Fiscal Multipliers at the Zero Lower Bound: International Theory and Evidence.

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Abstract

Can fiscal policy be effective in an open economy with flexible exchange rates? Standard open economy models suggest that the open economy fiscal multiplier is small when exchange rates are flexible. This paper reassesses this premise by explicitly incorporating the zero lower bound (ZLB) on nominal interest rates in a small open economy New Keynesian model. It finds (1) when the ZLB binds and uncovered interest rate parity (UIP) holds, then the open economy fiscal multiplier is larger than 1 and bigger than the closed economy fiscal multiplier, (2) these conclusions can be reversed given significant violations of UIP, and (3) for estimated departures from UIP, the open economy fiscal multiplier at the ZLB is above 1 but smaller than the closed economy fiscal multiplier.

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1 Introduction

The current crisis has generated a renewed interest in the effects of fiscal policy at the zero lower bound (ZLB). Much recent work has centered on the fiscal multiplier - the increase in real output for each unit of real government spending. For example, Christiano, Eichenbaum, and Rebelo [2011], Eggertsson [2006], Eggertsson [2009], and Woodford [2011] have shown, that when the ZLB on nominal interest rates is binding, then fiscal multipliers in New Keynesian models are generally above 1, and may even be as large as 3 or 4.[1] However, these may be overestimates of the fiscal multipliers because they are derived in closed economy models. Fiscal multipliers tend to be smaller in open economy models, because a fiscal expansion is usually associated with an appreciation in the real exchange rate and thus crowding out of net exports.[2]

In my first contribution, I show that open economy fiscal multipliers can be large when the economy is in a liquidity trap.[3] I build a small open economy model following Gali and Monacelli [2005] and Clarida and Gertler [2001], and derive fiscal multipliers in and outside the liquidity trap, assuming that uncovered interest rate parity (UIP) holds. The resulting fiscal multiplier in normal times behaves as expected: it is less than one and decreasing in the openness (import share) of the economy. However, at the ZLB, the fiscal multiplier is above one and *increasing* in the import share. Thus, once the zero bound binds, the fiscal multiplier in a closed economy (which has a zero import share) is *smaller* than the fiscal multiplier in an open economy.[4]

The intuition behind these results is as follows. A fiscal stimulus generates inflation, which, in normal times, precipitates the central bank to raise nominal interest rates such that real interest rates rise (the Taylor principle). Since the interest rate elasticity of output is strictly negative, i.e. the sum of consumption and net exports decline with rising real

[1] This contrasts with typical estimates from time series data when monetary policy is unconstrained, which tend to be below 1 (see e.g. Barro [1981], Blanchard and Perotti [2002], Ramey [2011], Hall [2010]). There has also been significant advances in measuring fiscal multipliers at the state and local level (Nakamura and Steinsson [2011]; Serrato and Wingender [2010]). However, the latter ultimately require a theoretical model to determine the aggregate fiscal multipliers consistent with these estimates.

[2] For example, in the (Dornbusch [1976]) model the decline in net exports is as large as the expansion in government spending so that the fiscal multiplier is zero. Ilzetzki, Mendoza, and Vegh [2010] provide empirical evidence that the fiscal multiplier in open economies with flexible exchange rates is in fact statistically indistinguishable from zero. However, their dataset does not cover ZLB episodes.

[3] I use the terms "zero lower bound" and "liquidity trap" interchangeably.

[4] In independent work, Fujiwara and Ueda [2010] have found a qualitatively similar result under more stringent conditions on the parameter space. Furthermore, they do not consider how sensitive the results are to violations of UIP and thus do not provide results for empirically estimated departures from UIP.

interest rates, the resulting fiscal multiplier is less than 1. For standard parameterizations, the closed economy will (in absolute value) have a lower interest rate elasticity of output than the open economy, so that it will also enjoy a larger multiplier.

However, if the economy finds itself in a liquidity trap then the Taylor principle is violated. The inflationary effect of government expenditures will not be met by higher nominal rates, so that real interest rates fall. Given the strictly negative interest rate elasticity of output, the sum of consumption and net exports will rise, and the fiscal multiplier will now exceed 1. Because the open economy has (in absolute value) a higher interest rate elasticity of output than the closed economy, its fiscal multiplier will be larger. Furthermore, assuming standard parameterizations, net exports rise following a fiscal expansion in the liquidity trap, so that fiscal policy becomes a beggar-thy-neighbour policy.

The second contribution of this paper is to derive fiscal multipliers when UIP is violated. Departures from UIP are rationalized through a wedge in the Backus-Smith condition, which is assumed to be an increasing function of excess real returns of domestic bonds over foreign bonds. This friction limits movements of the terms of trade following a government spending shock, and can even change the sign of the terms of trade response. Depending on the size of the friction, the net export response can be very different compared to the baseline model. In fact, for moderately sized frictions, the open economy fiscal multiplier will be decreasing in the import share, and for even larger frictions the multiplier will be below 1, thus overturning the results from the baseline model.

The third contribution of this paper is to estimate the size of the friction and thus determine the likely properties of the open economy fiscal multiplier at the ZLB. To the best of my knowledge this is the first attempt to empirically test one aspect of the large ZLB multipliers in the New Keynesian model. The friction is derived by comparing model-implied nominal exchange rate responses to generic inflation surprises with their empirical counterpart. I use generic inflation surprises to identify the friction, because both demand and supply shocks are subject to the same friction in the model. However, I also show that these inflation surprises behave like demand shocks, and are thus likely to be subject to similar departures from UIP as a government spending shock.

Given the high frequency exchange rate response to these inflation surprises, I find that the friction to UIP is quantitatively significant at the ZLB. While the frictionless baseline model predicts that the nominal exchange rate depreciates by at least 1% for each 1% point of surprise inflation, I estimate that the nominal exchange rate appreciates by 0.021% after a 1% positive inflation surprise.

A calibrated model illustrates that this estimated friction can significantly lower the fiscal multiplier at the ZLB, even at moderate import shares. For example, at an import share of $\gamma = 0.15$ - typical of the US - the fiscal multiplier at the ZLB is 2.5 in the frictionless baseline model, but "only" 1.5 in the model with friction. Furthermore, the open economy fiscal multiplier in the friction model is significantly smaller than in the closed economy. For example, for import shares typical of European countries, the open economy fiscal multiplier is 30% smaller than the closed economy fiscal multiplier. However, even though exchange rate crowding out can be quantitatively significant, the fiscal multipliers remain large by the standards of the open economy literature.

The rest of this paper proceeds as follows. In section 2, I develop a small open economy model that allows for government spending shocks and the zero lower bound. I derive the frictionless fiscal multiplier in normal times and at the ZLB in section 3, and I investigate its sensitivity to frictions to international asset markets in section 4. In section 5 I test for the exchange rate responses following inflationary shocks to estimate the friction to the UIP equation. In section 6 I calibrate the model with the estimated friction to explore quantitative implications for the fiscal multiplier at the ZLB. Section 7 concludes.

2 An open economy model

I begin with a variant of the open economy models developed by Gali and Monacelli [2005] and Clarida and Gertler [2001], which were designed for the purpose of analyzing monetary policy in the open economy. They lend themselves equally well to the analysis of open economy fiscal policy at the ZLB. In this section, I only report the log-linearized equations with a detailed description relegated to Appendix A.

There are two countries in this model: the home country denoted H and the foreign country denoted F. The home agent consumes both a domestically produced good $\hat{c}_t^H$ and a foreignly produced good $\hat{c}_t^F$,

$$\hat{c}_t = (1 - \gamma)\hat{c}_t^H + \gamma\hat{c}_t^F.$$

The weight on the foreign good in the consumption basket is γ, which is equal to the import share in the steady state. Since economies with higher γ import (and export) a greater fraction of their consumption, I interpret this parameter as a measure of "openness." The price index corresponding to the domestic basket is $\hat{p}_t = (1 - \gamma)\hat{p}_t^H + \gamma\hat{p}_t^F$. I abstract from nontradable goods as they significantly complicate derivations but provide little additional insight.[5]

The foreign representative agent purchases a basket with import share ψ,

$$\hat{c}_t^* = \psi \hat{c}_t^{H*} + (1-\psi)\hat{c}_t^{F*},$$

I let $\psi = \gamma/n$ where n is the relative size of the foreign economy.[6] I will typically consider the limit where $n \to \infty$, so that the home economy is small. The price of the foreign consumption basket is $\hat{p}_t^* = \psi \hat{p}_t^{H*} + (1-\psi)\hat{p}_t^{F*}$.

To satisfy the resource constraint, log domestic output $\hat{y}_t$ is the sum of home and foreign consumption of the domestic good as well as the home government's demand $\hat{g}_t$,

$$\hat{y}_t = s_g \hat{g}_t + (1-s_g)\left[(1-\gamma)\hat{c}_t^H + \gamma \hat{c}_t^{H*}\right],$$

where s_g is the steady-state share of government in domestic output. A similar equation holds for the foreign country with the appropriate weights on the domestic and foreign good.

