The zero-interest-rate bound and the role of the exchange rate for monetary policy in Japan\(^*\),\(^†\)

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Abstract

In this paper we study the role of the exchange rate in conducting monetary policy in an economy with near-zero nominal interest rates as experienced in Japan since the mid-1990s. Our analysis is based on an estimated model of Japan, the United States and the euro area with rational expectations and nominal rigidities. First, we provide a quantitative analysis of the impact of the zero bound on the effectiveness of interest rate policy in Japan in terms of stabilizing output and inflation. Then we evaluate three concrete proposals that focus on depreciation of the currency as a way to ameliorate the effect of the zero bound and evade a potential liquidity trap. Finally, we investigate the international consequences of these proposals.

JEL Classification System: E31, E52, E58, E61

Keywords: monetary policy rules, zero interest rate bound, liquidity trap, rational expectations, nominal rigidities, exchange rates, monetary transmission.

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1 Introduction

Having achieved consistently low inflation rates monetary policymakers in industrialized countries are now confronted with a new challenge—namely how to prevent or escape deflation. Deflationary episodes present a particular problem for monetary policy because the usefulness of its principal instrument, that is the short-term nominal interest rate, may be limited by the zero lower bound. Nominal interest rates on deposits cannot fall substantially below zero, as long as interest-free currency constitutes an alternative store of wealth.\(^1\) Thus, with interest rates near zero policymakers will not be able to stave off recessionary shocks by lowering nominal and thereby real interest rates. Even worse, with nominal interest rates constrained at zero deflationary shocks may raise real interest rates and induce or deepen a recession. This challenge for monetary policy has become most apparent in Japan with the advent of recession, zero interest rates and deflation in the second half of the 1990s.\(^2\) In response to this challenge, researchers, practitioners and policymakers alike have presented alternative proposals for avoiding or if necessary escaping deflation.\(^3\)

The purpose of this paper is two-fold. First, we provide a quantitative evaluation of the importance of the zero-interest-rate bound and the likelihood of a liquidity trap in Japan. Then, we proceed to investigate three recent proposals on how to stimulate and re-inflate the Japanese economy by exploiting the exchange rate channel of monetary policy. These three proposals, which are based on studies by McCallum (2000, 2001), Orphanides and Wieland (2000) and Svensson (2000, 2001), all present concrete strategies for evading the liquidity trap via depreciation of the Japanese Yen.

Our quantitative analysis is based on an estimated macroeconomic model with ratio-

\(^1\)For a theoretical analysis of this claim the reader is referred to McCallum (2000). Goodfriend (2000), Buiter and Panigirtzoglou (1999) and Buiter (2001) discuss how the zero bound may be circumvented by imposing a tax on currency and reserve holdings.

\(^2\)Ahearne et al. (2001) provide a detailed analysis of the lead up to deflation in Japan.

\(^3\)For example, Krugman (1998) proposed to commit to higher inflation target to generate inflationary expectations, while Meltzer (1998, 1999) proposed to expand the money supply and exploit the imperfect substitutability of financial assets to stimulate demand. Posen (1998) suggested a variable inflation target. Clouse et al. (2000) and Johnson et al. (1999) have studied the role of policy options other than traditional open market operations that might help ameliorate the effect of the zero bound.
nal expectations and nominal rigidities that covers the three largest economies, the United States, the euro area and Japan. We recognize the zero-interest-rate bound explicitly in the analysis and use numerical methods for solving nonlinear rational expectations models.\textsuperscript{4} First, we consider a benchmark scenario of a severe recession and deflation. Then, we assess the importance of the zero bound by computing the stationary distributions of key macroeconomic variables under alternative policy regimes.\textsuperscript{5} Finally, we proceed to investigate the role of the exchange rate for monetary policy as proposed by Orphanides and Wieland (2000) (OW), McCallum (2000, 2001) (MC) and Svensson (2000, 2001) (SV).

Orphanides and Wieland (2000) emphasize that base money may have some direct effect on aggregate demand and inflation even when the nominal interest rate is constrained at zero. In particular they focus on the portfolio-balance effect, which implies that the exchange rate will respond to changes in the relative domestic and foreign money supplies even when interest rates remain constant at zero. As a result, persistent deviations from uncovered interest parity are possible. Of course, this effect is likely small enough to be irrelevant under normal circumstances, i.e. when nominal interest rates are greater than zero, and estimated rather imprecisely when data from such circumstances is used. OW discuss the policy stance in terms of base money and derive the optimal policy in the presence of a small and highly uncertain portfolio-balance effect. They show that the optimal policy under uncertainty implies a drastic expansion of base money with a resulting depreciation of the currency whenever the zero-bound is effective.

McCallum (2000, 2001) (MC) also advocates a depreciation of the currency to evade the liquidity trap. In fact, he recommends switching to a policy rule that responds to output and inflation deviations similar to a Taylor-style interest rate rule, but instead considers

\textsuperscript{4}The solution algorithm is discussed further in the appendix to this paper.

Svensson (2001) (SV) recommends a devaluation and temporary exchange-rate peg in combination with a price-level target path that implies a positive rate of inflation. Its goal would be to raise inflationary expectations and jump-start the economy. SV emphasizes that the existence of a portfolio balance effect is not a necessary ingredient for such a strategy. By standing ready to sell yen and buy foreign exchange at the pegged exchange rate, the central bank will be able to enforce the devaluation. Once the peg is credible, exchange rate expectations will adjust accordingly and the nominal interest rate will rise to the level required by uncovered interest parity.

These authors presented their proposals in stylized, small open economy models. In this paper, we evaluate these proposals in an estimated macroeconomic model, which also takes into account the international repercussions that result when a large open economy such as Japan adopts a strategy based on drastic depreciation of its currency. In addition, we improve upon the following shortcomings. While OW used a reduced-form relationship between real exchange rate, interest rates and base money, we treat uncovered interest parity and potential deviations from it explicitly in the model. While MC compares interest rate and exchange rate rules within linear models we account for the nonlinearity due to the zero-bound when switching from one to the other and retain uncovered interest parity in both cases. Finally, we investigate the consequences of all three proposed strategies for the United States and the euro area.

