[23] As mentioned above, the variant of the model presented here differs in that domestic inflation is predetermined one period ahead rather than two and that the steady-state levels of some of the variables are not set equal to zero).

If the zero bound (2.12) is disregarded, the model is linear with a quadratic loss function. Then, the model is a standard linear stochastic regulator problem with rational expectations and forward-looking variables.

With forward-looking variables, there is a difference between the case of discretion and the case of commitment to an optimal rule. In the discretion case, the central bank each period minimizes the intertemporal loss function under discretion. Then, the forward-looking variables will, in equilibrium, be linear functions of the predetermined variables,

$$x_t = HX_t, \tag{2.27}$$

where the matrix H is endogenously determined. The equilibrium reaction function will be a linear function of the predetermined variables,

$$i_t = i + f(X_t - \bar{X}), \tag{2.28}$$

where the row vector f is endogenously determined and $\bar{X} \equiv (\hat{\pi}, 0, 0, 0, 0, 0, 0, 0)'$ denotes the steady-state levels of the predetermined variables.[24]

The dynamics of the economy are then described by

$$X_{t+1} = \bar{X} + M_{11}(X_t - \bar{X}) + v_{t+1}, \tag{2.29}$$

$$Y_t = (C_1 + C_2 H + C_i f)X_t, \tag{2.30}$$

as well as (2.27) and (2.28), where the matrix M is given by

$$M \equiv A \begin{bmatrix} I & 0 \\ H & 0 \end{bmatrix} + B \begin{bmatrix} f & 0 \end{bmatrix}, \tag{2.31}$$

where the matrices

$$M \equiv \begin{bmatrix} M_{11} & M_{21} \\ M_{12} & M_{22} \end{bmatrix}, \; C \equiv \begin{bmatrix} C_1 \\ C_2 \end{bmatrix} \tag{2.32}$$

are partitioned according to X_t and x_t.

When the zero bound is taken into account and binding in some states of the world, the solution is no longer linear and must be found with non-linear dynamic programming. In equilibrium, the forward-looking variables and the instrument will still be functions of the predetermined variables,

$$x_t = H(X_t), \tag{2.33}$$

$$i_t = F(X_t), \tag{2.34}$$

[24] In the commitment case, the optimal policy and the forward-looking variables also depend on the shadow prices of the forward-looking variables. Only the discretion solution is considered here. See Svensson and Woodford [66] for the difference between discretion and commitment and its importance for inflation targeting.

but the functions $H(\cdot)$ and $F(\cdot)$ are no longer linear.

2.3. The transmission channels

In summary, the model consists of the aggregate-supply equation, (2.1), the CPI equation, (2.6), the aggregate-demand equation, (2.9), the definitions of the sum of current and expected future real interest rates and the real interest rate, (2.10) and (2.11), real interest-rate parity, (2.15), and the equations for the exogenous variables: foreign inflation and output, the foreign-exchange risk premium and the foreign interest rate, (2.18)–(2.21).

Let us temporarily disregard the zero bound (2.12) and examine how the transmission mechanism of monetary policy is modelled here. The timing and the lags have been selected to provide somewhat realistic relative lags for the transmission of monetary policy. Consider a fall in the instrument, the short nominal interest rate i_t, in period t. Current domestic inflation and the output gap are predetermined. Domestic inflation in period $t+1$ will be sticky, and so are domestic inflation expectations, $\pi_{t+1|t}$. Thus, the short real interest rate, r_t, is affected, and falls.[25] The forward-looking variables ρ_t and q_t are affected by the current real interest rate but also by expected future real interest rates. Thus, the change in the whole expected future path of the real interest rate matters. Assume that there is some persistence in the real rate fall, so that also the expected real interest rate in the near future falls. Then, ρ_t falls and q_t rises unambiguously. That is, the long real rate falls, and there is a real depreciation of the domestic currency. The real depreciation affects current CPI inflation π_t^c by (2.6), the *direct exchange-rate channel to CPI inflation*.

Furthermore, $\rho_{t+1|t}$ falls, that is the expected future long real rate falls, since expected future real rates fall. This increases the output gap, y_{t+1}, by (2.9), and hence increases aggregate demand (since aggregate demand is the endogenous component of the output gap). This can be called the *real-interest-rate channel to aggregate demand*. Furthermore, the expected future real exchange rate, $q_{t+1|t}$, rises, which further increases aggregate demand one period ahead, which can be called the *exchange-rate channel to aggregate demand*.

Having traced the transmission channels to aggregate demand, we can examine the effect on domestic inflation one period ahead, π_{t+1}, in (2.1). In the Calvo model with inflation predetermined one period ahead that lies behind (2.1), domestic inflation in period $t+1$ is determined by

[25] In Svensson [65] and [61], $\pi_{t+1|t}$ is predetermined (because domestic inflation is assumed to be predetermined two periods ahead), so i_t affects r_t one-to-one. In this model, $\pi_{t+1|t}$ is endogenous, and r_t being increasing in i_t is an equilibrium property.

expectations in period t of inflation in period $t+2$ and of marginal cost of production in period $t+1$. Marginal cost is increasing in the output gap and, because imported-intermediate inputs are used in production, also in the real exchange rate. This is the reason $y_{t+1|t}$ and $q_{t+1|t}$ enter in (2.1). Thus, expectations of future increases in the output gap and real exchange rate from the expected fall in future real rates will lead to a rise in domestic inflation one period ahead. This can be called the *aggregate-demand channel* and the *exchange-rate channel to domestic inflation* (this can be said to constitute a marginal-cost channel to domestic inflation).

Finally, domestic inflation in period $t+1$ also depends on expectations of domestic inflation in period $t+2$, the term $\pi_{t+2|t}$ in (2.1). With persistence of the increase in inflation in period $t+1$, inflation expectations for $t+2$ rise, which then adds to domestic inflation in period $t+1$. This is a *direct expectations channel to domestic inflation* in period $t+2$. Naturally, this is not the only expectations channel; indeed, expectations channels abound in the transmission mechanism. We have seen above that $\rho_{t+1|t}$ and $q_{t+1|t}$ that enter into one-period-ahead aggregate demand in (2.9) are determined by accumulated expected future real interest rate. For a given future nominal interest rate, higher expected inflation also further decreases the expected future real rate, and hence, adds to the positive effect on aggregate demand. Indeed, expectations of future variables are crucial in the transmission mechanism.

Thus, by assumption, there is no lag in the monetary policy effect on CPI inflation, a one-period lag in the effect on aggregate demand, and a one-period lag in the effect on domestic inflation. Both VAR evidence and practical central-bank experience indicate that there is a shorter lag for the effect of a monetary-policy action on CPI inflation than for aggregate demand and domestic inflation.[26]

2.3.1. A credit channel and a direct money channel

The reader may have noticed that two potential transmission channels have not been modelled above, namely the *credit channel* and a separate *money channel* (for instance, a real-balance channel). A more elaborate model than the one underlying (2.1) and (2.9) with capital market imperfections would, as discussed in Bernanke and Gertler [9] and Bernanke, Gertler and Gilchrist [10], allow some firms' and consumers' borrowing possibilities to depend on their collateral (their balance sheet). These agents then face marginal borrowing costs exceeding the real interest rate referred to above, by an "external-finance premium". A reduction in the real inter-

[26] See, for instance, Cushman and Zha [18].

est rate would then increase the value of the collateral and thereby allow these agents to borrow at a lower external-finance premium and, in this way, additionally stimulate aggregate demand beyond the "pure" real interest rate effect discussed above, via a "balance-sheet channel". As detailed in Bernanke, Gertler and Gilchrist [10], improving balance sheets and increased credit flows may also have significant feedback and magnification effects; what these authors call the "financial accelerator". Since these effects would have the same signs as the "pure" real interest rate effects, they would, in the present simplified model, appear as larger coefficients on the real interest rate in (2.9) (although a more elaborate model would also introduce the initial financial position as an important state variable). Thus, in the present model, we take the credit channel to be included in the interest-rate channel to aggregate demand.