Given the Dixit-Stiglitz structure, the relative demand between home and foreign produced goods depends only on the terms of trade s_t,

$$\hat{c}_t^H - \hat{c}_t^F = \eta \hat{s}_t, \;\; \hat{c}_t^{H*} - \hat{c}_t^{F*} = \eta \hat{s}_t,$$

where η is the elasticity of substitution between home and foreign goods. The terms of trade are here defined as the ratio of foreign to domestic prices, $\hat{s}_t = \hat{p}_t^F - \hat{p}_t^H = \hat{p}_t^{F*} - \hat{p}_t^{H*}$, where the last equality follows from the Law of One Price.

It is typical in the literature to assume that financial markets are complete, which implies that the relative marginal utility levels of foreign and home residents must be proportional to the real exchange rate (the Backus and Smith [1993] condition). I consider a more general formulation which includes a friction $\hat{f}_t$ between the real exchange rate and relative marginal utilities. With the wedge I can accommodate departures from uncovered interest rate parity (UIP), which will ultimately be important to determine the size of the fiscal multiplier. I keep the friction in reduced form, because there is little agreement in the literature as to what mechanism accounts for deviations from UIP.[7] However, in Appendix B I also provide

[5] Intuitively, adding nontradable goods reduces the difference between open economy fiscal multipliers and closed economy fiscal multipliers, both in normal times and at the ZLB. However, the terms of trade response in a model with tradables is still given by equation (3). Thus, the empirical test in section 5 remains valid in a model with tradables.

[6] The foreign disutility of work is decreasing in n to generate this result. See appendix A for details.

[7] See Lustig and Verdelhan [2007] for a risk-based explanation and Burnside, Eichenbaum, and Rebelo

an example following Bodenstein [2008], where the Backus-Smith condition takes precisely this form. In summary, the modified Backus-Smith condition of the model is,

$$\sigma(\hat{c}_t - \hat{c}_t^*) = \hat{\lambda}_t - \hat{f}_t, \tag{1}$$

where $\hat{\lambda}_t = (1 - \gamma - \psi)\hat{s}_t$ is the real exchange rate and σ is the inverse of the intertemporal elasticity of substitution (IES).

Intertemporal optimization by domestic residents yields an Euler equation

$$\hat{c}_t = E_t\hat{c}_{t+1} - \frac{1}{\sigma}E_t[\hat{r}_{t+1} - \hat{\pi}_{t+1}^h - \gamma\Delta\hat{s}_{t+1} + \hat{\beta}_{t+1}],$$

where $\hat{r}_{t+1}$ is the current domestic nominal interest rate, $\hat{\pi}_{t+1}^H$ the inflation rate of domestically produced goods, and $\hat{\beta}_{t+1}$ a shock to the discount factor. An increase in the discount factor raises the desire to save, which lowers consumption today relative to tomorrow. If this shock is sufficiently large, then the only nominal interest rate that is consistent with market clearing in the savings-investment market is zero.[8]

The foreign residents also satisfy an Euler equation akin to (2), with the obvious substitutions. Combining the two Euler equations with the Backus-Smith condition also generates an equation similar to UIP, but for the terms of trade

$$E_t\Delta\hat{s}_{t+1} = (\hat{r}_{t+1} - E_t\hat{\pi}_{t+1}^H) - (\hat{r}_{t+1}^* - E_t\hat{\pi}_{t+1}^{F*}) - (\hat{f}_t - E_t\hat{f}_{t+1}). \tag{2}$$

Of course, this is equivalent to the typical UIP condition for the nominal exchange rate $\hat{e}_t$,

$$E_t\Delta\hat{e}_{t+1} = \hat{r}_{t+1} - \hat{r}_{t+1}^* - (\hat{f}_t - E_t\hat{f}_{t+1}). \tag{3}$$

When there is no friction, $\hat{f}_t = 0\,\forall t$, the above equation reduces exactly to UIP. Departures from UIP arise only if the friction is expected to change over time.

Calvo pricing of domestic and foreign varieties with Calvo probability θ, gives rise to a New Keynesian Phillips Curve for each country. The domestic Phillips Curve is given by,

$$\hat{\pi}_t^H = \beta E_t\hat{\pi}_{t+1}^H + \kappa[\nu\hat{y}_t + \sigma\hat{c}_t + \gamma\hat{s}_t].$$

[2011] for a liquidity-based explanation.

[8]Technically, this market will be cleared by the real interest rate. However, with sticky prices, some of the adjustment of the real interest rate has to be brought about by changes in the nominal rate.

where $\kappa = (1-\theta)(1-\beta\theta)/\theta$ and ν is the inverse frisch elasticity of labor supply. Real marginal cost for firms are also a function of the terms of trade, because workers care about the CPI-deflated wage rate, which is affected by the price of foreign goods.

The final piece of the log-linear model is the Taylor rule. I first log-linearize the Taylor rule without the zero bound constraint and then impose this constraint on the log-linear approximation. The lower bound on the log-linearized nominal interest rate is given by $\hat{r}_t = \log(1+R_t) - \log(1+R) \geq -\log(1+R) \equiv -\bar{r}$. The Taylor rule of the domestic central bank is thus,

$$\hat{r}_{t+1} = \max\{\phi\hat{\pi}_t^H, -\bar{r}\},$$

with the foreign central bank following a similar rule.

3 Fiscal Multipliers in the frictionless open economy

To simplify derivations and build intuition, I consider the small open economy without friction, where $n \to \infty$, $\psi \to 0$ and $f_t = 0\,\forall t$. The analysis of the large open economy is relegated to Appendix D and the analysis of the economy with friction is deferred to Section 4. In the frictionless model, I can then express output exclusively in terms of government spending, the terms of trade, and now exogenous foreign consumption,

$$\hat{y}_t = s_g\hat{g}_t + \underbrace{\frac{1-s_g}{\sigma}\left[1+\gamma(2-\gamma)(\sigma\eta-1)\right]}_{\equiv\epsilon_{ys}}\hat{s}_t + (1-s_g)\hat{c}_t^*, \tag{4}$$

where $\epsilon_{ys} > 0$ is the elasticity of output with respect to the terms of trade. This equation tells us that a deterioration in the terms of trade (increase in $\hat{s}_t$) is associated with an increase in domestic output. Intuitively, the deterioration in the terms of trade captures both the behavior of net exports, and, through its association with declining real interest rates, the increase in domestic consumption (by the Euler equation).

More precisely, solving the UIP condition (2) for the terms of trade forward and setting $f_t = 0$ yields,

$$\hat{s}_t = -E_t\sum_{j=1}^{\infty}[(\hat{r}_{t+j} - \hat{\pi}_{t+j}^H) - (\hat{r}_{t+j}^* - \hat{\pi}_{t+j}^*)]. \tag{5}$$

This equation emerges as a no-arbitrage condition in the friction-less model.[9] Intuitively, an

[9]Nevertheless, this model is not isomorphic to an incomplete market model with two bonds. The latter is non-stationary (see e.g. Schmitt-Grohé and Uribe [2003]) so that the complete markets assumption is

increase in domestic real interest rates relative to foreign real interest rates makes domestic real bonds more attractive. As arbitrageurs purchase domestic real bonds, the real exchange rate appreciates, which is reflected as an improvement in the terms of trade.

Substituting the solution for s_t condition into equation (4) yields,

$$\hat{y}_t = s_g \hat{g}_t + \epsilon_{yr} E_t \sum_{j=1}^{\infty} [(\hat{r}_{t+j} - \hat{\pi}^H_{t+j}) - (\hat{r}^*_{t+j} - \hat{\pi}^*_{t+j})] + (1-g)\hat{c}^*_t, \tag{6}$$

where $\epsilon_{yr} = -\epsilon_{ys} < 0$ is the real interest rate elasticity of output. According to equation (6), the effect of fiscal policy on output in this small open economy depends on the reaction of real interest rates. Differentiating (6) with respect to domestic government spending (taking foreign consumption and real interest rates as exogenous) yields the fiscal multiplier,

$$\frac{\partial Y_t}{\partial G_t} = 1 + \frac{\epsilon_{ys}}{s_g} \frac{\partial \hat{s}_t}{\partial \hat{g}_t} = 1 + \frac{\epsilon_{yr}}{s_g} \frac{\partial \sum_{j=1}^{\infty} [(\hat{r}_{t+j} - \hat{\pi}^H_{t+j})]}{\partial \hat{g}_t}, \tag{7}$$

According to equation (7), if real interest rates do not change with fiscal policy, then the fiscal multiplier is always equal to 1. This is independent of whether the economy is open ($\gamma > 0$) or closed ($\gamma = 0$). This result was proven by Woodford [2011] for the closed economy without capital, and it also extends to the frictionless small open economy.[10] The fiscal multiplier will be less than 1 if the sum of expected future interest rates increase with fiscal policy ($\partial E_t \sum_{j=1}^{\infty} [(\hat{r}_{t+j} - \hat{\pi}^H_{t+j})]/\partial \hat{g}_t > 0$), and greater than 1 if the sum of expected future interest rates fall with fiscal policy ($\partial E_t \sum_{j=1}^{\infty} [(\hat{r}_{t+j} - \hat{\pi}^H_{t+j})]/\partial \hat{g}_t < 0$).[11]

The sum of expected future interest rate changes (and thus the terms of trade) are a sufficient statistic for the fiscal multiplier, because they determine the behavior of both consumption and net exports. Solving the Euler equation forward, yields

$$\hat{c}_t = \underbrace{-\frac{1-\gamma}{\sigma}}_{\equiv \epsilon_{cr}} E_t \sum_{j=1}^{\infty} (\hat{r}_{t+j} - \hat{\pi}^H_{t+j}) - \frac{\gamma}{\sigma} E_t \sum_{j=1}^{\infty} (\hat{r}^*_{t+j} - \hat{\pi}^*_{t+j}). \tag{8}$$

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necessary to guarantee $\lim_{T\to\infty} s_T = 0$, which is embedded in equation (5).