Our findings indicate that the zero bound induces noticeable losses in terms of output and inflation stabilization in Japan, if the nominal equilibrium interest rate, that is the sum of the policymaker’s inflation target and real equilibrium interest rate, is 2% or lower. We show that aggressive liquidity expansions when interest rates are constrained at zero, may largely offset the effect of the zero bound. Furthermore, we illustrate the potential of the three proposed strategies to evade a liquidity trap during a severe recession and deflation. Finally, we show that the proposed strategies have non-negligible beggar-thy-neighbor effects and at least require the tacit approval of the main trading partners for their success.
The paper proceeds as follows. Section 2 reviews the estimated three-country macro model. In section 3 we discuss the consequences of the zero-interest-rate bound, first in case of a severe recession and deflation scenario, and then on average given the distribution of historical shocks as identified by the estimation of our model. In section 4 we explore the performance of the three different proposals for avoiding or escaping the liquidity trap by means of exchange rate depreciation. Section 5 concludes.

2 The Model

The macroeconomic model used in this study is taken from Coenen and Wieland (2002). The model assumes that expectations in financial markets, goods markets and labor markets are formed in a rational, model-consistent manner. As a result, monetary policy is neutral in the long-run. However, short-run real effects arise due to the presence of nominal rigidities in the form of staggered contracts.\textsuperscript{6} The model comprises the three largest world economies, the United States, the euro area and Japan. Model parameters are estimated using quarterly data from 1974 to 1999 and the model fits empirical inflation and output dynamics in these three economies surprisingly well. For a detailed presentation of the model the reader is referred to Coenen and Wieland (2002). In the following we only provide a short overview of the model.

The relevant model equations are summarized in Table 1. In Coenen and Wieland (2002) we have investigated the three staggered contracts specifications that have been most popular in the recent literature, the nominal wage contracting models proposed by Calvo (1983) and Taylor (1980, 1993) with random-duration and fixed-duration contracts respectively, as well as the relative real-wage contracting model proposed by Buiter and Jewitt (1981) and estimated by Fuhrer and Moore (1995). The Taylor specification obtained the best empirical fit for the euro area and Japan, while the Fuhrer-Moore specification performed better for the United States.\textsuperscript{7}

\textsuperscript{6}With this approach we follow Taylor (1993) and Fuhrer and Moore (1995a,b). Also, our model exhibits many similarities to the calibrated model considered by Svensson (2001).

\textsuperscript{7}Coenen and Wieland (2002) show that Calvo-style contracts do not fit observed inflation dynamics under
Due to the existence of staggered contracts, the aggregate price level $p_t$ corresponds to the weighted average of wages on overlapping contracts, $x_t$, (equation (M-1) in Table 1). The weights $f_i$ ($i = 1, \ldots, \eta(x)$) on contract wages from different periods are assumed to be non-negative, non-increasing and time-invariant and need to sum to one. The parameter $\eta(x)$ corresponds to the maximum contract length. Workers negotiate long-term contracts and compare the contract wage to past contracts that are still in effect and future contracts that will be negotiated over the life of this contract. As indicated by equation (M-2a) Taylor’s nominal wage contracting specification implies that the contract wage $x_t$ is negotiated with reference to the price level that is expected to prevail over the life of the contract as well as the expected deviations of output from its potential over this period. The output gap is defined by $q_t$. The sensitivity of contract wages to excess demand is measured by $\gamma$. The contract wage shock $\epsilon_{x,t}$, which is assumed to be serially uncorrelated with zero mean and unit variance, is scaled by the parameter $\sigma_{\epsilon_{x}}$.

The distinction between Taylor-style contracts and Fuhrer-Moore’s relative real wage contracts concerns the definition of the wage indices that form the basis of the intertemporal comparison underlying the determination of the current nominal contract wage. The Fuhrer-Moore specification assumes that workers negotiating their nominal wage compare the implied real wage with the real wages on overlapping contracts in the recent past and near future. As shown in equation (M-2b) in Table 1 the expected real wage under contracts signed in the current period is set with reference to the average real contract wage index expected to prevail over the current and the next following quarters, where $v_t = \sum_{i=0}^{\eta(x)} f_i (x_{t-i} - p_{t-i})$ refers to the average of real contract wages that are effective at time $t$.

Output dynamics are described by the open-economy aggregate demand equation (M-3), which relates the output gap to several lags of itself, to the lagged ex-ante long-term real interest rate $r_{t-1}$ and to the trade-weighted real exchange rate $e_{t}^{w}$. The demand shock $\epsilon_{d,t}$ the assumption of rational expectations. For a detailed discussion of the parameter estimates and the chosen model specification the reader is referred to that paper.
Table 1: Model Equations

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
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<tbody>
<tr>
<td>(M-1)</td>
<td>Price Level: $p_t = \sum_{i=0}^{\eta(x)} f_i x_{t-i}$, where $\sum_{i=0}^{\eta(x)} f_i = 1$ and $f_i \geq f_{i+1}$</td>
</tr>
<tr>
<td>(M-2a)</td>
<td>Contract Wage: $x_t = E_t \left[ \sum_{i=0}^{\eta(x)} f_i p_{t+i} + \gamma \sum_{i=0}^{\eta(x)} f_i q_{t+i} \right] + \sigma_e \epsilon_{x,t}$, Taylor</td>
</tr>
<tr>
<td>(M-2b)</td>
<td>Contract Wage: $x_t - p_t = E_t \left[ \sum_{i=0}^{\eta(x)} f_i v_{t+i} + \gamma \sum_{i=0}^{\eta(x)} f_i q_{t+i} \right] + \sigma_e \epsilon_{x,t}$, Fuhrer-Moore</td>
</tr>
<tr>
<td>(M-3)</td>
<td>Aggregate Demand: $q_t = \delta(L) q_{t-1} + \phi (r_{t-1} - r) + \psi e^{w}<em>t + \sigma</em>{e_{d}} \epsilon_{d,t}$, where $\delta(L) = \sum_{j=1}^{\eta(q)} \delta_j L^{-j}$</td>
</tr>
<tr>
<td>(M-4)</td>
<td>Real Interest Rate: $r_t = l_t - 4 E_t \left[ \frac{1}{\eta(t)} (p_{t+\eta(t)} - p_t) \right]$</td>
</tr>
<tr>
<td>(M-5)</td>
<td>Term Structure: $l_t = E_t \left[ \frac{1}{\eta(l)} \sum_{j=1}^{\eta(l)} i_{t+j-1} \right]$</td>
</tr>
<tr>
<td>(M-6)</td>
<td>Monetary Policy Rule: $i_t = r + \pi_t^{(4)} + 0.5 (\pi_t^{(4)} - \pi^*) + 0.5 q_t$, where $\pi_t^{(4)} = p_t - p_{t-4}$</td>
</tr>
<tr>
<td>(M-7)</td>
<td>Trade-Weighted Real Exchange Rate: $e^{w,i(i)}<em>t = w</em>{(i,j)} e^{(i,j)}<em>t + w</em>{(i,k)} e^{(i,k)}_t$</td>
</tr>
<tr>
<td>(M-8)</td>
<td>Uncovered Interest Parity: $e^{(i,j)}<em>t = E_t \left[ e^{(i,j)}</em>{t+1} \right] + 0.25 \left( e^{(j)}<em>t - 4 E_t \left[ p</em>{t+1}^{(j)} - p_t^{(j)} \right] \right) - 0.25 \left( e^{(i)}<em>t - 4 E_t \left[ p</em>{t+1}^{(i)} - p_t^{(i)} \right] \right)$</td>
</tr>
</tbody>
</table>