What about a direct money channel, for instance, a real-balance effect, to aggregate demand, in addition to the real interest-rate channel emphasized above? Naturally, money lies behind the transmission mechanism outlined below in the sense that central banks use open-market operations, especially repurchase contracts, to affect the amount of reserves supplied and, in this way, supply whatever reserves are demanded at the desired level of the instrument rate (an operating target), an overnight rate or a two-week repurchase rate, say. Given this, nothing is lost if we think of the instrument rate as the central-bank instrument and consider reserves to be demand-determined. A direct money channel, however, is something different than supplying reserves to achieve a particular level of the instrument rate; furthermore it involves broad money rather than the monetary base. Meltzer [46] and Nelson [48] find some empirical support for a direct effect of real money on aggregate demand, in addition to the effect via the interest rate. Such an effect might be expected to show up as real money entering on the right side of (2.9), in addition to the other variables. However, as Woodford [76] emphasizes, to the extent that such an effect is interpreted as a wealth effect, the Euler condition used in deriving an aggregate-demand relation as (2.9) already incorporates any wealth effects (and, more generally, an intertemporal budget constraint).[27] As discussed by Woodford [76], Nelson [48] and McCallum [39], a direct money effect would arise, if real balances entered the representative agent's utility function and this utility function was not additively separable in consumption and real balances but had a positive cross-derivative. However, reasonable parameter values make any such effect so small that it can safely be disregarded. Meltzer [46] and Nelson [48] emphasize that a direct effect

[27] This is due to the fact that the Euler condition that is solved forward to get (2.9) is such that current consumption depends negatively on the real interest rate and positively on expected future consumption, and the wealth effect (and generally the impact of the intertemporal budget constraint) enters via expected future consumption.

of money may instead be a proxy for effects of other asset prices and interest rates than the short nominal interest rate, in particular long bond rates. However, if this is the reason for a direct money effect, including those asset prices and interest rates explicitly would seem more satisfactory. In our case, a long rate is already included via the variable ρ_t, and among other potential other asset prices at least the exchange rate is already included. For this reason, I choose not to include a separate direct-money channel to aggregate demand here.[28] [29]

2.4. A binding zero bound

Let us now consider the transmission mechanism when the zero bound (2.12) is taken into account and sometimes binds. Consider a situation where the zero bound is binding, in the sense that (2.28) implies a negative interest rate. This could, for instance, be the result of a series of negative demand shocks, which would call for expansionary monetary policy. If the usual instrument rate hits the zero bound, are there any other expansionary monetary policy actions available, or does monetary policy become ineffective and the central bank can only wait for better times? Several potential actions have been discussed in the literature (see the references in footnote 1).

In the model above, it is ρ_t and even $\rho_{t+1|t}$ that matter, rather than r_t. If there are expectations of the nominal interest rate becoming positive in the future, the central bank may try to commit (as suggested by Orphanides and Wieland [54]) to maintaining the nominal interest rate at zero for longer than so far expected by the private sector . If this commitment is credible, this will shift expectations of future nominal rates downward and, at unchanged inflation expectations, expected future real rates downward to the same extent. This will reduce ρ_t and stimulate the economy, everything else equal. However, absent any particular commitment mechanism, the commitment may not be credible and interest rate expectations not much affected.

Another action is further expansion of the monetary base, even when the short interest rate has fallen to zero, along the lines of Meltzer [46] and [45]. But with a zero interest rate, short

[28] Although admittedly, ρ_t, which is proportional to a long real rate, is determined by the simple expectations hypothesis in (2.10). This may not do justice to Meltzer and Nelson; they may have in mind risk premia, a term premium, for instance, that depend on real money via some portfolio-balance effect.

[29] The so-called P^* model is of a different category (see Hallman, Porter and Small [27], Tödter and Reimers [68] and Svensson [64]). Here, the price gap (the current price level less the prive-level in long-run equilibrium with an unchanged broad money stock) or, equivalently (with a change of sign), the *real money gap* (current real broad money less real broad money in a long-run equilibrium) enters into a traditional accelerationist Phillips curve in the place of the output gap. Although there is some empirical support for the P^* model (see Hallman, Porter and Small [27], Tödter and Reimers [68] and Gerlach and Svensson [25]), absent any microfoundations, this empirical support is difficult to interpret. As shown in Rudebusch and Svensson [58], the real money gap and the output gap may be highly correlated, in which case the real money gap may enter as a proxy for the output gap. Therefore, I do not incorporate the P^* model here.

government bonds would be more or less perfect substitutes for reserves, so it is not clear that the private sector holding more money and less short government bonds would have much effect on other asset prices, including the exchange rate, unless a further expansion of the monetary base somehow affects inflation and exchange-rate expectations. Meltzer actually suggests open-market operations in other assets than short government bonds, in order to affect other asset prices, notably the exchange rate, via imperfect substitutability and portfolio-balance effects.

One possibility is to do open-market operations in longer government bonds and, in this way try, to reduce long nominal and real interest rates (also suggested by Lebow [36]). If this works, it is either because this action reduces expectations of future nominal rates (under the expectations hypothesis) or because the relation between long and short rates involves risk premia, term premia (not included in the model above), that depend on outstanding stocks of longs bonds via a portfolio-balance effect that can be exploited by the central bank. A third possibility is that such open-market operations increase inflation expectations and thus lowers ρ_t.

Naturally, r_t and ρ_t are not the only interest rates in a more elaborate setting, there is a whole spectrum of rates on corporate bonds and loans which are, in equilibrium, higher than the government bond rates because of some default risk. Thus, the central bank can, in principle, do open-market operations in corporate bonds and even open a window and lend directly to the private sector and thereby lower these rates and stimulate the economy. Since buying these bonds and making these loans means taking on some risk, the central bank is subsidizing this risk, so such actions have elements of fiscal policy in them. This can also be interpreted as an attempt to exploit the credit channel, by making some firms less dependent on their balance sheet to obtain loans and effectively lowering their external-finance premium.