[10]Similar isomorphisms between a closed economy and a complete markets small-open economy also extend to monetary policy, as stressed by Clarida and Gertler [2001].

[11]Note that equation (7) yields a multiplier for each period. Thus a sequence of $\{\partial E_t \sum_{j=1}^{\infty} [(\hat{r}_{t+j} - \hat{\pi}^H_{t+j})]/\partial \hat{g}_t\}_{t=0}^{\infty}$ will deliver a (potentially different) fiscal multiplier for each time period, $\{\partial Y_t / \partial G_t\}_{t=0}^{\infty}$. However, this does not imply that the contemporaneous fiscal multiplier is independent of the expected path of future fiscal policy. Rather, these expectations are already reflected in the current realization of $\partial E_t \sum_{j=1}^{\infty} [(\hat{r}_{t+j} - \hat{\pi}^H_{t+j})]/\partial \hat{g}_t$.

Thus, higher expected domestic real interest rates are associated with lower consumption and vice versa, through standard intertemporal substitution. However, the interest rate elasticity of consumption ϵ_{cr} is smaller (in absolute value) in the open economy, because the domestic consumer can substitute towards foreign goods when higher real interest rates generate an improvement in the terms of trade.

Similarly, domestic net exports, defined as $\hat{nx}_t = \gamma(c_t^{H*} - c_t^F)$, are equal to

$$\hat{nx}_t = \underbrace{-\left[(2-\gamma)\gamma\eta - \frac{\gamma(1-\gamma)}{\sigma}\right]}_{\equiv \epsilon_{nxr}} E_t \sum_{j=1}^{\infty}[(\hat{r}_{t+j} - \hat{\pi}^H_{t+j}) - (\hat{r}^*_{t+j} - \hat{\pi}^*_{t+j})]. \tag{9}$$

Depending on the parameters, higher expected domestic real interest can be associated with either increased or decreased net exports as there are two competing effects. The first term in the square brackets of equation (9) captures the substitution effect - higher domestic real interest rates generate an appreciation in the terms of trade and thus a substitution away from domestic goods in both the foreign and home consumption bundle. The second term in the square brackets reflects the risk sharing condition, which demands that aggregate domestic consumption falls more than aggregate foreign consumption, because the cost of domestic consumption has risen more. This will increase net exports because domestic consumption demand for the foreign good declines more than the foreign consumption demand for the home good. However, even though the sign of the interest rate elasticity of net exports is ambiguous, the interest rate elasticity of the sum of consumption and net exports (equal to $\epsilon_{cr} + \epsilon_{nxr}$) is strictly negative. Therefore the behavior of real interest rates alone can tell us what is happening to the private components of output following a fiscal shock.

While one may be skeptical about such a close connection between the fiscal multiplier, real interest rates, and the terms of trade, recent results by Ilzetzki, Mendoza, and Vegh [2010] are at least suggestive of such a relationship. Specifically, they show that a government spending shock in a flexible exchange rate regime is associated with an immediate rise in nominal interest rates, an appreciation in the real exchange rate, and a long-run fiscal multiplier below 1. On the other hand, with fixed exchange rates, nominal interest rates fall, the real exchange rate depreciates and the long-run fiscal multiplier is above 1.[12] Since the

[12]In the baseline model there is no distinction between long-run and short-run multipliers because it has no internal persistence. Therefore the mapping from the Ilzetzki, Mendoza, and Vegh [2010] should be interpreted somewhat cautiously. However, since the real exchange rate is a forward looking variable, it presumably contains information about the long-run effect of fiscal policy. Therefore I take the long-run fiscal multiplier as the natural benchmark.

real exchange rate in this model, $\hat{\lambda}_t$, is proportional to the terms of trade, $\hat{\lambda}_t = (1-\gamma)\hat{s}_t$, the estimates by Ilzetzki, Mendoza, and Vegh [2010] suggest that a relationship like equation (7) is not implausible.

In order to calculate $\partial E_t \sum_{j=1}^{\infty}[(\hat{r}_{t+j} - \hat{\pi}_{t+j}^H)]/\partial \hat{g}_t$ and the associated fiscal multiplier in the model, I need to specify the nature of the exogenous stochastic process $\upsilon_t = (\hat{g}_t\, \hat{\beta}_t\, \hat{c}_t^*)'$. I assume that the exogenous shocks υ_t follows a stochastic process as in Christiano, Eichenbaum, and Rebelo [2011]. At time t, υ_t unexpectedly takes on a positive value, $\upsilon_t > \mathbf{0}$ (some elements of υ_t may still be zeros). At time $t+1$, and all future dates, I assume the following transition probabilities: If at $t+j > t$, $\upsilon_{t+j} > \mathbf{0}$, then it remains at this level with probability p, $\text{Prob}\left[\upsilon_{t+j+1} = \upsilon_{t+j} | \upsilon_{t+j} = \upsilon_t\right] = p$. With probability $1-p$, $\upsilon_{t+j+1} = \mathbf{0}$, which is an absorbing state. The transition probabilities imply that $E_t \upsilon_{t+j} = p^j \upsilon_t$.

I outline the solution procedure with this shock process in Appendix C. This stochastic process is particularly useful because it allows me to derive analytic solutions to the fiscal multiplier in and outside the liquidity trap. In particular, the fiscal multiplier in normal times is given by,

$$\mu_G = \frac{(1-p)(1-\beta p) + \kappa(\phi - p)}{(1-p)(1-\beta p) + \kappa(\phi - p)\left\{1 + (1-s_g)\frac{\nu}{\sigma}\left[1 + \gamma(2-\gamma)(\sigma\eta - 1)\right]\right\}}, \tag{10}$$

and satisfies $0 < \mu_G < 1$. The fiscal multiplier in normal times is decreasing in openness, $\frac{\partial \mu_G}{\partial \gamma} < 0$, if and only if $\sigma\eta > 1$.

If the duration of the liquidity trap remains unchanged, then the fiscal multiplier in the liquidity trap is given by,

$$\mu_G^{LT} = \frac{(1-p)(1-\beta p) - \kappa p}{(1-p)(1-\beta p) - \kappa p\left\{1 + (1-s_g)\frac{\nu}{\sigma}\left[1 + \gamma(2-\gamma)(\sigma\eta - 1)\right]\right\}}, \tag{11}$$

and satisfies $\mu_G^{LT} > 1$.[13] The fiscal multiplier in the liquidity trap is *increasing* in openness, $\frac{\partial \mu_G^{LT}}{\partial \gamma} > 0$, if and only if $\sigma\eta > 1$.

The intuition behind these results is as follows. An increase in government spending will initially cause an equal increase in output. As output increases, firms have to pay higher wages because of increasing disutility of labor. Since firms' marginal cost increase, they will pass these costs onto consumers in form of higher prices. Thus, an increase in government spending raises inflation. In normal times, the central bank will raise nominal interest rates

[13] It is easy to show that in a liquidity trap the denominator must be positive. See also Christiano, Eichenbaum, and Rebelo [2011] and Eggertsson [2009].

to fight this inflation. In fact, because of the Taylor principle, real interest rates will rise in response to inflation.

According to equation (8), higher domestic real interest rates will generate a fall in consumption, whereas the effect on net exports (equation (9)) depends on the interest rate elasticity of the terms of trade. However, the sum of domestic consumption and net exports unambiguously falls. This offsets some of the increase in output due to fiscal policy and explains why the multiplier is less than one.

The condition on $\sigma \cdot \eta$ determines how the interest rate elasticity of output changes with openness (γ).[14] In standard calibrations[15] $\sigma\eta > 1$, which implies that the (absolute) interest rate elasticity of net exports rises sufficiently with γ, to compensate for the reduced interest rate elasticity of domestic consumption. Thus, if $\sigma\eta > 1$, then a higher value of γ implies that a given rise in real interest rates will have a greater negative impact on output. Since real interest rates increase following a fiscal shock in normal times, a greater interest rate elasticity of output will imply a lower fiscal multiplier. Therefore, in normal times, the fiscal multiplier in an open economy ($\gamma > 0$) is smaller than in a closed economy ($\gamma = 0$).