Notes: $p$: aggregate price level; $x$: nominal contract wage; $q$: output gap; $y$: actual output; $y^*$: potential output; $\epsilon_x$: contract wage shock; $v$: real contract wage index; $r$: ex-ante long-term real interest rate; $r^*$: equilibrium real interest rate; $e^{w}$: trade-weighted real exchange rate; $\epsilon_{d}$: aggregate demand shock; $l$: long-term nominal interest rate; $i$: short-term nominal interest rate; $\pi^{(4)}$: annual inflation; $\pi^*$: inflation target; $e$: bilateral real exchange rate.

in equation (M-3) is assumed to be serially uncorrelated with mean zero and unit variance and is scaled with the parameter $\sigma_{e_d}$. A possible rationale for including lags of output is to account for habit persistence in consumption as well as adjustment costs and accelerator effects in investment. We use the lagged instead of the contemporaneous value of the real interest rate to allow for a transmission lag of monetary policy. The trade-weighted real exchange rate enters the aggregate demand equation because it influences net exports.
The long-term real interest rate is related to the long-term nominal rate and inflation expectations by the Fisher equation (M-4). As to the term structure that is defined in (M-5), we rely on the accumulated forecasts of the short rate over $\eta(l)$ quarters which, under the expectations hypothesis, will coincide with the long rate forecast for this horizon. The term premium is assumed to be constant and equal to zero. The short-term nominal interest rate is set according to Taylor’s (1993b) rule (equation (M-6)) in response to inflation deviations from the policymaker’s inflation target $\pi^*$ and output deviations from potential.

The trade-weighted real exchange rate is defined by equation (M-7). The superscripts $(i, j, k)$ are intended to refer to the economies within the model without being explicit about the respective economy concerned. Thus, $e^{(i,j)}$ represents the bilateral real exchange rate between countries $i$ and $j$, $e^{(i,k)}$ the bilateral real exchange rate between countries $i$ and $k$, and consequently equation (M-7) defines the trade-weighted real exchange rate for country $i$. The bilateral trade-weights are denoted by $(w_{(i,j)}, w_{(i,k)}, \ldots)$. Finally, equation (M-8) constitutes the open interest rate parity condition with respect to the bilateral exchange rate between countries $i$ and $j$ in real terms. It implies that the difference between today’s real exchange rate and the expectation of next quarter’s real exchange rate is set equal to the expected real interest rate differential between countries $i$ and $j$.

In the deterministic steady state of this model the output gap is zero and the long-term real interest rate equals its equilibrium value $r^*$. The equilibrium value of the real exchange rate is normalized to zero. Since the overlapping contracts specifications of the wage-price block do not impose any restriction on the steady-state inflation rate, it is determined by monetary policy alone and equals the target rate $\pi^*$ in the policy rule.

Parameter estimates for the preferred staggered contracts specifications and the aggregate demand equations are presented in the appendix in Table A. The overall model fit is discussed in substantial detail in Coenen and Wieland (2002).
3 Recession, Deflation and the Zero-Interest-Rate Bound

3.1 The Zero-Interest-Rate Bound

Under normal circumstances, when the short-term nominal interest rate is well above zero, the central bank can ease monetary policy by expanding the supply of the monetary base and bringing down the short-term rate of interest. Since prices of goods and services adjust more slowly than those on financial instruments, such a money injection reduces real interest rates and provides a stimulus to the economy. Whenever monetary policy is expressed in form of a Taylor-style interest rate rule such as equation (M-6), implicitly it is assumed that the central bank injects liquidity so as to achieve the short-term nominal interest rate that is prescribed by the interest rate rule. Thus, the appropriate quantity of base money can be determined recursively from the relevant base money demand equation. Of course, at the zero bound further injections of liquidity have no additional effect on the nominal interest rate, and a negative interest rate prescribed by the interest rate rule cannot be implemented.

Orphanides and Wieland (2000) illustrate this point using recent data for Japan. To this end it is convenient to use the concept of the “Marshallian \( K \)”, which corresponds to the ratio of the monetary base, that is the sum of domestic credit and foreign exchange reserves, \( M_t = DC_t + FXR_t \), and nominal GDP, \( P_tY_t \). Thus, \( K_t = M_t/P_tY_t \), or in logs \( k_t = m_t - p_t - y_t \). Then the relationship between the short-term nominal interest rate and the Marshallian \( k \) can be described by the following inverted base money demand equation;

\[ i_t - i^* = [\theta(k_t - k^*) + \epsilon_{k,t}]_+, \]  

(1)

where \( i^* \) and \( k^* \) denote the corresponding equilibrium levels that would obtain if the economy were to settle down to the policymaker’s inflation target \( \pi^* \). \( \epsilon_{k,t} \), which summarizes other influences to the demand for money, in addition to changes in interest rates or income,

\footnote{An implicit restriction of such a specification is that of a unit income elasticity on money demand.}
is set to zero in the remainder of the analysis.\textsuperscript{10}

The function $[\cdot]_+$ truncates the quantity inside the brackets at zero and implements the zero bound.\textsuperscript{11} As shown by Orphanides and Wieland (2000) Japanese data from 1970 to 1995 suggests that reducing the Marshallian $K$ by one percentage point would be associated with a change in the short-term nominal rate of interest of about four percentage points. Increases in the Marshallian $K$ in the latter half of the 1990s, when the nominal interest rate was close to zero, had no further effect on the rate of interest just as indicated by equation (1).

As discussed above, one implication of this constraint will be a reduction in the effectiveness of monetary policy. A further important implication is that the model with the zero bound, as written so far in Table 1, will be globally unstable. Once shocks to aggregate demand and/or supply push the economy into a sufficiently deep deflation, a zero interest rate policy may not be able to return the economy to the original equilibrium. With a shock large enough to sustain deflationary expectations and to keep the real interest rate above its equilibrium level, aggregate demand is suppressed further sending the economy into a deflationary spiral. Orphanides and Wieland (1998) resolved this global instability problem by assuming that at some point, in a depression-like situation, fiscal policy would turn sufficiently expansionary to rescue the economy from such a deflationary spiral. Orphanides and Wieland (2000) instead concentrated on the role of other channels of the monetary transmission mechanism that may continue to operate even when the interest rate channel is ineffective. An example of such a channel that we will include in this paper, is the portfolio balance effect.