Suppose current and expected future nominal rates cannot be further affected. If the central bank can increase the real exchange rate, that is, cause a real depreciation of the currency, it can still stimulate aggregate demand and inflation via the exchange-rate channels discussed above. Can the central bank affect the exchange rate when the nominal interest rate is zero? McCallum [39] has argued that foreign-exchange interventions can still affect the exchange rate, even if interest rates are zero. If the real exchange rate fulfills the interest-rate parity condition (2.15) with an exogenous foreign-exchange risk premium, φ_t, as in (2.20), the real exchange rate can only be affected if ρ_t is affected. If the central bank cannot affect current and expected nominal interest rates and expected inflation, it cannot affect ρ_t and hence, not q_t. However, suppose that the foreign-exchange risk premium φ_t is partly endogenous and in the simplest possible case via a portfolio-balance effect affected by relative holdings domestic- and foreign-currency assets. Then, instead of (2.20) we might have

$$\begin{aligned}\varphi_t &= \psi(b_t - b_t^* - s_t) + \bar{\varphi}_t,\\ \bar{\varphi}_t &= \bar{\varphi} + \gamma_\varphi(\bar{\varphi}_t - \bar{\varphi}) + \xi_{\varphi,t+1},\end{aligned}$$

where b_t and b_t^* are private (log) holdings of domestic- and foreign-currency nominated assets (including currency), respectively, ψ is a positive constant, and $\bar{\varphi}_t$ is the exogenous component of the foreign-exchange risk premium. Then, foreign-exchange interventions that change the relative holdings of domestic- and foreign-currency nominated assets would affect the nominal and real exchange rate. McCallum does not provide any calibration of the parameters or discuss the magnitude of interventions needed to affect the foreign-exchange risk premium, though. Again, aggressive foreign-exchange interventions might affect exchange-rate expectations and thus affect the current exchange rate, even in the absence of a portfolio-balance effect.

I have already referred to private sector expectations and several expectations channels in the transmission mechanism several times. More specifically, if the central bank can somehow affect private-sector expectations of future inflation, everything else equal it will be reducing expected future real interest rates, reduce current and expected future real rates, increase (depreciate) the current and expected future exchange rate, increase actual future output, and increase actual future inflation. Krugman [33], who has strongly emphasized the role of expectations in getting out of a zero-bound situation (a temporary liquidity trap), has stated that the central bank should "credibly promise to be irresponsible." In less striking but more precise words, the central bank should attempt to restore inflation expectations to a sound positive level, more precisely to its inflation target, $\hat{\pi} > 0$. That is, it should credibly promise to be responsible and bring the inflation back to its target.

Although any increase in private inflation expectations would be helpful in the short run, as emphasized by Posen [55] it is advantageous to anchor inflation expectations to a suitable inflation target, that is, getting a credible inflation target. This should help avoiding the opposite problem, getting too high and/or unstable inflation expectations and risking a change to a high, unstable and uncertain inflation rate. For Japan, Krugman [33] has suggested a 4 percent inflation target for 15 years. A more moderate target may be more credible, in the sense of it being more desirable to keep it unchanged after having escaped from the liquidity trap. For

Japan, Posen [55] has suggested an initial inflation target of 3 percent, to be reduced to 2 percent within a few specified years.

An announcement is not likely to be enough, though. Setting up the whole inflation-targeting framework, with published inflation forecasts, transparent inflation reports, etc., is a more serious commitment. Acting accordingly, motivating the interventions, explaining the role of the emergency measures used, etc., is then a natural ingredient in building credibility for the inflation target and getting rid of deflationary expectations.

A price-level target (path) corresponding to a positive long-run inflation (say 2 percent), may, if it can be made credible, have special advantages. With a credible price-level target, some deflation would, by itself, increase expected future inflation, and hence reduce real interest rates and cause a real depreciation of the currency, even if nominal interest rates are unchanged. Furthermore, long-run inflation expectations would not depend on whether the price-level target will be missed in the near future.[30]

Although a number of potential monetary-policy actions have been suggested for a situation with a liquidity trap and a binding zero bound, there remains considerable uncertainty about how effective they might be, especially when they rely on portfolio-balance effects of uncertain magnitude. None of them seem to be foolproof ways of escaping from a liquidity trap. In particular, although a credible positive inflation target or a credible price-level target path would clearly be very desirable, and by itself stimulate the economy in a liquidity trap via the expectations channels, it is not clear how effective actions to establish such credibility would be, at least in the short run.

Fortunately, for an open economy, there seems to be a foolproof way of escaping from a liquidity trap.

3. A foolproof way of escaping from a liquidity trap

Let us now consider an open economy in the above model in an initial liquidity trap. The zero bound is binding, so short nominal interest rates are zero. Expected domestic inflation is negative, so the real interest rate is positive. The economy is in recession and the current output gap is negative. Expectations and forecasts point to continued deflation and a negative output

[30] It is an open question whether, away from the zero bound, inflation targeting or price-level targeting is the preferred policy. Conventional wisdom has been that price-level targeting would imply more short-term inflation variability and/or output-gap variability. This conventional wisdom has recently been challenged by Svensson [62], Woodford [77], Vestin [72], King [32] and Batini and Yates [5], where it is shown that different forms of price-level targeting may very well reduce short-term inflation and/or output-gap variability.

gap for some time ahead. The nominal interest rate is lower than in the rest of the world so, to the extent uncovered interest parity holds, the domestic currency is expected to appreciate. Flexible inflation targeting with a small positive inflation target and some weight on stabilizing output around potential output calls for a more expansionary monetary policy and a lower real interest rate, but the central bank is prevented from lowering its instrument rate by the zero bound.

3.1. The foolproof way

I would like to suggest that there is indeed a foolproof way of implementing a more expansionary monetary policy and escaping from such a liquidity trap. This involves introducing a price-level target path corresponding to a small positive long-run inflation target and jump-starting the economy by a devaluation of the currency and temporary exchange-rate peg. More precisely, a central bank that wants to escape from the liquidity trap should:

(1) Announce an upward-sloping price-level target path $\{\hat{p}_t\}_{t=t_0}^{\infty}$ for the domestic price level,

$$\hat{p}_t = \hat{p}_{t_0} + \hat{\pi}(t - t_0), \quad t \geq t_0, \tag{3.1}$$

with the price-level target for the current period t_0 exceeding the current price level,

$$\hat{p}_{t_0} > p_{t_0}, \tag{3.2}$$

and with a small positive long-run inflation target (for instance, 2 percent per year),

$$\hat{\pi} > 0.$$

(2a) Announce that the currency will be devalued and that the exchange rate will be pegged to a crawling exchange-rate target,

$$s_t = \bar{s}_t, \quad t \geq t_0, \tag{3.3}$$

where the exchange-rate target $\bar{s}_t$ is given by

$$\bar{s}_t = \bar{s}_{t_0} + (\hat{\pi} - \pi^*)(t - t_0), \quad t \geq t_0. \tag{3.4}$$

That is, the central bank makes a commitment to buy and sell unlimited amounts of foreign currency at the exchange rate $\bar{s}_t$. The initial exchange-rate target after the devaluation, $\bar{s}_{t_0}$, is chosen such that there is real depreciation of the domestic currency relative to the steady state,

$$q_{t_0} \equiv p^*_{t_0} + \bar{s}_{t_0} - p_{t_0} > q \tag{3.5}$$

(recall that the domestic price level is sticky, so that in the short run, the real exchange rate moves one-to-one with the nominal exchange rate). The exchange-rate target then corresponds to a nominal depreciation of the domestic currency at the rate of the difference between the domestic inflation target and average foreign inflation, $\hat{\pi} - \pi^*$. That is, if $\hat{\pi} < \pi^*$, there is a nominal appreciation, and if $\hat{\pi} = \pi^*$, the peg is fixed instead of crawling.