However, if the economy is in a liquidity trap then nominal interest rates remain fixed at zero. The inflation generated by government spending will then reduce real interest rates. According to equations (8) and (9), the sum of domestic consumption and net exports now expands, which amplifies the output response to the fiscal policy shock and generates a fiscal multiplier above 1. If $\sigma\eta > 1$, then the liquidity trap fiscal multiplier in an open economy ($\gamma > 0$) is larger than in a closed economy ($\gamma = 0$), because its interest rate elasticity of output is greater in absolute value.

In this example there need not be crowding out of net exports in a liquidity trap. Indeed, if $\sigma\eta > 1$, then the interest rate elasticity of net exports is negative and there can be crowding in if real interest rates fall. Thus, at the ZLB, the open economy dimension may actually support fiscal efforts to lift the economy. Of course, if domestic net exports expand then foreign net exports must decline, so that a domestic fiscal expansion may actually reduce foreign output. This would make fiscal expansion in the liquidity trap a beggar-thy-neighbour policy, which will require a different policy coordination than fiscal expansion in normal times (which is a free-rider problem). In particular, with uncoordinated fiscal

[14] This condition is weaker than in Fujiwara and Ueda [2010] who assume $\eta = 1$.

[15] For example, Ferrero, Gertler, and Svensson [2008] set $\sigma = 1$ and $\eta = 2$, while Bodenstein, Erceg, and Guerrieri [2010] set $\sigma = 1$ and $\eta = 1.5$. Obstfeld and Rogoff [2005] argue that $\eta = 2$ is a reasonable calibration balancing micro and macro estimates. However, they suggest that micro estimates (which imply higher elasticities) are likely less biased, and thus also experiment with higher values of η.

policy, countries may expand government spending too much, as they do not internalize the beggar-thy-neighbour effects of fiscal expansion.

4 Fiscal Multipliers in friction economy

The results in the preceding section have been derived assuming that UIP holds in the data, at least conditional on a government spending shock. To see how the results may be sensitive to departures from UIP, consider the exchange rate movements implied by the model: In normal times the nominal exchange rate appreciates by

$$\frac{\partial \hat{e}_t}{\partial \hat{g}_t} = -\frac{\phi - 1}{(1-p)(1-\gamma)} \frac{\partial \hat{\pi}_t}{\partial \hat{g}_t} < 0. \tag{12}$$

However, even without any exchange rate response the terms of trade would improve in normal times, and there would have been some crowding out of domestic net exports (for reasonable parameters). This suggests that the qualitative results for the fiscal multiplier in normal times would still hold, even if the nominal exchange rate fails to appreciate due to limits to arbitrage.

The results are more sensitive in the liquidity trap. In this case the nominal exchange rate depreciates by,

$$\frac{\partial \hat{e}_t}{\partial \hat{g}_t} = \frac{1}{(1-p)(1-\gamma)} \frac{\partial \hat{\pi}_t}{\partial \hat{g}_t} > 0, \tag{13}$$

which generates a deterioration in the terms of trade even though domestic prices rise. Suppose that limits to arbitrage prevent the nominal exchange rate from adjusting at all. Then the terms of trade would improve and we would likely see a crowding out of net exports. This suggests that the fiscal multiplier in the liquidity trap may be particularly sensitive to departures from UIP.

To investigate this issue more formally, I determine the fiscal multiplier for various degrees of friction in the UIP condition. I assume that the friction is proportional to the excess return on domestic real bonds,

$$\hat{f}_t = \frac{\tau}{1-p}[(\hat{r}_{t+1} - E_t \hat{\pi}^H_{t+1}) - (\hat{r}^*_{t+1} - E_t \hat{\pi}^{F*}_{t+1})], \tag{14}$$

where τ captures the size of the friction, which is scaled by $(1-p)$ since the expected friction also enters the UIP condition. Typically in this model, $E_t \hat{f}_{t+1} = p\hat{f}_t$, and the UIP condition becomes

$$E_t \Delta \hat{s}_{t+1} = (1-\tau)[(\hat{r}_{t+1} - E_t \hat{\pi}^H_{t+1}) - (\hat{r}^*_{t+1} - E_t \hat{\pi}^{F*}_{t+1})]. \tag{15}$$

When $\tau > 0$ the friction will limit the movement of the terms of trade and thus the nominal exchange rate relative to the baseline model. For example, $\tau = (\phi - 1)/(\phi - p) > 0$ corresponds to the case where the nominal exchange rate fails to appreciate in normal times, whereas $\tau = 1/p > 0$ implies that the nominal exchange rate does not depreciate at the ZLB. The functional form of f_t may appear somewhat arbitrary, but since τ will be estimated conditional on it, it is more akin to a convenient normalization.

The friction τ will affect the fiscal multiplier in two ways. First, by limiting the movement in the nominal exchange rate, it can reduce the effect of fiscal shock on net exports, and even switch the sign of the net export response. For example, at the ZLB when $\tau = 1/p$, the nominal exchange rate is unchanged, so that the terms of trade improve. This will crowd out net exports, whereas in the baseline model ($\tau = 0$) net exports were crowded in. Second, for a given terms of trade response the friction now allows for a non-proportional consumption response, unlike the baseline model. Suppose that the friction is such that the terms of trade response is zero following a government spending shock ($\tau = 1$). If consumption falls (as it does in normal times), then a fraction of it will fall on foreign production, so the multiplier in normal times will be higher. Vice-versa, if consumption rises (as at the ZLB), then the increase in consumption will benefit foreign producers and the domestic fiscal multiplier is smaller. This behavior was absent in the baseline model, because a zero terms of trade response implied a zero consumption response.

We can see both effects in action by calculating the fiscal multipliers as in section 3. Incorporating the friction, fiscal multiplier in normal times is now given by,

$$\mu^F_G = \frac{(1-p)(1-\beta p) + \kappa(\phi - p)}{(1-p)(1-\beta p) + \kappa(\phi_\pi - p)\left\{1 + (1-s_g)\frac{\nu}{\sigma}\left[(1-\tau\gamma) + (1-\tau)\gamma(2-\gamma)(\sigma\eta - 1)\right]\right\}}.$$

The friction has only affected the last two terms in the denominator: The weight $(1-\tau)$ on the second term reflects the first effect discussed above - by limiting the change in the terms of trade, net exports become less sensitive to government spending. The first term, $(1-\tau\gamma)$, captures the second effect noted in the preceding paragraph: When domestic consumption falls, for a given terms of trade response, then this is partly absorbed by net exports. This allows for a higher multiplier in normal times, so long as the import share γ is positive. Note that when $\gamma = 0$, we obtain the closed economy fiscal multiplier for all values of τ. Intuitively, net exports are always zero independent of the terms of trade, and consumption is entirely determined by domestic real interest rates, for which the friction is irrelevant.

For small to moderate frictions, the results derived in the preceding section also hold in normal times. In particular, if $\tau < 1$, then the multiplier is less than 1, $0 < \mu_G^F < 1$. In fact, for realistic calibrations of $\sigma\eta$ and the import share γ, much larger frictions can also satisfy this inequality. Thus, the upper bound on the fiscal multiplier in normal times is quite robust to deviations from UIP. On the other hand, the comparative static with respect to the import share can be quite sensitive to τ. In the friction economy, the fiscal multiplier in normal times is decreasing in openness, $\frac{\partial \mu_G^F}{\partial \gamma} < 0$, if $\sigma\eta > 1$ and $\tau < \tilde{\tau} = 2(1-\gamma)(\sigma\eta - 1)/[1 + 2(1-\gamma)(\sigma\eta - 1)] < 1$. Depending on parameter values this expression can be quite small, although standard calibrations will put $\tilde{\tau}$ in the upper half of the unit interval.

The friction affects the multiplier at the ZLB symmetrically,

$$\mu_G^{LT,F} = \frac{(1-p)(1-\beta p) - \kappa p}{(1-p)(1-\beta p) - \kappa p \left\{1 + (1-s_g)\frac{\nu}{\sigma}\left[(1-\tau\gamma) + (1-\tau)\gamma(2-\gamma)(\sigma\eta - 1)\right]\right\}}. \quad (16)$$

where once again $\mu_G^{LT,F} > 1$ if $\tau < 1$. However, even for larger τ the multiplier will be above 1 for standard parameterizations. The fiscal multiplier in the liquidity trap is increasing in openness, $\frac{\partial \mu_G^{LT,F}}{\partial \gamma} > 0$, if $\sigma\eta > 1$ and $\tau < \tilde{\tau} < 1$. Thus, the friction is more likely to affect the relative size of open and closed economy fiscal multipliers, rather than the relative size of the fiscal multiplier in normal times and at the ZLB.