\textsuperscript{10}This term includes short-run shocks to money demand but also reflects changes in the transactions or payments technology or in preferences that may have long-lasting and even permanent effects on the level of the Marshallian $k$ consistent with the steady state inflation $\pi^*$. Regardless of its determinants, since the central bank controls $k_t$ and can easily observe the nominal interest rate $i_t$, $\epsilon_{k,t}$ is essentially observable to the central bank. That is, fixing $k_t$, even a slight movement in the nominal interest rate can be immediately recognized as a change in $\epsilon_{k,t}$ and, if desired, immediately counteracted.

\textsuperscript{11}For a theoretical analysis of this lower bound as a function of preferences and transactions technology see McCallum (2000).
3.2 A Severe Recession and Deflation Scenario

To illustrate the potentially dramatic consequences of the zero-interest-rate bound and deflation we simulate an extended period of recessionary and deflationary shocks in the Japan block of our three-country model. Initial conditions are set to steady state with an inflation target of 1%, a real equilibrium rate of 1%, and thus an equilibrium nominal interest rate of 2%. Then the Japanese economy is hit by a sequence of negative demand and contract price shocks for a total period of 5 years. The magnitude of the demand and contract price shocks is set equal to 1.5 and -1 percentage points respectively.

Figure 1 compares the outcome of this sequence of contractionary and deflationary shocks when the zero bound is imposed explicitly (solid line) to the case when the zero bound is disregarded and the nominal interest rate is allowed to go negative (dashed line). As indicated by the dashed line, the central bank would like to respond to the onset of recession and disinflation by drastically lowering nominal interest rates. If this were possible, that is, if interest rates were not constrained at zero, the long-term real interest rate would decline by about 6% and the central bank would be able to contain the output gap and deflation both around $-8\%$. The reduction in nominal interest rates would be accompanied by a 12% real depreciation of the currency.

However, once the zero lower bound is enforced, the recessionary and deflationary shocks are shown to throw the Japanese economy into a liquidity trap. Nominal interest rates are constrained at zero for almost a decade. Deflation leads to increases in the long-term real interest rate up to 4%. As a result, Japan experiences a double-digit recession that lasts substantially longer than in the absence of the zero bound. Rather than depreciating, the currency temporarily appreciates in real terms.

Clearly, in the event of such severe negative shocks the zero bound and the resulting ineffectiveness of monetary policy has a major impact on the economy. The economy only returns slowly to steady state once the shocks subside. Of course, the likelihood of such a sequence of shocks is extremely small. For this reason, we now turn to a quantitative
Figure 1: The Effect of the Zero Bound in a Severe Recession and Deflation

Output Gap

Quarter

Annual Inflation

Quarter

Short-Term Nominal Interest Rate

Quarter

Ex-Ante Long-Term Real Interest Rate

Quarter

Real Effective Exchange Rate

Quarter
3.3 The Importance of the Zero Bound in Japan

The likelihood that nominal interest rates are constrained at zero depends on a number of key factors, in particular the size of the shocks to the economy, the propagation of those shocks throughout the economy (i.e. the degree of persistence exhibited by important endogenous variables), the level of the equilibrium nominal interest rate (i.e. the sum of the policymaker’s inflation target and the equilibrium real interest rate) and the choice of the policy rule. In the following we present results from stochastic simulations of our model with the shocks drawn from the covariance matrix of historical shocks. In these simulations we consider alternative values of the equilibrium nominal interest rate, $i^* = r^* + \pi^*$, between 1% and 5%. Taylor’s rule is maintained throughout these simulations except if the nominal interest rate is constrained at zero.

Figure 2 shows the frequency of zero nominal interest rates as a function of the level of the equilibrium rate, $i^*$. With an equilibrium nominal rate of 3%, the zero bound represents

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12 The derivation of this covariance matrix and the nature of the stochastic simulations are discussed in more detail in the appendix.
a constraint for monetary policy for about 10% of the time. It becomes substantially more important for lower equilibrium nominal rates and occurs almost 40% of the time with a rate of 1%, which corresponds, for example, to an inflation target of 0% and an equilibrium real rate of 1%.

Figure 3: Distortion of Stationary Distributions of Output and Annual Inflation

Whenever the zero bound is binding, nominal interest rates will be higher than prescribed by Taylor’s rule. Similarly, the real interest rate will be higher and stabilization of output and inflation will be less effective. Since there exists no similar constraint on
the upside an asymmetry will arise. The consequences of this asymmetry are apparent
from Figure 3. As shown in the top left and top right panels, on average output will be
somewhat below potential and inflation somewhat above target. Both panels display this
bias in the mean output gap and mean inflation rate as a function of the equilibrium nom-
inal interest rate. With an equilibrium nominal rate of 1% the bias in the means is about
0.2% and 0.1% respectively. The lower-left and lower-right panels in Figure 3 indicate the
upward bias in the standard deviation of output and inflation as a function of the equilib-
rium nominal interest rate. Clearly, economic performance deteriorates noticeably with an
increased likelihood of zero interest rates.

Figure 4: Stationary Distributions of the Output Gap and the Inflation Gap

\[ -6.0 \quad -3.0 \quad 0.0 \quad 3.0 \quad 6.0 \]

\[ -5.0 \quad -2.5 \quad 0.0 \quad 2.5 \quad 5.0 \]

\[ i^* = 1 \]
\[ i^* = 3 \]

Figure 4 illustrates how the stationary distributions of the output and inflation gaps
change with increased frequency of zero interest rates. Each of the two panels shows two
distributions, generated with an equilibrium nominal interest rate of 3% and 1% respec-
tively. In the latter case, the distribution becomes substantially more asymmetric. The
pronounced left tails of the distributions indicate an increased incidence of deep recessions
and deflationary periods.

As we discussed in the preceding subsection these deep recessions carry with them the
potential of a deflationary spiral, where the zero bound keeps the real interest rate sufficiently high so that output stays below potential and reinforces further deflation, at least within the model as specified so far. This points to a limitation inherent in linear models such as this which rely on the real interest rate as the sole channel for monetary policy. But it also brings into focus the extreme limiting argument regarding the ineffectiveness of monetary policy in a liquidity trap. Orphanides and Wieland (1998), which conducted such a stochastic simulation analysis for a model of the U.S. economy, ensured global stability of the model by specifying a nonlinear fiscal expansion rule that would boosts aggregate demand in a severe deflation until deflation returns to near zero levels. In this paper, we will instead follow Orphanides and Wieland (2000) and introduce a direct effect of base money in the next section, the portfolio balance effect that will remain active even when nominal interest rates are constrained at zero. This effect will ensure global stability under all circumstances. With regard to the preceding simulation results, we note that deflationary spirals did not yet arise for the variability of shocks and the level of the nominal equilibrium rate considered so far.