(2b) Announce that, when the price-level target path has been reached, the peg will be abandoned, either in favor of flexible price-level targeting with the same target path, that is, with a period loss function given by

$$L_t = \frac{1}{2}[(p_t - \hat{p}_t)^2 + \lambda y_t^2], \tag{3.6}$$

or in favor of flexible inflation-targeting with the same inflation target, that is, with a period loss function given by (2.22). Which alternative is announced would be determined by whether a price-level targeting without base drift of the price level or inflation targeting with such base drift is preferred in the long run.[31] [32]

(3) Then, just do it.

3.2. Why would this work?

Why would this work? The argument proceeds in several steps, to be explained in detail below: (i) It is technically feasible for the central bank to devalue the currency and peg the exchange rate at a level corresponding to an initial real depreciation of the domestic currency relative to the steady state. (ii) If the central bank demonstrates that it both can and wants to hold the peg, the peg will be credible. That is, the private sector will expect the peg to hold in the future. (iii) When the peg is credible, the central bank has to raise the short nominal interest rate above the zero bound to a level corresponding to uncovered interest rate parity. Thus, the economy is formally out of the liquidity trap. In spite of the rise of the nominal interest rate, the long real rate falls, as we shall see. (iv) Since the initial real exchange rate corresponds to a real depreciation of the domestic currency relative to the steady state, the private sector must expect a real appreciation eventually. (v) Expected real appreciation of the currency implies, by

[31] The central bank may also announce that it wants to shift to targeting the CPI level or inflation rather than domestic price level or inflation. Escaping from the liquidity trap is more easily discussed in terms of the domestic price level, though.

[32] Flexible price-level targeting without base drift in the price level would correspond to the period loss function (3.6) rather than (2.22). With such a loss function, the model can be expressed in the state-space form (2.24)–2.26), with the vectors of predetermined variables, target variables and target levels defined as $X_t \equiv (\pi_t, y_t, \pi_t^* - \pi^*, y_t^*, i_t^* - i^*, \varphi_t - \varphi, y_t^n, q_{t-1} - q, p_{t-1} - \hat{p}_{t-1}, \hat{p}_t)$, $Y_t \equiv (p_t - \hat{p}_t, y_t)'$ and $\hat{Y}_t \equiv (0, 0)'$. That is, the domestic price level and the price-level target are additional predetermined variables.

real interest parity (2.15) and (2.16), that the long real interest rate is lower. (vi) Furthermore, given the particular crawling peg (3.4), a real appreciation of the domestic currency will arise only if domestic inflation exceeds the inflation target. Therefore, the private sector must expect inflation to eventually rise and even exceed the inflation target.

(vii) The economy is hence jump-started by (a) a real depreciation of the domestic currency, (b) a lower long real interest rate and (c) increased inflation expectations. Via the transmission channels discussed in section 2, the output gap will rise because of (a) and (b). Inflation will increase above the inflation target by (a), (c) and the increase in the output gap, and thus induce a real appreciation of the domestic currency. (viii) With actual inflation above the inflation target, the price level will eventually catch up with the price-level target path. (ix) When the price-level target path has been reached, the peg will be abandoned, and monetary policy shifts to flexible price-level targeting or flexible inflation targeting, depending on what has previously been announced.

Let me explain this argument in more detail. With regard to step (i), it is indeed possible for the central bank to devalue the domestic currency and peg the nominal exchange rate at a level corresponding to a real depreciation relative to the steady state. The central bank will make a commitment to buy and sell unlimited amounts of domestic currency for foreign currency at the target exchange rate. Since the currency has been devalued so as to achieve a real depreciation relative to the steady state, the currency will be *strong* in the sense of there being appreciation pressure. Thus, the domestic currency will be in demand, and the central bank can always fulfill that demand by issuing enough volumes of domestic currency. The central bank's foreign-exchange reserves will rise, but this is not a problem in a situation when the central bank wants inflation and inflation expectations to pick up.

In contrast, a central bank defending a *weak* currency, in the sense of there being depreciation pressure, would be buying the domestic currency and paying with its foreign-exchange reserves, eventually risking running out of foreign-exchange reserves and having to float the currency. There is indeed a big difference between defending a strong currency and a weak one, since by issuing more domestic currency and allowing foreign-exchange reserves to grow without bounds, the strong currency can be defended indefinitely. There are many examples of central banks pegging a weak currency being overwhelmed by speculative attacks, and having to float because they have run out of foreign-exchange reserves or because the level of domestic interest rates needed to stop the onslaught are too costly to be credible.[33] In contrast, a central bank pegging a strong currency would only abandon the peg by choice, if the size of the foreign-exchange reserves and the stock of money become too inflationary or the low interest rate to counter the appreciation pressure is too expansionary and causes the economy to overheat. This is obviously not the situation for an economy in a liquidity trap. When inflation and activity starts picking up, the price-level will eventually hit the price-level target path, and the peg will be abandoned. The idea is that the price-level target shall be met before the economy has become dangerously overheated.

Note that the argument does not depend on any portfolio-balance effects of foreign-exchange interventions, in contrast to the argument of Meltzer [46] and McCallum [39], and thus, it is more general. Indeed, we can assume that there is no portfolio-balance effect and that uncovered interest parity (2.14) holds, with an exogenous or even zero foreign-exchange risk premium. As long as the central bank supplies an unlimited amount of domestic currency at the target exchange rate $\bar{s}_t$, arbitrage in the foreign-exchange market will ensure that this exchange rate is the equilibrium exchange rate.[34] Alternatively, as discussed in appendix B, one can think of the temporary peg as supported by a threat of foreign-exchange interventions of huge volumes, at which a portfolio-balance effect would realistically appear and depreciate the currency. This threat excludes the possibility that the peg would fail.

With regard to step (ii), if the central bank thus demonstrates that it can hold the peg, the peg will become credible. That is, private-sector exchange-rate expectations will fulfill

$$s_{t+\tau|t} = \bar{s}_{t+\tau}, \quad \tau \geq 0 \tag{3.7}$$

With regard to step (iii), combining (3.7) with (3.4), we have that private-sector exchange-rate expectations fulfill

$$s_{t+1|t} = s_t + \hat{\pi} - \pi^*. \tag{3.8}$$

Together with (2.14), this implies that the equilibrium interest rate will no longer be zero but rise to fulfill

$$i_t = i_t^* + \hat{\pi} - \pi^* + \varphi_t, \tag{3.9}$$

[33] See, for instance, Svensson [60] for more discussion.

[34] If there is a portfolio-balance effect and sterilized interventions are effective, the central bank will the have a choice between nonsterilized interventions, which amounts to buying foreign-exchange reserves and paying in domestic currency; thus see the monetary base rise with the foreign-exchange reserves, or sterilized interventions, which amount to selling domestic bonds for the foreign-exchange reserves (that is, reducing domestic credit) and keep the monetary base constant. However, the central bank might run out of domestic credit, in which case it would have to switch to nonsterilized interventions. Since the central bank always has the option to use nonsterilized interventions by issuing more currency, it can always fulfill the demand for the currency.

and the zero bound is no longer binding (I assume that $i_t^* + \hat{\pi} - \pi^* + \varphi_t > 0$). That is, when the peg becomes credible, if the central bank sets the interest rate equal to (3.9), domestic and foreign investors are indifferent between holding domestic-currency and foreign-currency nominated short bonds, and the central bank need no longer intervene on the foreign-exchange market to support the exchange-rate peg. Then, the monetary base will be demand-determined, at the interest rate given by (3.9). Appendix A supplies some further details on the establishment of the peg.[35]

At first thought, we might think that the rise in the nominal interest rate to (3.9) implies that the real interest rate has increased and monetary policy may not necessarily have become more expansionary, when the effect of both the real interest rate and the real exchange rate are taken into account.[36] As we shall see, however, increased inflation expectations dominate over the rise in the nominal rate.