5 Empirical Strategy & Results

Ultimately, the degree to which UIP fails and its influence on the size and properties of the fiscal multiplier at the ZLB is an empirical question. While ideally one would like to side track this issue and obtain direct estimates of fiscal multipliers there is not enough data to use standard empirical tools such as SVARs or estimated DSGE models. The aim of this paper is thus more modest: obtain estimates of the friction in UIP and, through the lens of the model, ask if the results obtained in the frictionless case are robust. In particular, given empirical departures from UIP,

1. is the fiscal multiplier at the ZLB above 1?

2. is the open economy fiscal multiplier at the ZLB larger than the closed economy fiscal multiplier?

To the best of my knowledge this is the first approach that tries to empirically test an aspect of the large fiscal multipliers that obtain in New Keynesian models at the ZLB.

There is a long literature that has estimated unconditional departures from UIP by directly estimating equation (3) with realized exchange rate data (see e.g. Engel [1996]). However, determining the size of the fiscal multiplier requires knowledge of the *conditional* departures from UIP. In other words, we need to know the size of the friction conditional on a government spending shock. Typically conditional deviations tend to be smaller than unconditional departures (e.g. Faust, Rogers, Wang, and Wright [2007]), so this distinction can be quantitatively important.

To determine the conditional departures from UIP I examine the nominal exchange rate response following generic inflationary shocks. If the inflation surprise was due to a government spending shock, then the nominal exchange rate in the frictionless model appreciates in normal times as in equation (12). As we increase the friction parameter τ, this appreciation will get smaller and smaller,

$$\frac{\partial \hat{e}_t}{\partial \hat{g}_t} = \underbrace{-\left[\frac{\phi - 1}{1-p} + \tau \frac{\phi - p}{1-p}\right] \frac{1}{1-\gamma}}_{\delta^{NT}} \frac{\partial \hat{\pi}_t}{\partial \hat{g}_t}, \tag{17}$$

and may even turn into a depreciation for large values of τ. Similarly, at the ZLB the nominal exchange rate depreciates in the frictionless model as in equation (13). However, a large enough friction can again switch the sign of the exchange rate response,

$$\frac{\partial \hat{e}_t}{\partial \hat{g}_t} = \underbrace{\left[\frac{1}{1-p} - \tau \frac{p}{1-p}\right] \frac{1}{1-\gamma}}_{\delta^{ZLB}} \frac{\partial \hat{\pi}_t}{\partial \hat{g}_t}. \tag{18}$$

The empirical strategy is to estimate the coefficient δ and, given estimates for ϕ, γ and p, infer the value for τ. I allow the estimate for τ to differ in normal times and at the ZLB, since the latter period featured more financial turmoil in international asset markets. The rest of this section will address some concerns about this empirical strategy.

First, it is unlikely that most generic inflation surprises are due to government spending shocks. However, equations (17) and (18) hold for any generic inflationary shock in the model, with the exception of f_t which I will discuss below. We can simply replace g_t by some other shock $x_t \neq f_t$, which could be either a demand or supply shock, and still use the estimated exchange rate response to determine the friction parameter τ. I show in Appendix E that the inflation surprises I use appear to be to hitherto unobserved demand shocks. Since there is little a priori reason why conditional deviations from UIP should vary across different types of demand shocks, using these inflation surprises as proxy is unlikely to considerably bias an estimate of τ.

Second, when f_t shocks are a major source of inflation surprises, then this will bias the estimation of τ. In particular, shocks to f_t will add a shock to the estimated exchange rate equation,

$$\Delta\hat{e}_t = \delta\Delta\hat{\pi}_t + \epsilon_t$$

where ϵ_t is the shock to f_t, and δ is δ^{NT} in normal times (equation (17)) or δ^{ZLB} at the ZLB (equation (18)). The estimated coefficient in this regression will be biased depending on the correlation between $\hat{\pi}_t$ and the shock ϵ_t,

$$E(\hat{\delta}) = \delta\left(1 + \frac{cov(\hat{\pi}_t, \epsilon_t)}{var(\hat{\pi}_t)}\right).$$

In the model, $cov(\hat{\pi}_t, \epsilon_t) \geq 0$ if $\sigma\eta > 1$, which implies that f_t shocks will bias the estimates $\hat{\delta}$ away from zero and $\hat{\tau}$ downwards. Thus, if the estimated $\hat{\tau}$ is positive, then this is not a consequence of exogenous shocks to the UIP equation.

Third, for a large open economy, there is also some pass-through to inflation of goods produced in the foreign country $\hat{\pi}_t^F$, which will mitigate the movements in nominal exchange rate. However, for plausible parameter values this effect is small and can be ignored: With a domestic import share of $\gamma = 0.15$ and a relative size of the foreign country of $n = 3$ (plausible for the US), the foreign import share is just $\psi = 0.05$. This limits the substitution by foreign consumers away or towards foreign goods, and thus the spill-over from domestic inflation, which is typically less than 10% for plausible parameter values. For parameters typical of European countries ($\gamma \approx 0.3$ and $n \geq 9$) the pass-through rate is even smaller. I also split the sample into large and small open economies and find little difference in the estimated exchange rate responses, suggesting that spill-overs do not bias the estimation.

Fourth, if generic inflation shocks are global then the exchange rate effects will be very different from those derived above. When both countries face a simultaneous shock to the excess return of their bonds, the effects on the nominal exchange rate are ambiguous. I consider this possibility in to following section, where I show that inflation surprises in other countries do not forecast current or future inflation in the US, and thus appear to represent local shocks.

5.1 Inflation Surprises

I construct inflation surprises following Clarida and Waldman [2008]: The announced inflation values and the associated professional forecasts for inflation are from Bloomberg Financial Services. Bloomberg surveys numerous professional forecasters on their expectations of the next inflation announcement and I take the median of these expectations as the market expectation. The data covers eight countries from February 2000 until January 2010: the US, Great Britain, the Eurozone, Japan, Sweden, Norway, Switzerland, and Canada. For most countries inflation forecasts are available for the CPI and the core CPI. The definitions of the price indices used are tabulated in Appendix Table 4 and summary statistics are tabulated in Appendix Table 5 for headline inflation and appendix Table 6 for core inflation. I define inflation surprises as the difference between the *announced* and the *expected* inflation rate.

Since the empirical test allows inflation surprises, both from demand or supply shocks, I relegate a more detailed analysis to Appendix E and provide only an informal summary here. I show that they contain news about current and future macroeconomic conditions, and are largely exogenous with respect to past macroeconomic conditions. However, contemporaneously and over the next two years, inflation surprises are associated with higher inflation, lower unemployment and (outside the ZLB) higher policy rates. This is consistent with inflation surprises being caused by hitherto unobserved demand shocks, a novel finding to the best of my knowledge.

In addition, neither lagged nor contemporaneous foreign inflation surprises predict the inflation levels in the US, the reference country in this analysis. In Table 1 I regress current US inflation levels on current and lagged foreign inflation surprises and find p-values that are consistently above 0.2. This suggests that the demand shocks are local in nature, and that have the exchange rate effects described in the preceding section.

To infer an estimate of the friction, I need to determine the persistence of the inflation shock. As shown in Appendix E, the IRF of inflation to an inflation surprise is close to an AR(1) process. In Table 2, I restrict the impulse to AR(1) in a GMM estimation, which easily satisfies the over-identification restrictions, with p-values of 0.91 and 0.86 respectively. The estimated persistence for headline inflation corresponds to a value of $\hat{p} = 0.8$ at quarterly frequency.

Table 1: Correlation of Inflation Surprise with US Inflation.

Timing:	Current	Lead	Current	Lead
Inflation Type:	Headline	Headline	Core	Core
Canada	0.330	0.535	-0.0849	-0.245
	(0.522)	(0.538)	(0.223)	(0.213)
Switzerland	0.997	1.107		
	(0.616)	(0.659)		
Eurozone	1.744	1.238	-0.312	-0.522
	(2.370)	(2.342)	(0.365)	(0.367)
Japan	1.804	1.609	-0.0635	-0.209
	(1.365)	(1.391)	(0.310)	(0.279)
Norway	0.241	0.0560	0.303	0.292
	(0.467)	(0.476)	(0.233)	(0.242)
Sweden	0.263	0.433		
	(0.652)	(0.635)		
UK	-1.182	-1.274	-0.571*	-0.590*
	(1.080)	(1.150)	(0.228)	(0.288)
Constant	2.548***	2.543***	2.133***	2.126***
	(0.139)	(0.140)	(0.0446)	(0.0445)
Observations	109	108	109	108
R^2	0.070	0.071	0.042	0.054
F	0.980	1.085	1.491	1.436
p-value	0.450	0.379	0.200	0.218

Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Current = Inflation level in the Month of the Inflation surprise.
Lead = Inflation level in the Month following the Inflation surprise.

Table 2: Persistence of Inflation Surprise in Revised Inflation (Monthly Frequency).