As discussed above, the distortion of output and inflation distributions is driven by a distortion of the real interest rate. The left-hand panels of Figure 5 report the upward bias in the mean real rate and the downward bias in the variability of the real rate depending on the level of the nominal equilibrium rate of interest. The downward bias in the variability of the real rate accounts for the reduced effectiveness of stabilization policy. What is perhaps more surprising, is the appreciation bias in the mean of the real exchange rate and the downward bias in its variability as shown in the right-hand panels of Figure 5. This reduction in the stabilizing function of the real exchange rate is consistent with what we observed in the recession and deflation scenario discussed in the preceding subsection. In the following we proceed to analyse how the exchange rate channel of monetary policy can be used to ameliorate the effect of the zero bound in deflationary and recessionary episodes.
4 Exploiting the exchange rate channel of monetary policy to evade the liquidity trap

4.1 A proposal by Orphanides and Wieland (2000)

Orphanides and Wieland (2000) (OW) recommend to expand the monetary base aggressively during episodes of zero interest rates so as to exploit direct quantity effects such as a portfolio-balance effect. The objective of this proposal is to stimulate aggregate demand and fuel inflation by a depreciation of the currency. This simply requires buying foreign
exchange reserves with domestic currency in a large enough quantity to achieve a depre-
cation. OW indicate a concrete strategy for implementing this proposal within a small
calibrated and largely backward-looking model. As a short-cut they specify a reduced-
form relationship between the real exchange rate, real interest rate differentials and the
differential Marshallian $k$ instead of the uncovered interest parity condition.

Following OW we use equation (1) to express the policy setting implied by Taylor’s
interest rate rule (equation (M-6)), in terms of the monetary base:

$$k_t - k^* = -\kappa_\pi \left( \pi_t - \pi^* \right) - \kappa_q q_t,$$

where the response coefficients $(\kappa_\pi, \kappa_q)$ are functions of the response coefficients in the
interest rate rule (M-6) and the inverse of the slope $\theta$ of the base money demand equation (1).

Next, we allow the relative quantities of base money at home and abroad to have a direct
effect on the exchange rate in addition to the effect of interest rate differentials. Due to this
so-called portfolio-balance effect, uncovered interest parity (UIP) need not hold exactly. To
account for it UIP in nominal terms is typically extended as follows:

$$s_{t}^{(i,j)} = E_t \left[ s_{t+1}^{(i,j)} \right] + 0.25 \left( i_{t}^{(i)} - i_{t}^{(j)} \right) + \lambda_b \left( b_{t}^{(i)} - b_{t}^{(j)} - s_{t}^{(i,j)} \right),$$

where $s_t$ denotes the nominal exchange rate. Again the superscripts $(i, j)$ refer to the two
respective countries. $b_t$ represents the log of government debt including base money in
the two countries. Rewriting the uncovered interest rate parity condition in real terms
and substituting in the monetary base as the relevant component of $b_t$ for our purposes, we
obtain the extended version of the expected real exchange rate differential originally defined
by equation (M-8) in Table 1:

$$e_{t}^{(i,j)} = E_t \left[ e_{t+1}^{(i,j)} \right] + 0.25 \left( i_{t}^{(j)} - 4 E_t \left[ p_{t+1}^{(j)} - p_{t}^{(j)} \right] \right)$$

$$- 0.25 \left( i_{t}^{(i)} - 4 E_t \left[ p_{t+1}^{(i)} - p_{t}^{(i)} \right] \right)$$

$$+ \lambda_k \left( k_{t}^{(i)} - k_{t}^{(j)} - e_{t}^{(i,j)} \right).$$

\[13\] This specification from Dornbusch (1980, 1987) is also considered by McCallum (2000) and Svensson
Figure 6: Liquidity expansion and depreciation in a severe recession and deflation
Given $\lambda_k > 0$ the monetary base still has an effect on aggregate demand via the real exchange rate even when the interest channel is turned off because of the zero bound. Thus, a policy rule defined in terms of the monetary base, such as (2), may also be carried out when nominal interest rates are constrained at zero. Increased liquidity injection due to the recessionary and deflationary impact of the zero bound will tend to depreciate the currency and help stabilize the economy.

However, the portfolio-balance effect is at best very small. Empirical studies by Frankel (1982, 1984), Dooley and Isard (1983) and others failed to find empirical support. Of course, the data used stemmed from normal episodes when nominal interest rates were positive and interest differentials would dominate the effect of relative base money supplies substantially. More recently, empirical studies such as Evans and Lyons (2001) and research using data Japanese foreign exchange interventions such as Ito (2002) and Fatum and Hutchison (2002) are more supportive of a portfolio balance effect. We follow Orphanides and Wieland (2000) and calibrate $\lambda_k$ so that is small enough not to be noticeable in times of non-zero interest rates and choose a value of 0.025.

Given such a small portfolio-balance effect, the liquidity expansion that follows from a linear base money rule such as (2) is likely to be of little consequence. This is confirmed by the simulation results reported in Figure 6. The solid line in each panel repeats the recession-cum-deflation scenario from the preceding section where no portfolio-balance effect is present. The dotted line, which differs only very little from the solid line, indicates the outcome with a small portfolio-balance effect under the linear base money rule (2). In this case, the Marshallian $k$ continues to expand a bit while the interest rate is constrained at zero, and the exchange rate depreciates slightly.

As an alternative, OW proposed a nonlinear policy rule, which results in a drastic liquidity expansion (i.e. increase in the Marshallian $k$) whenever the nominal interest is constrained at zero. We implement this rule such that it switches to substantially more aggressive response coefficient whenever the nominal interest rate is zero, and switches back
to the original equation that corresponds to Taylor’s rule subsequently,

\[ k_t - k^* = \begin{cases} 
-\kappa_\pi (\pi_t^{(4)} - \pi^*) - \kappa_q q_t, & \text{if } i_t > 0 \\
-30 [\kappa_\pi (\pi_t^{(4)} - \pi^*) + \kappa_q q_t], & \text{if } i_t = 0.
\end{cases} \tag{5} \]

The performance of this nonlinear rule in the recession and deflation scenario corresponds to the dashed-dotted line in each panel of Figure 6. The huge expansion of liquidity results in a dramatic real depreciation of up to 40%. As a result of this depreciation the recessionary and deflationary impact of the shocks to the economy is dampened substantially. The depth
of the recession and deflation is similar to the first simulation shown in Figure 1, where interest rates were allowed to go negative. Thus, in principle the proposal of OW is effective in ameliorating the impact of the zero bound in a deflationary period.