Indeed, because the initial real exchange rate corresponds to a real depreciation relative to the steady state, (3.5), a real appreciation of the domestic currency must eventually occur, and the private sector must expect it to eventually occur, step (iv) above. Furthermore, by (2.16), we see that the real depreciation relative to the steady state implies a low ρ_t relative to ρ_t^*. Thus, we have demonstrated step (v), that the long real interest rates is lower.

With regard to step (vi), if the peg holds, by (2.5), (3.3) and (3.4), we have

$$q_{t+1} - q_t = -(\pi_{t+1} - \hat{\pi}) + (\pi_{t+1}^* - \pi^*). \tag{3.10}$$

For simplicity, let me temporarily take foreign inflation to be deterministic and constant, so that

$$\pi_{t+1}^* \equiv \pi^* \tag{3.11}$$

(that is, I assume that $\gamma_\pi^* = 0$ and $\varepsilon_t^* \equiv 0$ in (2.18); the more general case with (2.18) and base drift in the foreign price level is discussed in appendix C). Then, we have

$$q_{t+1} - q_t = -(\pi_{t+1} - \hat{\pi}), \tag{3.12}$$

so a real appreciation of the domestic currency occurs only if domestic inflation exceeds the inflation target. When the peg is credible, (3.7), this means that the private sector must expect

[35] A rise in short and long nominal interest rates implies capital losses for holders of government bonds and corresponding gains for the government. If these losses are a problem, they can obviously be undone by adjustment of the coupon on government bonds.

[36] Blinder [11], in his comments at the conference "Monetary Policy in a Low Inflation Environment," October 1999, in reference to an intervention from the floor by Dale Henderson suggesting a peg of the yen, observes that the nominal interest rate would then rise to the level of the foreign interest rate and concludes that the increase in the interest rate would imply a *tightening* of monetary policy.

inflation to eventually exceed the inflation target,

$$\pi_{t+\tau|t} - \hat{\pi} = -\left(q_{t+\tau|t} - q_{t+\tau-1|t}\right) > 0, \tag{3.13}$$

for some $\tau \geq 1$, and step (vi) has been demonstrated.

Thus, in step (vii), monetary policy is indeed expansionary, and the economy is jump-started by (a) a real depreciation of the domestic currency relative to the steady state, (b) a lower long real interest rate and (c) increased inflation expectations.

With regard to step (viii), we have already noted that a real appreciation (after the initial real depreciation) of the domestic currency implies that domestic inflation is higher than the inflation target. Thus, we know that the price level is approaching the price-level target path from below. Do we know that the price level will actually hit the price-level target path in finite time?

Suppose the exchange-rate peg would be maintained forever, and consider the steady-state domestic price-level path, $\{\bar{p}_t\}_{t=t_0}^{\infty}$, that is consistent with the exchange-rate peg. It is given by

$$\begin{aligned} \bar{p}_t &\equiv p_t^* + \bar{s}_t - q && (3.14) \\ &= p_{t_0}^* + \bar{s}_{t_0} - q + \hat{\pi}(t - t_0), && (3.15) \end{aligned}$$

where I have used (2.8), (3.1), (3.3) and (3.11). We realize that if this steady-state price-level path is above the price-level target path,

$$\bar{p}_t > \hat{p}_t, \tag{3.16}$$

the price-level target will be reached in finite time. Furthermore, from (3.1) and (3.15), we have

$$\begin{aligned} \bar{p}_t - \hat{p}_t &= p_{t_0}^* + \bar{s}_{t_0} - q - \hat{p}_{t_0} \\ &\equiv (q_{t_0} - q) - (\hat{p}_{t_0} - p_{t_0}). \end{aligned}$$

Thus, in order for (3.16) to be fulfilled, we must have

$$q_{t_0} - q > \hat{p}_{t_0} - p_{t_0} > 0,$$

where the last inequality restates (3.2).

Thus, the central bank wants the initial devaluation to cause a real depreciation relative to the steady state that is larger than the difference between the initial price-level target and the initial price level. The central bank can use the initial real depreciation relative to the steady-state level, $q_{t_0}-q$, as a measure of the extent to which monetary policy is initially expansionary.[37] The difference between the price-level target and the initial price-level, $\hat{p}_{t_0}-p_{t_0}$, will be a measure of how much the economy is intended to inflate and expand before the price-level target is hit; that is, how much of the "price gap" caused by several years of zero or negative inflation that the central bank intends to undo. For a given initial depreciation relative to the steady state $(q_{t_0}-q)$, the price-level target will be hit sooner the smaller the difference $\hat{p}_{t_0}-p_{t_0}$. For a given difference $\hat{p}_{t_0}-p_{t_0}$, the economy will hit the price-level target sooner and with higher activity and inflation, the larger the initial real depreciation relative to steady state $(q_{t_0}-q)$. Clearly, a greater and quicker recovery from the liquidity trap runs the risk of overheating the economy before or as the price-level target is being hit.[38]

3.3. The roles of the price-level target path and the exchange-rate peg

The role of the price-level target path is to provide the best nominal anchor for the economy. Once credible, a price-level target implies that long-run inflation expectations are independent of inflation the first few periods, and even that a few periods of deflation increases inflation expectations for the near future, thus providing automatic stimulation of the economy. Furthermore, the uncertainty about long-run inflation falls with the horizon. The difference between the initial price-level target from the initial price level provides a measure of how much accumulated above-normal future inflation the central bank wants, that is, how much of the price gap it wants to undo. The price-level target path also provides a well-defined criterion for abandoning the peg when the latter has done its work.

The role of the devaluation and peg corresponding to a real depreciation relative to the steady-state level is to jump-start the economy out of the liquidity trap. The difference between the initial real exchange rate after the devaluation and either the steady-state level of the exchange rate or the initial real exchange rate before the devaluation provides a measure of the magnitude of the jump-start, the initial boost to the economy.[39]

[37] Letting the real exchange rate in the liquidity trap immediately before the announcement be denoted by q_{t_0-}, we can use the difference $q_{t_0}-q_{t_0-}\equiv s_{t_0}-s_{t_0-}$ as (one measure of) the change in monetary policy with the new policy, the boost to the economy.

[38] Obviously, the precise path of the economy can be characterized more explicitly, for instance by simulations of the model.

[39] The price-level target path and the peg that is maintained until the price-level target path is reached makes the foolproof way differ from Feldstein's [21] proposal (see footnotes 4 and 7). Feldstein suggests an initial depreciation followed by a gradual nominal appreciation: "The Japanese government could add that it recognizes that such an exchange rate cannot last indefinitely and that it expects to permit the yen to rise at, say, 8% a year, reaching 129 after one year, 119 after two years and so on until the currency reaches a level at which intervention

3.4. The central bank's balance sheet

What are the balance-sheet consequences for the central bank of this policy? The initial devaluation will give the central bank a capital gain on (the domestic-currency value of) its initial foreign-exchange reserves. While defending the peg in the initial phase, the central bank acquires foreign-currency denominated assets with a depreciated domestic currency, at the exchange rate $\bar{s}_{t_0}$. The extent to which the central bank's foreign-exchange reserves will rise initially depends on how long and how massive foreign-exchange interventions it takes to gain credibility for the peg. Once credibility has been achieved and the domestic interest rate has risen to (3.9), the money base will be demand-determined, and the domestic-currency return on foreign-exchange reserves equals (3.9). Thus, initial capital gain on the foreign-exchange reserves is the main balance-sheet consequence for the central bank. Appendix A provides further details on the initial currency flows.