	Headline Inflation	Core Inflation
AR(1) coefficient	0.930***	0.895***
	(0.012)	(0.020)
Hansen's J	14.68	15.82
p-value	0.91	0.86

Estimated by GMM. HAC standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5.2 Exchange Rate Response to Inflation Surprises

Next, I examine the exchange rate response to inflation surprises by estimating

$$\Delta e_{i,t} = \delta_0 + \delta_1 \tilde{\pi}^s_{i,t} + \delta_2 LT_{i,t} + \delta_3 LT_{i,t} \cdot \tilde{\pi}^s_{i,t} + \epsilon_{i,t}, \tag{19}$$

where $\Delta e_{i,t}$ is the change in the natural logarithm of the nominal exchange rate of country i, $\tilde{\pi}^s_{i,t}$ is an inflation surprise,[16] and $LT_{i,t}$ is a dummy variable equal to 1 if the economy is in a liquidity trap. The estimate of δ_1 maps into δ^{NT}, while $\delta_1 + \delta_3$ maps into δ^{ZLB}.

I classify a country to be a liquidity trap at time t as follows. First, I estimate a Taylor rule for all countries except Japan up to the fourth quarter of 2007 (if available). I then use this rule to forecast the predicted unconstrained interest rate up to 2010Q1 and determine in which quarters the predicted rate is below zero. Second, I check if the nominal interest rate in those quarters is the lowest observed in the sample, so that there is no more room for the central bank to cut rates given its implicit interest rate floor. If a quarter satisfies both conditions then I set the liquidity trap dummy for that quarter equal to 1. The details of the estimation procedure are relegated to Appendix G. For Japan the zero bound constraint is binding too frequently in the sample to estimate a Taylor rule. I therefore define Japan to be in a liquidity trap, whenever its policy rate is less than or equal to 0.25.

The exchange rate changes $\Delta e_{i,t}$ are high-frequency as in Clarida and Waldman [2008]. For each inflation announcement from January 2005 until January 2010 I calculate the percentage change of the exchange rate against the US Dollar from 5 minutes before the announcement to 5 minutes after the announcement.[17,18] I tabulate summary statistics for the percentage change in the exchange rate in Appendix Table 7. All exchange rates are expressed in terms of units of foreign currency so a negative percentage change corresponds to an appreciation (as in the model).

Since equation (19) is non-structural it may be helpful to provide some interpretation on its form. First, it is not necessary to include inflation announcements of the foreign country in equation (19). Inflation announcements are made at different times across countries so whenever $\tilde{\pi}^s_{i,t} \neq 0$, then for all other countries $j \neq i$, $\tilde{\pi}^s_{j,t}$, within the 10-minute window that I consider. Thus, equation (19) will yield the same result as if I was controlling for foreign inflation surprises within the 10-minute window.

Second, it is not necessary to control if the foreign country is in a liquidity trap or not.

[16]Inflation that is not a surprise will already be reflected in the exchange rate.
[17]The data was supplied by Olsen Data and is recorded at 5-minute frequency.
[18]I use the British Pound as a reference currency for the US Dollar.

Within the small open economy model of section 3 the exchange rate response will be the same irrespective of the foreign state. Intuitively, the domestic inflation surprise does not spill over to the large foreign country, so there is no foreign interest rate response even if the foreign country was unconstrained. For plausible parameters of a large open economy such as the US, the spill-overs in a calibrated model are also small. Nevertheless, as one robustness check I limit the estimation to small open economies.

I estimate equation (19) as a pooled regression with bootstrapped standard errors corrected for the presence of estimated regressors. The estimates are tabulated in Table 3. The first column contains the regression using year-on-year headline inflation surprises. Accordingly, in normal times a one percent inflation surprise is associated with a 0.876% appreciation of the home currency. The standard error of this estimate is 0.189, so the estimate is statistically significant at the 1% level. With $\hat{p} = 0.8$, $\gamma = 0.15$ and $\phi = 1.5$ this estimate implies a moderate friction in normal times, $\hat{\tau} = 0.50$. Higher values for the import share do not affect his estimate very much, e.g. setting $\gamma = 0.3$ yields $\hat{\tau} = 0.54$.

The estimates for δ_1 are very stable across the robustness checks I consider: In column (2) I add country and time fixed effects, in column (3) I restrict the sample to small open economies (excluding the US and the Eurozone), in column (4) I exclude Japan, and in column (5) I use core inflation surprises instead of headline inflation surprises. The estimate for δ_1 ranges from -0.84 to -0.93 and is always significant at the 1% level. This result confirms earlier estimates by Clarida and Waldman [2008], who find that a 1% point (quarterly) surprise inflation generates a 0.6% appreciation in the nominal exchange rate in a set of 10 countries using data from July 2001 until December 2005.[19] The implied range for $\hat{\tau}$ is correspondingly tight - it ranges from 0.48 to 0.51 across these estimates.

Turning now to the estimates for the liquidity trap, I tabulate the total exchange rate response (the sum of the first row and the third row) along with the standard error in the two bottom rows of Table 3. Accordingly, the exchange rate appreciates by 0.063% for each percentage point of the inflation surprise, with a standard error of 0.366. This is significantly different from the exchange rate response outside the liquidity trap at the 10% level. However, the frictionless model predicted a depreciation in the domestic currency,

[19] Nevertheless, the implied appreciation in the real exchange rate contrasts with growing literature, which estimates real exchange *depreciations* following fiscal shocks (Corsetti, Meier, and Muller [2009]; Monacelli and Perotti [2010]; Ravn, Schmitt-Grohé, and Uribe [2007]). However, Ilzetzki, Mendoza, and Vegh [2010] find that the real exchange rate appreciates following a fiscal shock for countries with flexible exchange rates. Furthermore, in robustness checks by Corsetti, Meier, and Muller [2009] the real exchange rate appreciates if fiscal shocks are identified using the Ramey and Shapiro [1998] dates. Thus, a real exchange rate appreciation following a fiscal shocks does not appear to be implausible.

which suggests that the friction to UIP must have been particularly large at the ZLB. In fact, with $\hat{p} = 0.8$ and $\gamma = 0.15$ I obtain an estimate of $\hat{\tau} = 1.26$, which is significantly larger than in normal times. This estimate is even less sensitive to the choice of γ than the estimate for normal times.

The robustness checks yield similar results, although less precisely estimated than δ_1. Reading across columns (1) through (5) in Table 3, the estimate ranges from -0.01 (column (5)) to -0.23 (column (4)). In all cases I can reject the hypothesis that the domestic currency depreciates as predicted by the frictionless model. The implied range of $\hat{\tau}$ for the ZLB estimates is 1.25 to 1.30.

Table 3: Exchange Rate Response to Inflation Surprises

Inflation Measure	Headline Inflation				Core Inflation
	All Countries Pooled (1)	Country &Time FE (2)	SOE only (3)	Excluding Japan (4)	All Countries Pooled (5)
Surprise Inflation (δ_1)	-0.867***	-0.831***	-0.936***	-0.915***	-0.861***
	(0.189)	(0.165)	(0.214)	(0.195)	(0.246)
Liquidity Trap (δ_2)	-0.012	0.147	-0.027	0.015	-0.027
cle	(0.045)	(0.087)	(0.054)	(0.054)	(0.051)
Inflation-Liquidity Trap	0.804*	0.675*	0.741	0.690	0.852
Interaction (δ_3)	(0.417)	(0.366)	(0.519)	(0.486)	(0.543)
Country & Time FE	No	Yes	No	No	No
Observations	485	485	363	426	356
R^2	0.107	0.279	0.279	0.126	0.072
$\delta_1 + \delta_3$	-0.063	-0.156	-0.195	-0.225	-0.009
	(0.366)	(0.330)	(0.471)	(0.441)	(0.479)

Bootstrapped standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

All regressions use CPI non-flash inflation announcements.

The results are unlikely to be driven by measurement error: First, inflation surprises are followed by significant movements in macroeconomic aggregates, which suggests that they do contain useful information about shocks (see Appendix E). Second, the estimates at the ZLB would have been even more negative if there is bias towards zero, which would imply an even greater distortion to UIP. Therefore, measurement error in the data cannot explain the discrepancy between the estimates and the predictions of the frictionless baseline model.

6 Quantitative analysis

Given estimates for τ in normal times and at the ZLB, I can calibrate the model to assess the quantitative and qualitative importance of departures from UIP. I calibrate the model with a set of standard parameters, which largely follow Christiano, Eichenbaum, and Rebelo [2011] and Bodenstein, Erceg, and Guerrieri [2009]. The discount factor β is calibrated at 0.99 to match an average real interest rate of 4% per year. The inverse Frisch elasticity ν is set to 0.5 and the IES σ^{-1} is set to 1 to allow for sufficient output variation in a model without capital. The share of government in output s_g is set to 0.2 and the import elasticity η to 2 as suggested by Obstfeld and Rogoff [2005]. The Calvo probability θ is calibrated at 0.85 to accord with the small inflation response in this recession.[20] The persistence of the shock is set to $p = 0.8$ as estimated in Section 5.1.