Next, we proceed to evaluate the effectiveness of the non-linear base money rule (5) in terms of its ability to reduce the biases and asymmetries in output and inflation distributions resulting from the zero bound that we discussed in the preceding section. To do so we conduct further stochastic simulations based on the covariance matrix of historical shocks. The results are summarized in Figure 7, which compares the biases in the means and standard deviations of output and inflation gaps under the linear and non-linear rules for the Marshallian $k$, denoted by diamonds and squares respectively. Clearly, the biases are substantially reduced even for very low levels of the equilibrium nominal interest rate.

However, the improvement in output and inflation distributions comes at the expense of substantially higher variability of the real exchange rate as well as a depreciation bias in its mean as depicted in Figure 8. The variability of the real exchange rate is substantially higher than in the case of the linear rule. Of course, aggressive depreciation of the currency of a large open economy will have beggar-thy-neighbor-type spill-over effects on its trading
partner. Figure 9 provides a quantitative assessment of these spillover effects in the United States and the euro area when monetary policy in Japan follows the nonlinear rule defined in (5). As it turns out the implied costs for Japan’s trading partners in terms of output and inflation stabilization are non-negligible. We observe a small downward bias in both output and inflation and overall upward biases in their variability. Of course, the central banks in those countries have the ability to respond to this development by easing policy more aggressively themselves.

Figure 9: Distortion of Output and Inflation Distributions in the Euro Area and the U.S.
The approach suggested by OW and others, namely to express policy in terms of a base money rule and substantially expand liquidity when nominal interest rates are constrained at zero has been criticized for relying too heavily on the existence of direct quantity effects. The portfolio-balance effect, for example, is at best small and rather imprecisely estimated, which may make it difficult to determine the appropriate policy stance in terms of base money. OW show that this is a problem of multiplicative parameter uncertainty as in Brainard (1967), which can be addressed appropriately by reducing the responsiveness of the base money rule compared to the degree that would be optimal when the portfolio-balance effect is known with certainty.

A related criticism concerns the other effects on the demand for base money summarized by the shock term $\epsilon_{k,t}$ in equation (1) that needs to be accounted for in determining the appropriate policy stance. Under normal circumstances, that is, when the nominal interest rate is positive, these factors can be dealt with by active money supply management because the interest rate is observed continuously. By fixing $k$, even a slight movement in the nominal interest rate can be immediately recognized as a change in $\epsilon_{k,t}$ and counteracted. It is exactly these additional influences that encourage the treatment of the nominal interest rate as the central bank’s operating instrument rather than a quantity of base money.

Unfortunately, when the nominal interest rate is constrained at zero, it provides no useful information for money supply management anymore. However, there exists an alternative choice for the central bank’s operating instrument, namely the nominal exchange rate, which can be observed continously even when the interest rate is constrained at zero. Thus, one could instead specify a policy rule for the nominal exchange rate and then conduct interventions in the foreign exchange market as required to achieve the desired exchange rate. A further advantage is that one need not know the size of a possible portfolio-balance effect, nor is it a required element for the formulation of the strategy.
4.2 A proposal by McCallum (2000, 2001)

McCallum recommends to switch to the nominal exchange rate as policy instrument whenever the economy is stuck at the zero bound. He suggests to set the rate of change of the nominal exchange rate just like a Taylor-style interest rate rule in response to deviations of inflation from target and output from potential. Thus, in case of a deflation and recession the policy rule will respond by depreciating the currency. If credible this will imply that expectations of future exchange rates will reflect the policy rule and help in stabilizing the economy. The necessary level of the exchange rate may be achieved by standing ready to buy foreign currency at the rate prescribed by the rule.

We implement McCallum’s proposal as follows:

- if $i_t > 0$, then $i_t$ is set according to Taylor’s rule (equation (M-6) in Table 1), $k_t$ is determined recursively from the money demand equation (1), and $s_t$ is determined by the extended uncovered interest parity condition as defined in equation (4);

- if $i_t = 0$, then the nominal exchange rate is set according to

$$s_t - s_{t-1} = -\chi_p (\pi_t^{(4)} - \pi^*) - \chi_q q_t$$  \hspace{1cm} (6)

and the Marshallian $k$ is determined recursively so that the portfolio-balance term adjusts to satisfy the extended uncovered interest parity condition (4).

McCallum (2000, 2001) compares two types of scenarios. In one scenario nominal interest rates are set endogenously according to an interest rate rule but the zero bound is never enforced and the exchange rate results from open-interest parity. In the second scenario, the nominal interest rate is always held at zero, the open-interest parity equation is dropped from the model, and the nominal exchange rate is set according to the rule defined by equation (6). Thus, he can analyze both scenarios in a linear model. Instead, we consider the nonlinearity that results from a temporary period of zero nominal interest rates explicitly in our analysis.
Figure 10: Directly Setting the Rate of Depreciation according to a State-Dependent Rule
Figure 10 provides a comparison between the benchmark simulation of a severe recession and deflation (solid line in each panel) and a simulation, in which the central bank switches to the exchange rate rule defined by equation (6) as soon as the interest rate hits zero (dashed line in each panel). The exchange rate rule is abandoned in favor of the original interest rate rule when the interest rate implied by the interest rate rule returns above zero.

The exchange rate rule generates a substantial nominal and real depreciation. As a result, inflationary expectations increase and the ex-ante long-term real interest rates stays flat rather than increases as in the benchmark scenario and the recession and deflation are significantly dampened. Once we switch back to the interest rate rule, the Marshallian $K$ is determined by the base-money demand equation, (1), and the nominal exchange rate adjusts to satisfy uncovered interest parity, (4). This adjustment implies a one-time nominal and real appreciation.

4.3 A proposal by Svensson (2001)

Svensson (2001) (SV) offers what he calls a “foolproof” way of escaping from a liquidity trap. With interest rates constrained at zero and ongoing deflation he recommends to stimulate the economy and raise inflationary expectations by switching to an exchange rate peg at a substantially devalued exchange rate and announcing a price-level target path. The exchange rate peg is intended to be temporary and should be abandoned in favor of price-level or inflation targeting when the price-level target is reached. SV delineates the concrete proposal as follows:

- announce an upward-sloping price-level target path for the domestic price level,

$$p_t^* = p_{t_0}^* + \pi^* (t - t_0), \quad \text{for } t \geq t_0$$

with $p_{t_0}^* > p_t^*$ and $\pi^* > 0$;

The response coefficients in the exchange rate rule $\chi_{\pi}, \chi_{q}$ are set equal to 0.25.