4. Conclusions for Japan

The monetary policy of Bank of Japan is very controversial. A number of economists, including Bernanke [8], Blinder [11], Fedstein [21], Ito [31], Krugman [33], McCallum [39], Meltzer [43]-[46], Mussa [47], Posen [55] and Svensson [63] have suggested monetary policy actions and changes that may improve the economic situation in Japan. In particular, Bernanke, Krugman, Meltzer and Posen have contributed more detailed arguments, criticism and suggestions. In contrast, responses from Bank of Japan, including Okina [50] and [52] and Ueda [69] and [70], have consistently defended a policy of not taking any actions beyond lowering the instrument rate to zero.

The gist of the Bank of Japan argument, as far as I can see, seems to be that, since one cannot be absolutely sure that any given policy action or change in the monetary policy regime will succeed in getting the economy out of the liquidity trap, it is safer not to try. The logic of this argument escapes me. Instead, as argued in Svensson [63], it seems that, if a monetary expansion is deemed desirable, prudent policy calls for trying a number of the suggested remedies (as long as they are not inconsistent), in the hope that some may work. Some of the Bank of Japan arguments for no further action have pointed to potential negative consequences for its balance sheet and that the responsibility for foreign-exchange interventions rests with the Ministry of

is no longer needed." With a gradual nominal appreciation, inflation and inflation expectations would not be generated to the same extent, or not at all.

Finance. This seems like setting myopic bureaucratic interests and technical details above the welfare of the country, in a situation where leadership and resolve is called for (see Bernanke [8]).

Now, there is an additional possibility for Bank of Japan (and the Ministry of Finance): a foolproof way of escaping from its liquidity trap and recession, namely combining a price-level target path corresponding to positive inflation with a devaluation of the yen and a temporary exchange-rate peg to jump-start the economy. Exchange-rate policy and monetary policy cannot be separated under free international capital mobility, since exchange rates and interest rates cannot then be set independently. Nevertheless, many countries, including Japan, have the inconsistent institutional setup that exchange-rate policy is the responsibility of the government, via the ministry of finance, rather than the responsibility of the central bank. For Japan, I understand that the Bank of Japan is not allowed to undertake independent foreign-exchange interventions in order to affect the exchange rate. Given this, the temporary exchange-rate peg required for the foolproof way of escaping a liquidity trap requires an explicit agreement between Bank of Japan and the Ministry of Finance. When the welfare of the country is at stake, it would seem that such an agreement should not be difficult to conclude.[40]

Given the discussion in Okina [50]-[52] and Ueda [69] and [70], if a monetary expansion is deemed desirable, what objections might Bank of Japan still have to the foolproof way? The proposal of Krugman [33] and others of a positive inflation target has been rejected by Bank of Japan with the argument that the proposal does not in itself suggest any means for the Bank of Japan to achieve the inflation target. Regardless of the validity of this argument, it does not apply to the foolproof way with its price-level target path, since the foolproof way suggests a very specific means to achieve the price-level target, namely the temporary exchange-rate peg. With regard to the proposal by Meltzer [46], McCallum [39] and others to depreciate the yen, Okina [50]-[52] emphasizes that it is the Ministry of Finance and not Bank of Japan that is responsible for exchange-rate policy, seems to agree that unlimited foreign-exchange

[40] Since the net balance-sheet consequences for Bank of Japan of the proposed way of escaping from the liquidity trap seem to be positive, they provide no reason for Bank of Japan objections. The Bank of Japan Law has the asymmetric provision that Bank of Japan profits are delivered to the Government whereas losses are born by the Bank (see Okina [50]). Because of this, Bank of Japan has resisted proposals to buy long-term government bonds, since it would suffer capital losses when long-term bond rates rise to normal levels (even though these losses would correspond one-for-one to Government capital gains). It may be advantageous, as suggested by Bernanke [8], to revise the law to put Bank of Japan on a fixed operating allowance and make the Government the residual claimant of gains and losses to the Bank's balance sheet. Before such a revision, it would seem that an agreement with the Ministry of Finance on how to escape from the liquidity trap could also include a Government guarantee to cover any capital losses encountered by the Bank. To most observers, it of course seems bizarre if minor balance-sheet consequences (especially if they cancel between the Bank and the Government) are allowed to stand in the way of the welfare of the country.

interventions (in cooperation between Bank of Japan and the Ministry of Finance) to achieve a target exchange rate would work, but warns that "given that the floating exchange rate system has prevailed among industrialized countries for quite a long time, any attempt at unlimited intervention to bring the foreign exchange rate back to something akin to a fixed exchange rate regime would be a grand experiment" [51, p. 196] (probably meaning "*too* grand an experiment"). This argument (again regardless of its validity) does not seem to apply to the foolproof way, since that is for a *temporary* devaluation and exchange-rate peg to achieve the price-level target and not a permanent shift to a fixed exchange-rate regime (as proposed by McKinnon [41] and [42]).

One possible objection to the foolproof way is that it is similar to a competitive devaluation, and that trading partners may have objections. First, one can observe that, due to (2.16), *any* monetary expansion that results in a lower long real interest rate must in equilibrium be associated with a real depreciation. Hence, if one objects to any real depreciation, one essentially objects to any monetary expansion. Second, jump-starting the Japanese economy should sooner or later increase Japanese demand for import from the rest of the world. As is well known, the current account effects of a devaluation are generally ambiguous, with substitution and income effects of opposite signs. To most observers, it seems rather uncontroversial that Japanese, Asian and world welfare would all be well served by an expansion of the Japanese economy.[41]

[41] At the time of writing, the official view of Bank of Japan is that the Japanese economy has improved to such an extent that any further monetary expansion is not needed, and Bank of Japan has just (defying practically all external advice, including IMF [30]) taken the very controversial action of raising the interest rate above zero, stating that "deflationary concern has been dispelled" (Bank of Japan [3]) without reference to forecasts of the CPI or GDP-deflator and in spite of current deflation in these price indices.

A. Devaluing the currency and establishing the peg

This appendix discusses the establishment of the temporary peg in some detail.

A.1. Before the peg

In the initial situation, before the devaluation, we have a zero interest rate ($i_t = 0$), a clean float and, by (2.14),

$$s_{t+1|t} - s_t = -i_t^* < 0, \tag{A.1}$$

where I for simplicity set the foreign-exchange risk premium equal to zero ($\varphi_t \equiv 0$). That is, the currency is expected to appreciate at a rate equal to the foreign interest rate. The foreign-exchange market is in equilibrium and there are no foreign-exchange interventions. The expected domestic-currency (one-period) return on foreign(-currency one-period) bonds equals the zero domestic-currency (one-period) return on domestic(-currency one-period) bonds. Let t_0- denote the "beginning" of period t_0, before the (unanticipated) announcement of the devaluation and the peg, so the initial exchange rate, s_{t_0-}, and exchange rate expectations, $s_{t_0+1|t_0-}$, in the beginning of period t_0 fulfill

$$s_{t_0+1|t_0-} - s_{t_0-} + i_{t_0}^* = 0,$$

hence making the expected one-period domestic-currency return on foreign bonds equal to zero.