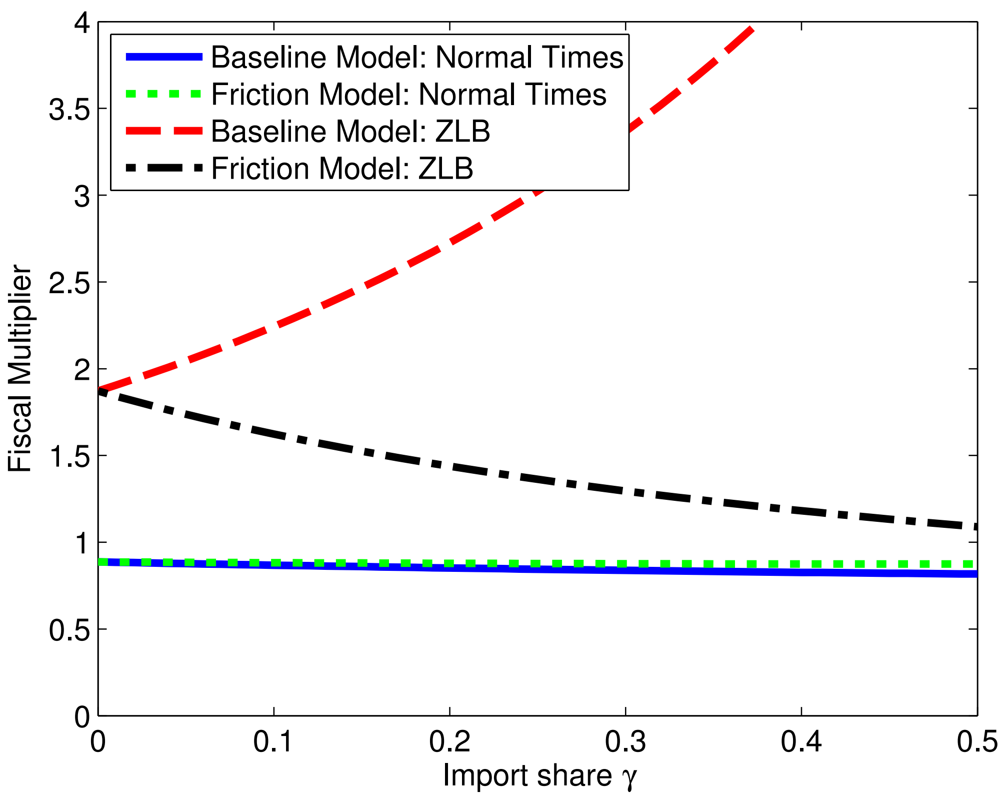

Figure 1: Fiscal multipliers for baseline model in normal times and at the ZLB, as well as fiscal multiplier for friction model in normal times and at the ZLB.

[20]This calibration is equivalent to a model with firm-specific labor, where the Calvo probability is set to $\theta = 0.7$ (as suggested by Nakamura and Steinsson [2008]) and the elasticity of substitution across goods equals $\epsilon = 10$.

In Figure 1 I display the baseline fiscal multiplier in normal times and at the ZLB, as well as the multipliers in the friction model while varying the import share γ from 0 to 0.5. As proven in section 3, in the baseline model the fiscal multiplier is less than 1 and decreasing in the import share in normal times, while it is greater than 1 and increasing in the import share at the ZLB. The estimated friction barely affects the multiplier much in normal times - it is still less than 1 and decreasing in the import share. In fact, even much larger frictions, such as those estimated during the ZLB, will not push the fiscal multiplier above 1 during normal times. Small fiscal multipliers appear to be a robust feature during normal times, irrespective of weather UIP holds or not.

The same cannot be said for the ZLB. For small import shares as in the US ($\gamma = 0.15$), the fiscal multiplier in the friction model is "only" 1.5, whereas it assumes a value of 2.5 in the baseline model. Nevertheless, it is above 1 and it would require an extremely large friction - $\tau = 3.5$ - to push the multiplier below 1 for these parameters. However, unlike the baseline model the multiplier in the friction model is now decreasing in γ. The resulting difference between the closed economy fiscal multiplier and the friction multiplier are quantitatively significant, particularly at import shares relevant for European countries. For example, with $\gamma = 0.3$ the friction multiplier is 30% smaller than the closed economy fiscal multiplier. This suggests that for empirically relevant departures from UIP, exchange rate crowding out can be quantitatively important even at the ZLB.

6.1 A model with capital

In this section I add capital to the model to check the robustness of the results in the previous section. I allow capital to be completely mobile across firms, that have Cobb-Douglas technology with capital share α. Aggregate capital depreciates at rate δ and is accumulated subject to a quadratic adjustment cost $\frac{\psi}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 K_{t-1}$, where K_t is capital and I_t is investment. Investment goods are produced using the same weights on domestic and foreign goods as consumption in the baseline model,

$$\hat{i}_t = (1-\gamma)\hat{i}_t^H + \gamma\hat{i}_t^F \tag{20}$$

and with elasticity of substitution η between home and foreign goods. Allowing for capital results in two new (log-linearized) first order conditions, an Euler equation for capital,

$$\hat{c}_t = E_t\hat{c}_{t+1} - \frac{1}{\sigma}\left[\beta R(1-\alpha)(\hat{n}_{t+1} - \hat{k}_t) + \beta\hat{q}_{t+1} - \hat{q}_t + \hat{\beta}_{t+1}\right] \tag{21}$$

and an equation for Tobin's q,

$$\hat{q}_t = \psi(\hat{k}_t - \hat{k}_{t-1}) \tag{22}$$

This model can no longer be solved analytically for the fiscal multiplier, so I solve this model using the algorithm from Bodenstein, Erceg, and Guerrieri [2009]. Coibion, Gorodnichenko, and Wieland [forthcoming] show that this algorithm remains accurate even for large shocks that will push the economy to the ZLB. To make the estimates comparable to the baseline model, I let the ZLB bind for 5 quarters. I set the capital share $\alpha = 0.33$, the depreciation rate at $\delta = 0.02$ and the investment adjustment cost at $\psi = 7$ as in Shapiro [1986]. In addition the Frisch elasticity of labor supply ν^{-1} is reduced to 2/3, and the IES σ^{-1} to 0.5, since investment will now induce sufficient output variability.

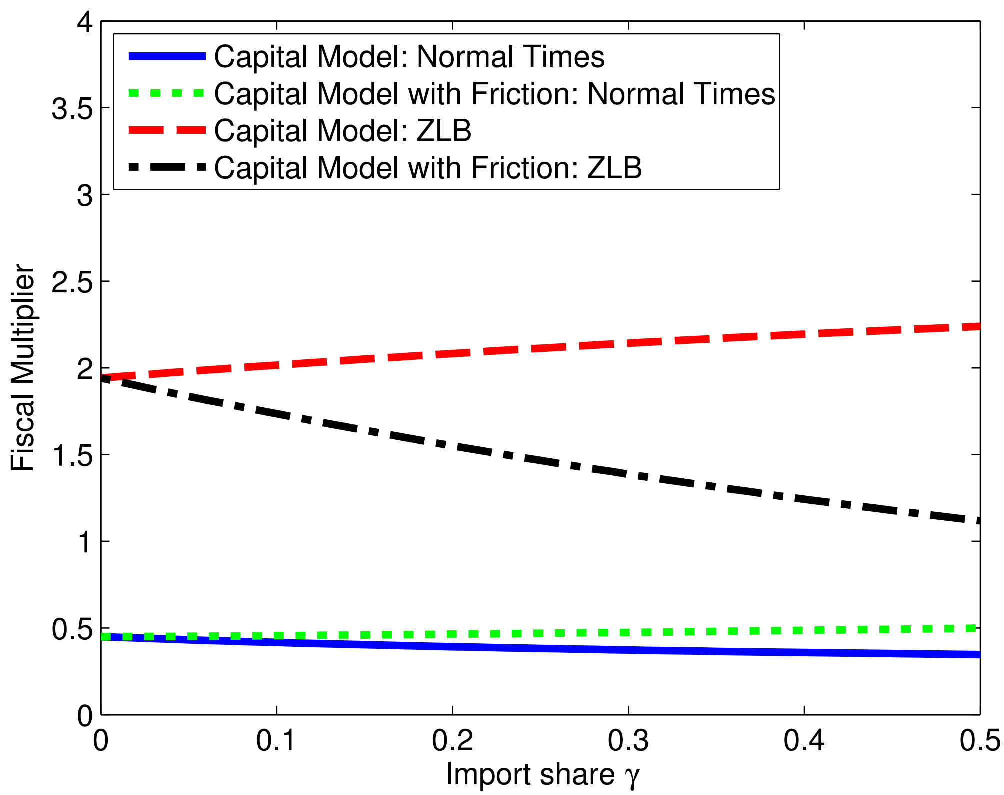

Figure 2: Fiscal multipliers for the capital model. The fiscal multipliers are calculated for normal times, binding ZLB, normal times with friction, and binding ZLB with friction.