14
• announce that the currency will be devalued and that the nominal exchange rate will be pegged to a fixed or possibly crawling exchange rate-target,

\[ s_{t}^{i,j} = \bar{s}_{t}, \quad \text{for} \ t \geq t_{0}, \] (8)

where \( \bar{s}_{t} = \bar{s}_{t_{0}} + \left( \pi^{*}(i) - \pi^{*}(j) \right) (t - t_{0}); \)

• announce that when the price-level target path has been reached, the peg will be abandoned, either in favor of price-level targeting or inflation targeting with the same inflation target.

This will result in a temporary crawling or fixed peg depend on the difference between domestic and foreign target inflation rates. SV combines the exchange rate peg with a switch to price-level targeting because he expects the latter to stimulate inflationary expectations more strongly than an inflation target. Of course, this choice will become less important the longer the exchange rate peg lasts.

Svensson (2001) emphasizes that the existence of a portfolio-balance effect is not necessary to be able to implement this proposal. The central bank should be able to enforce the peg at a devalued rate by standing ready to buy up foreign currency at this rate to an unlimited extent if necessary. This will be possible because the central bank can supply whatever amount of domestic currency is needed to buy foreign currency at the pegged exchange rate. This situation differs from the defense of an overvalued exchange rate, which requires selling foreign currency and poses the risk of running out of foreign exchange reserves.

Thus, SV considers the outcome of an exchange rate peg when uncovered interest rate parity holds exactly, that is, without a portfolio-balance effect:

\[ s_{t}^{(i,j)} = E_{t} \left[ s_{t+1}^{(i,j)} \right] + 0.25 \left( i_{t}^{(i)} - i_{t}^{(j)} \right). \] (9)

The UIP condition and exchange rate expectations play a key role. Suppose, for example, the central bank announces a fixed peg at the rate \( \bar{s} \) and this peg is credible, then the expected exchange rate change ought to be zero and the nominal interest rate needs to rise
Figure 11: Switching to an Exchange Rate Peg
to the level of the foreign nominal interest rate absent any foreign exchange risk premium. Thus, as soon as the exchange rate peg has become credible the nominal interest rate will jump to the level of the foreign rate and the period of zero interest rates will end.

Thus, here we allow for an important difference to our analysis of the proposals by OW and MC in the preceding subsections. In those cases we specified the policy rule such that the depreciation-oriented policy stance (by aggressively expanding liquidity or by setting the change of the exchange rate directly) was implemented only when the nominal interest rate was equal zero. The resulting deviation from exact UIP was made up by the portfolio-balance effect and an appropriate adjustment of base money. Here, however, the peg continues for a specified period even though the nominal interest rate will rise immediately to satisfy UIP.

We investigate the consequences of Svensson’s proposal if it is adopted during the severe recession and deflation scenario discussed in the preceding sections. The outcome is shown in Figure 11. The solid line in each panel repeats the benchmark scenario from the earlier sections. The dashed-dotted line indicates the outcome following Svensson’s proposal. We assume that the central bank adopts the Svensson proposal in the 11th period, after she has observed the outcome of 10 deflationary and recessionary shocks. Important choice variables are the initial price level of the implied target path, the extent of the devaluation and the length of the peg. Credibility of the peg turns out to be absolutely essential.

The peg is implemented with respect to the bilateral nominal exchange rate of the Japanese YEN vis-à-vis the US$. The implied devaluation and the associated price-level target path are shown in the lower-left panel of Figure 11. The middle-left panel shows that the nominal interest rate jumps to a positive level immediately upon the start of the peg, as required by the UIP condition. The nominal devaluation results in a 16% real depreciation in the trade-weighted exchange rate. The peg delivers the intended results. Inflationary expectations are jump-started and rise very quickly. As a result the real interest rate declines very rapidly, and the economy recovers from recession. This decline in the real interest rate is substantially stronger than in the case of the base money rule that we analyzed following
Figure 12: A Constant versus a Crawling Peg

- Output Gap
- Annual Inflation
- Nominal Short-Term Interest Rate
- Ex-Ante Long-Term Real Interest Rate
- Real Effective Exchange Rate
- Price Level and Nominal Exchange Rate
the proposal of Orphanides and Wieland (2000). A key factor driving this increase in inflationary expectations is the central banks explicit and credible commitment to a future exchange rate path.

While the Svensson proposal delivers the promised outcome, it turns out not to be quite as foolproof as suggested. As the simulation in Figure 11 shows the proposal may not be as easy to implement as it seems at first glance. In particular, if the devaluation is larger or the peg period shorter than shown in the economy may fall back into the liquidity trap either during the peg or at the end of the peg period. An important point to note is that absent any risk premium a nominal interest rate of zero during the peg would imply that the foreign nominal interest also reaches zero. In other words, the depreciation may drive the respective trading partner into the liquidity trap.

We avoided this danger by fine-tuning the length of the peg, the initial target price level and the size of the devaluation. In the end this required a very long peg period of over 10 years. Clearly, in practice such a long peg period of over 10 years would not be considered a temporary policy change but rather a seemingly permanent one. The probability of falling back into the liquidity trap is ameliorated if we allow for a crawling instead of a fixed peg. This comparison is shown in Figure 12. The dashed-dotted line indicates the path under the crawling peg. As can be seen from the middle-left panel, in this case the nominal interest rate remains well in the positive throughout the peg.

4.4 Beggar-thy-neighbor effects and international cooperation

All three proposals for avoiding or evading the liquidity trap that we have analyzed, have one important drawback, namely they always require at least the tacit cooperation of Japan’s main trading partners. Their central banks need to allow Japan to depreciate or devalue its currency substantially more than would be necessary if nominal interest rates were not constrained at zero. We have already indicated the potential implications for the euro area and the United States based on the stochastic simulations of the nonlinear Marshallian $k$.

\[ \text{The nominal YEN/US$ exchange rate was pegged at a level which lies 5 percent above the initial exchange rate level, while the initial target price level was set at -3 percent below the initial price level.} \]
rule proposed by Orphanides and Wieland (2000) in subsection 4.1. Essentially the trading partners need to tolerate a “beggar-thy-neighbor” type effect from this depreciation or devaluation.