A.2. Initial lack of credibility of the peg

Let t_0 denote the "middle" of period t_0, after the announcement of the devaluation and the central bank's commitment to buy and sell unlimited amounts of foreign exchange at the exchange rate $\bar{s}_{t_0} > s_{t_0-}$. Suppose that the peg is not credible. More precisely, suppose that expectations of the period-t_0+1 exchange rate remain the same, so $s_{t_0+1} = s_{t_0+1|t_0-}$. Let the domestic interest rate be held at zero. Then the expected one-period domestic-currency return on foreign bonds at the exchange rate $\bar{s}_{t_0}$ fulfills

$$s_{t_0+1|t_0} - \bar{s}_{t_0} + i_{t_0}^* < 0,$$

so the expected one-period domestic-currency return on foreign bonds is less than the return on domestic bonds. Then there will be excess demand for domestic currency and excess supply of foreign currency. The central bank then intervenes and equilibrates the foreign-exchange market at the exchange rate $\bar{s}_{t_0}$ by supplying the corresponding amount of domestic currency, thereby adding to its foreign-exchange reserves. Arbitrage among foreign-exchange traders ensures that the market exchange rate equals $\bar{s}_{t_0}$.

A.3. A credible peg and a zero interest rate

Next, suppose that the peg becomes credible, when the central bank has demonstrated that it can fulfill the excess demand for domestic currency, so exchange rate expectations fulfill

$$s_{t+1|t} = \bar{s}_{t+1|t}$$

for $t \geq t_0$. Suppose the interest rate is still held at zero. Then the expected one-period domestic-currency return on foreign bonds in period t_0 is by (3.4) given by

$$\bar{s}_{t_0+1|t_0} - \bar{s}_{t_0} + i^*_{t_0} = \hat{\pi} - \pi^* + i^*_{t_0} > 0,$$

(where I again assume that $\hat{\pi} - \pi^* + i^*_t > 0$). Now, the expected domestic-currency return on foreign bonds has become positive and *larger* than the zero return on holding domestic bonds. Then foreign exchange will be in excess demand and domestic currency will be in excess supply. The central bank will have to intervene in the *opposite* direction, buying domestic currency and selling foreign exchange. It will hence be reducing its foreign-exchange reserves and it will have to raise the domestic interest rate before its foreign-exchange reserves are extinguished.

A.4. A credible peg and an equilibrium interest rate

So, let the central bank raise the domestic interest rate to equal

$$i_t = \hat{\pi} - \pi^* + i^*_t$$

for $t \geq t_0$ (corresponding to (3.13) with $\varphi_t \equiv 0$). Then the expected domestic-currency returns on domestic and foreign bonds are equal, the foreign-exchange market is in equilibrium, and no foreign-exchange interventions are needed. The total demand for base money will, in the simplest case, be a function of and decreasing in the domestic interest rate and increasing in the volume of transactions in domestic currency, which we assume depends on the output level. Thus we can write

$$\frac{M_t}{P_t} = g(i_t, Y^d_t), \tag{A.2}$$

where M_t is the quantity of base money, $P_t \equiv e^{p_t}$ is the absolute domestic price level and $Y_t^d \equiv e^{y_t^d}$ is the level of real domestic output (aggregate demand). More precisely, the central bank will be reducing the monetary base, via open-market operations or unsterilized foreign-exchange interventions, so as to increase the interest rate to the equilibrium level. Furthermore, the monetary base will equal the sum of the central bank's holding of domestic bonds (domestic credit), D_t, and the domestic-currency value of is holdings of foreign-currency bonds (foreign-exchange reserves), R_t (measured in foreign currency),

$$M_t = D_t + \bar{S}_t R_t,$$

where $\bar{S}_t \equiv e^{\bar{s}_t}$ is the absolute level of the exchange rate peg. Thus, although the total domestic monetary base, as usual under an exchange rate peg, is given to the central bank by (A.2) in equilibrium, the central bank can affect the composition of the monetary base into domestic credit and foreign-exchange reserves. For instance, in the previous stage A.3 (when the peg is credible, the domestic interest rate is at zero (below the equilibrium level) and the central bank is loosing foreign-exchange reserves) the central bank can time the increase in the interest rate to the equilibrium level so as to be able to stop foreign-exchange intervention when the foreign-exchange reserves have fallen to a desirable level.

A.5. Announcing the peg and increasing the interest rate simultaneously

Note that the central bank could in principle announce the peg and increase in the interest rate at the same time. The expected domestic-currency excess return on foreign bonds would then, at the pegged exchange rate, be given by

$$s_{t_0+1|t_0} - \bar{s}_{t_0} + i^*_{t_0} - i_{t_0} = s_{t_0+1|t_0} - \bar{s}_{t_0} - (\hat{\pi} - \pi^*).$$

If the peg is not credible, so $s_{t_0+1|t_0} < \bar{s}_{t_0+1}$, the excess return is negative, there will be excess demand for domestic currency, and the central bank will intervene and increase its foreign-exchange reserves. At the same time it will be doing open-market operations so as to reduce the overall monetary base and increase the interest rate. When credibility of the peg has been restored, it can stop intervening. How much foreign-exchange reserves have increased by then depends on how quickly credibility of the peg is achieved. This may come very quickly, in which case little foreign-exchange interventions may be needed. Alternatively, the foreign-exchange reserves may have risen to a level larger than desirable, for instance, having replaced most of domestic credit, which will require unwinding of the reserves over time. For this reason, it may be preferable to follow the sequence A.2–A.4 above, and only increase the domestic interest rate after credibility of the peg has been achieved.

A.6. Balance-sheet consequences

What are the balance-sheet consequences of the operations above. At the devaluation, the central bank makes a capital gain on its initial foreign-exchange reserves, $(\bar{S}_{t_0} - S_{t_0-})R_{t_0-} > 0$. After the devaluation, any foreign-exchange interventions are done at the pegged exchange rate $\bar{S}_t$, and domestic credit and foreign-exchange reserves earn the same return. When the temporary peg is later abandoned, the central bank will make capital gains and losses if the exchange rate jumps then. The magnitude of the capital gains and losses are then affected by the volume of foreign-exchange reserves, which is under control by the central bank.

A.7. An implicit short-run flow model of the foreign-exchange market

Note that the discussion in sections A.1–A.5 above is consistent with an implicit short-term flow model of the foreign-exchange market, where the volume of foreign-exchange intervention (the capital flow) is proportional to the expected excess return on holding foreign-currency bonds,

$$\begin{aligned} s_{t+1|t} - s_t + i_t^* - i_t &= -\varphi_t \\ \varphi_t &= \psi_t(R_t - R_{t-1}) + \bar{\varphi}_t, \end{aligned}$$

where φ_t is the total foreign-exchange risk premium, the coefficient ψ_t is positive and its dependence on t allows it to depend on the state of the economy (X_t), and $\bar{\varphi}_t$ is an exogenous component of the total foreign-exchange risk premium.