To further quantify these spillover effects, Figure 13 reports the consequences of the three alternative deprecation-based strategies for evading the liquidity trap discussed above for output and inflation in the United States. In all three cases we observe a noticeable recession and disinflation as a result of the drastic US$ appreciation. Output declines between 0.75 and 2 percent while the inflation rate falls between 0.5 and 1.5 percent. Depending on the conditions and potential shocks hitting the US economy the appreciation of the US$ may even end up pushing US nominal interest rates to the zero bound. We conclude that it will be difficult to implement such exchange-rate based strategies for evading the liquidity trap without some support of Japan’s major trading partners.\footnote{So far direct spillover effects only arise due to the trade-weighted real-exchange term in in the aggregate demand equations. In addition, one could consider an foreign income term in aggregate demand as well as a direct price effect of the exchange rate via import prices. We have already calibrated a small foreign-income effect and found that the spillover effects to the United States in terms of the output and inflation reduction are even larger than in Figure 13.}
5 Conclusion

Based on an estimate macroeconomic model of Japan, the United States and the euro area, we have been able to quantify the effect of the zero bound on stabilization performance in Japan. Furthermore, we have evaluated three concrete proposals for avoiding or evading the impact of the zero-interest-rate bound by depreciating the Yen with regard to the euro and the US$. Finally, we have quantified the resulting spill-over effects to the United States and the euro area.

We have focussed our analysis on the case where all three central banks follow Taylor’s (1993b) nominal interest rate rule. Our findings indicate that the zero bound induces noticeable losses in terms of output and inflation stabilization in Japan once the nominal equilibrium interest rate, that is the sum of the policymaker’s inflation target and real equilibrium interest rate, is set at 2% or lower. We have included a small direct effect of base money on the exchange rate in the model. Due to this portfolio balance effect monetary policy remains effective even when nominal interest rates are constrained at zero, however this effect is so small that it is usually not noticeable.

Following the proposal of Orphanides and Wieland (2000), we show that aggressive liquidity expansions when interest rates are constrained at zero may largely offset the effect of the zero bound. Furthermore, we illustrate the potential of the proposals by McCallum (2000, 2001) and Svensson (2001) to evade a liquidity trap during a severe recession and deflation by setting a state-dependent or exogenous path for the nominal exchange rate. Finally, we show that the proposed strategies have non-negligible beggar-thy-neighbor effects and may require the tacit approval of the main trading partners for their success.
References


Buiter, W. H. and N. Panigirtzoglou, 1999, Liquidity traps: How to avoid them and how to escape them, working paper, March.


Fuhrer, Jeffrey and Brian Madigan, 1997, Monetary policy when interest rates are bounded at zero, Review of Economics and Statistics, November.


Johnson, Karen, David Small and Ralph Tryon (1999) Monetary policy and price stability,

Juillard, M., 1994, DYNARE - A Program for the resolution of non-linear models with forward-looking variables, Release 1.1, mimeo, CEPREMAP.


Meltzer, A., 1999, Monetary policy at zero inflation, August.


Taylor, J. B., 1993a, Macroeconomic policy in the world economy: From econometric design to practical operation, New York: W.W. Norton.

Appendix

A.1 Simulation techniques

We conduct stochastic simulations of the model to obtain the stochastic distributions of the endogenous variables under alternative monetary policy rules. In preparation for these simulations, we first computed the structural residuals of the model based on Japanese, euro area and U.S. data from 1980:Q1 to 1998:Q4. The process of calculating the structural residuals would be straightforward if the model in question were a purely backward-looking model. For a rational expectations model, however, structural residuals can be computed only by simulating the full model and computing the time series of model-consistent expectations with respect to historical data. The structural shocks differ from the estimated residuals to the extent of agents’ forecast errors.

Since the non-negativity constraint for nominal interest rates was never binding during this period and our model is otherwise linear, we obtained the structural shocks by solving the model analytically for the reduced form using the AIM implementation (Anderson and Moore, 1985, and Anderson, 1997) of the Blanchard and Kahn (1980) method for solving linear rational expectations models.

We calculated the covariance matrix of those structural residuals and using this covariance matrix, we generated 100 sets of artificial normally-distributed shocks with 100 quarters of shocks in each set from which the first 20 twenty quarters of shocks were discarded in order to guarantee that the effect of the initial values die out. We then used the sets of retained shocks to conduct stochastic simulations under alternative values of the nominal equilibrium interest rate, while imposing the non-negativity constraint on nominal interest rates. If it were not for this nonlinearity, we could use the reduced form of the model to compute unconditional moments of the endogenous variables without having to resort to stochastic simulations.

We simulate the model using an efficient algorithm that was recently implemented in TROLL based on work by Boucekkine (1995), Juillard (1994) and Laffargue (1990) and is related to the Fair-Taylor (1983) extended path algorithm. A limitation of the algorithm is that the model-consistent expectations of market participants are computed under the counterfactual assumption that “certainty equivalence” holds in the nonlinear model being simulated.\footnote{This means, when solving for the dynamic path of the endogenous variables from a given period onwards, the algorithm sets future shocks equal to their expected value of zero.} There are other solution algorithms for nonlinear rational expectations models that do not impose certainty equivalence. But these alternative algorithms would be prohibitively costly to use with our model, which has more than twenty state variables.
A.2 Parameter Estimates

The following table presents the preferred parameter estimates for our macroeconomic model of Japan, the euro area and the United States. For a more detailed discussion of these results and the fit of the model to empirical inflation and output dynamics we refer the reader to Coenen and Wieland (2002).

Table A: Parameter Estimates: Staggered Contracts and Aggregate Demand

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<th>Taylor Contracts</th>
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<th>$f_1$</th>
<th>$f_2$</th>
<th>$f_3$</th>
<th>$\gamma$</th>
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<td>(0.0057)</td>
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Notes: $(a)$ Simulation-based indirect estimates using a VAR(3) model of quarterly inflation and the output gap as auxiliary model. Estimated standard errors in parentheses. $(b)$ Output gap measure constructed using OECD data. $(c)$ Inflation in deviation from linear trend and output in deviation from log-linear trend. $(d)$ GMM estimates using a constant, lagged values (up to order three) of the output gap, the quarterly inflation rate, the short-term nominal interest rate and the real effective exchange rate as instruments. In addition, current and lagged values (up to order two) of the foreign inflation and short-term nominal interest rates have been included in the instrument set. The weighting matrix is estimated by means of the Newey-West (1987) estimator with the lag truncation parameter set equal to the maturity implied by the definition of the long-term nominal interest rate minus one. Estimated standard errors in parentheses. $(e)$ For the euro area, the German long-term real interest rate has been used in the estimation. Similarly, German inflation and short-term nominal interest rates have been used as instruments.