B. The threat of huge foreign-exchange interventions[42]

Arguably, the temporary peg could fail in the following way. The central bank announces the peg and commits to buying and selling unlimited amounts of foreign currency at the pegged rate, $\bar{s}_t$. However, assume that there is in fact a large but finite upper *limit* to how much domestic currency the central bank is willing to issue, and that this is anticipated by the market. Then, one possible equilibrium would seem to be that the foreign-exchange market just absorbs the increased supply of domestic currency up to the central bank's limit, after which the central

[42] I have benefitted from comments by Michael Woodford on this issue.

bank abandons the attempt to defend the peg. The domestic currency never depreciates to the desired peg and continues to float after the defence of the peg is abandoned. If domestic currency is a perfect substitute for foreign(-currency denominated) assets, the exchange rate would even follow exactly the same path, corresponding to (A.1), as followed if the central bank had never attempted to institute the peg. The foreign-exchange traders who bought the domestic currency at the pegged price has made a good deal (and the central bank has suffered a corresponding loss), but otherwise nothing has changed (obviously I am disregarding the fiscal consequences of the central bank's loss and the wealth effects of the traders' gains).

If the limit is small, the above is of course the likely scenario. However, if the limit is very large, it is realistic at such volumes of currency issue that domestic currency would no longer be a perfect substitute for foreign assets and some portfolio-balance effect would appear and depreciate the domestic currency, in which case the investors who just bought domestic currency would suffer losses. This would seem sufficient to exclude the equilibrium where the peg fails because the large issue of domestic currency is just absorbed by the foreign-exchange market with no effect on the exchange rate. Given this, the threat and any portfolio-balance effects need never materialize, and uncovered interest parity holds in the equilibrium with the temporary peg.

C. Base drift in the foreign price level

Now, I allow π^*_{t+1} to be determined by (2.18) instead of (3.11), so that p^*_t, given by (2.8), will no longer be deterministic but include a unit root and hence, be integrated order one, I(1). In particular, it follows from (2.8) and (2.18) that

$$p^*_t = p^*_{t_0} + \pi^*(t - t_0) + \frac{1 - (\gamma^*_\pi)^{t-t_0}}{1 - \gamma^*_\pi}\gamma^*_\pi(\pi^*_{t_0} - \pi^*) + \sum_{\tau=1}^{t-t_0}(\gamma^*_\pi)^\tau \varepsilon^*_{t+\tau}. \tag{C.1}$$

Suppose that the central bank pursues the same foolproof policy (1)–(3) with the same price-level target, (3.1), and the same peg, (3.3) and (3.4). Then, (3.10) implies

$$q_{t+1} - q_t = -(\pi_{t+1} - \hat{\pi}) + (\pi^*_{t+1} - \pi^*),$$

instead of (3.12). Thus, now

$$q_{t+\tau|t} - q_{t+\tau-1|t} = -(\pi_{t+\tau|t} - \pi^*) + (\gamma^*_\pi)^\tau(\pi^*_t - \pi^*).$$

If the term $(\gamma^*_\pi)^\tau(\pi^*_t - \pi^*)$ is sufficiently small, expected real appreciation would still approximately mean expected domestic inflation above the inflation target.

The domestic price-level consistent with the peg and the steady-state level of the real exchange rate, (3.14), is now

$$\bar{p}_t = p^*_{t_0} + \bar{s}_{t_0} - q + \hat{\pi}(t - t_0) + \frac{1 - (\gamma^*_\pi)^{t-t_0}}{1 - \gamma^*_\pi}\gamma^*_\pi(\pi^*_{t_0} - \pi^*) + \sum_{\tau=1}^{t-t_0}(\gamma^*_\pi)^\tau \varepsilon^*_{t+\tau},$$

instead of (3.15). This will introduce the same base drift in $\bar{p}_t$ and p_t as in p^*_t, which will introduce more variability in the time required for the domestic price level to catch up with the price-level target path. Unless foreign inflation is far off its steady-state level or the shocks to foreign inflation are large, if the catch-up would occur fairly soon in the absence of foreign price-level drift, this base drift will not matter much.

We note that $\bar{p}_t$ expected in period t_0, $\bar{p}_{t|t_0}$, fulfills

$$\bar{p}_{t|t_0} - \hat{p}_t = (q_{t_0} - q) - (\hat{p}_{t_0} - p_{t_0}) + \frac{1 - (\gamma^*_\pi)^{t-t_0}}{1 - \gamma^*_\pi}\gamma^*_\pi(\pi^*_{t_0} - \pi^*).$$

Thus, to ensure that $\bar{p}_{t_0+T|t_0} > \hat{p}_T$ for some horizon $T > 0$, the initial devaluation should be adjusted to fulfill

$$q_{t_0} - q > \hat{p}_{t_0} - p_{t_0} - \frac{1 - (\gamma^*_\pi)^T}{1 - \gamma^*_\pi}\gamma^*_\pi(\pi^*_{t_0} - \pi^*) > 0.$$

That is, the initial devaluation should take into account the expected foreign price-level increase in excess of that corresponding to average foreign inflation. This excess foreign price-level increase is measured by the term

$$\frac{1 - (\gamma^*_\pi)^T}{1 - \gamma^*_\pi}\gamma^*_\pi(\pi^*_{t_0} - \pi^*).$$

Note that there is a more sophisticated crawling (and drifting) peg that compensates for the base drift in the foreign price level. This would instead of (3.4) be

$$\bar{s}_t = \bar{s}_{t_0} + \hat{\pi}(t - t_0) - p^*_t.$$

With p^*_t given by (C.1), this implies

$$\bar{s}_t = \bar{s}_{t_0} + (\hat{\pi} - \pi^*)(t - t_0) + \frac{1 - (\gamma^*_\pi)^{t-t_0}}{1 - \gamma^*_\pi}\gamma^*_\pi(\pi^*_{t_0} - \pi^*) + \sum_{\tau=1}^{t-t_0}(\gamma^*_\pi)^\tau \varepsilon^*_{t+\tau}. \tag{C.2}$$

Thus, this crawling and drifting peg differs from the crawling peg (3.4) by the last two terms in (C.2). With this peg, we would again have (3.12), (3.13) and (3.15), and no drift is introduced into $\bar{p}_t$ and p_t during the peg.

D. Sticky initial deflation

I assume that the economy is initially in a liquidity trap with deflation, $\pi_{t_0} < 0$. Given the dependence of inflation on lagged inflation in (2.1), the deflation is sticky, and even if the temporary peg immediately becomes credible, and the economy is jump-started, deflation may continue for a few periods. Furthermore, it may take a few additional periods before inflation is above the long-run inflation target, $\hat{\pi}$. During those periods, by (3.12), the real exchange rate is depreciating further, increasing the expansionary effect of the real exchange rate on the output gap in (2.9) and inflation in (2.1). While there is deflation and expected deflation, because the nominal interest rate has been increased from zero to (3.13), the short real interest rate will be higher in the first few periods. This might seem to be contractionary. However, the aggregate-demand relation (derived from a forward-looking first-order condition in Svensson [61, appendix]) implies that it is the long real interest rate, corresponding to ρ_t, that matters for aggregate demand. This long-real interest rate depends on the degree of real depreciation relative to a long-run equilibrium, (2.16). Thus, a few periods of deflation and further real depreciation lowers the long real interest rate further. Even though the first few periods' short real interest rates increase, future real interest rates decrease more due to increased inflation, so the net effect on the long real interest rate is a decrease.

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