Importantly, introducing capital does not invalidate the empirical analysis in section 5, as the friction enters the UIP relationship in exactly the same fashion. Thus, the same estimated friction can be used to calibrate the model with capital.[21] The fiscal multipliers for the capital model, as well as the capital model with friction are reported in Figure 2.

Adding capital does not change the qualitative behavior of fiscal multipliers in normal times: They are small, less than 0.5, both in the standard model and the model with friction. More action occurs at the ZLB: Here, the fiscal multiplier is increasing in the import share in the baseline model with capital, but this is reversed when I add the friction to international asset markets. The differences between the baseline multiplier and the friction multiplier are smaller than in the model without capital, but still quantitatively significant. Furthermore, letting $\gamma = 0.3$ in the friction model again reduces the fiscal multiplier by about 30% relative to the closed economy, which confirms the earlier finding that exchange rate crowding out can be quantitatively important. Finally, the friction fiscal multipliers remain above 1 for reasonable import shares, and are significantly larger than fiscal multipliers in normal times.

In summary, incorporating the empirically estimated friction into the standard models significantly affects the properties of the fiscal multiplier at the ZLB. It will be smaller in the open economy than in the closed economy, because the friction prevents favorable exchange rate adjustments that occur in the baseline model. However, it typically remains above 1, which is large by the standards of the economy literature. This suggests that fiscal policy in the open economy is effective at the ZLB, although not as much as our baseline models may lead us to believe.

7 Conclusion

In this paper I have provided both theory and evidence on the open economy fiscal multiplier in a liquidity trap. I show that in open economy New Keynesian models, the fiscal multiplier at the ZLB is greater than 1 and increasing in the import share if there are no frictions to international asset markets. Intuitively, the open economy's interest rate sensitivity of output is greater (in absolute value), so that it gets a larger boost from a given decline in real interest rates. Indeed, for standard parameterization, the home countries' net exports rise, so that domestic fiscal expansion in the liquidity trap has a beggar-thy-neighbour effect.

I then show that sufficiently large frictions in international asset markets that manifest themselves as departures from UIP, can overturn both conclusions. In this case, a large friction will prevent the nominal exchange rate depreciation that occurs in the baseline

[21] Because the persistence of inflation is endogenous in the capital model I adjust p in equation (14) to hit the estimated exchange rate response in Table 3.

model, so that the terms of trade improve. This can crowd out net exports sufficiently such that the open economy has a smaller multiplier than the closed economy, and that this multiplier is below 1.

To distinguish between these conflicting predictions and determine the likely properties of the open economy fiscal multiplier at the ZLB, I estimate the size of the friction by examining the exchange rate response to generic inflation surprises. While the frictionless model predicts that the nominal exchange rate depreciates by more than 1% for each 1% point of inflation at the ZLB, I estimate essentially a zero response. Thus, large frictions are needed to rationalize this exchange rate response.

A model calibrated with the estimated friction shows quantitatively important deviations from the baseline model at the ZLB. The fiscal multipliers are significantly smaller, even at moderate import shares, and decline as the import share rises. Nevertheless, the fiscal multipliers in the friction model are typically above 1, which is large given the standards of an open economy (e.g. Dornbusch [1976], Ilzetzki, Mendoza, and Vegh [2010]).

As more data on ZLB episodes becomes available, more empirical work will be required to sharpen our estimates of the fiscal multiplier in the current economic environment. In the meantime, as we resort to model-based analysis, the results of this paper suggest that frictions in international asset markets can have important quantitative implications for the open economy fiscal multiplier, particularly at the ZLB. Evidently, more research is needed to understand the sources of these frictions and their connections to the real economy.

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A Complete Model

A.1 Households

Each country is populated by a representative household. The objective function for the household in the home country is given by,

$$\max_{\{C_t,N_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \left(\prod_{s=0}^{t} \beta_s \right) \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \chi_t \frac{N_t^{1+\nu}}{1+\nu} \right], \tag{23}$$

where C_t is domestic consumption and N_t is domestic labour supply. The discount factor β_t follows a stationary stochastic process with steady state value β. At time t, the household knows next period's value of the stochastic discount factor, β_{t+1}, as well as its history, but it does not know any other future values with certainty. Discount factor shocks are a standard method to generate a liquidity trap (see Christiano, Eichenbaum, and Rebelo [2011] and Eggertsson and Woodford [2003]). σ is the inverse of the elasticity of substitution and ν is the inverse of the Frisch elasticity of labour supply. Finally, $\chi_t > 0$ governs the steady state labour supply and also follows a stationary stochastic process. For the foreign country, I let $\chi^* = n^{-(\sigma+\nu)}\chi$, to make it produce n times as much output than the home country. The home country becomes a small open economy as I take the limit $n \to \infty$.

The domestic household maximizes its objective (23), subject to its budget constraint each period,

$$P_t C_t + E_t[Q_{t,t+1} D_{t+1}] \leq D_t + W_t N_t + T_t \quad \forall\, t = 0, 1, ... \tag{24}$$

where P_t is the price of the domestic consumption good, W_t is the wage rate for domestic labor and T_t are net transfers from the government and firms. D_{t+1} is a vector of payoffs from the portfolio held from time t until $t+1$. I assume that financial markets are complete, which implies that the stochastic discount factor $Q_{t,t+1}$ is the unique asset pricing kernel for the vector of payoffs D_{t+1}.

The optimality conditions for the domestic households are as follows. (For the foreign household there exists an analogous set of first order conditions.) First, the marginal utility of consumption multiplied by the real wage rate must equal the marginal disutility of labor,

$$C_t^{-\sigma} \frac{W_t}{P_t} = \chi_t N_t^{\nu}. \tag{25}$$

Second, the household satisfies the Euler equation,

$$\beta_t R_{t+1} E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \left(\frac{P_t}{P_{t+1}} \right) \right] = 1, \tag{26}$$

where R_{t+1} is the gross nominal interest rate on the domestic one-period riskless bond.

The asset pricing equations for the home and foreign safe bonds imply that the excess return of domestic over foreign bonds has a price of zero,

$$E_t \left[Q_{t,t+1} \left(R_{t+1} - \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} R^*_{t+1} \right) \right] = 0. \tag{27}$$

Here R^*_{t+1} is the gross nominal interest rate on the foreign bond and $\mathcal{E}_t$ is the nominal exchange rate between the home and the foreign currency. The latter is defined as the quantity of domestic currency for each unit of foreign currency, so that a fall in $\mathcal{E}_t$ corresponds to an appreciation of the domestic currency. Equation 27 will become an uncovered interest rate parity (UIP) condition in the log-linearized small open economy.

The household in the foreign country also satisfied an Euler equation,

$$\beta_t R^*_{t+1} E_t \left[\left(\frac{C^*_{t+1}}{C^*_t} \right)^{-\sigma} \left(\frac{P^*_t}{P^*_{t+1}} \right) \right] = 1, \tag{28}$$

where C^*_t is foreign consumption, and P^*_t the foreign price level. Foreign consumption C^*_t is exogenous with respect to the domestic economy, due to the large size of the foreign country.

A.2 Final Goods Firms

The production structure in the economy is as follows. In each country there is a continuum of firms that produce intermediate goods with local labor inputs. These intermediate goods are then assembled by final goods firms into the final consumption good.

For both countries, there are two types of perfectly competitive firms. In the home country, one set of firms produces an aggregate C^H_t by combining a continuum of home-produced varieties $C^H_t(j)$, $C^H_t = \left(\int_0^1 C^H_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}$, where ϵ is the elasticity of substitution between different domestically-produced varieties. The firms' cost minimization problem implies that home-produced varieties are demanded according to the standard Dixit-Stiglitz demands,

$$C^H_t(j) = \left(\frac{P^H_t(j)}{P^H_t} \right)^{-\epsilon} C^H_t,$$

where $P^H_t(j)$ is the price of a given variety and $P^H_t = \left(\int_0^1 P^H_t(j)^{1-\epsilon} dj \right)^{\frac{1}{1-\epsilon}}$ is the price of the aggregate C^H_t. Analogous equations apply to the set of firms in the foreign country that produce C^F_t.

The remaining domestic final good firms then combine the aggregates C^H_t and C^F_t into the desired consumption good. In particular, for the home country,

$$C_t = \left[(1-\gamma)^{\frac{1}{\eta}} (C^H_t)^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} (C^F_t)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}},$$

where γ is the share of imports in aggregate home consumption and η the elasticity of substitution between home and foreign goods. I define the degree of openness of an economy to be equal to γ. Intuitively, when $\gamma = 0$ the home country will never import any goods and it effectively becomes a closed economy.[22] When $\gamma = 1$, then the economy only consumes foreign goods, so it will have to export all its production to finance this consumption. Since the gross amount of trade increases in γ, I will treat this parameter as measuring the degree of "openness:" Economies with higher values for γ are more "open" because they will trade more goods.

Given this particular final consumption good, the optimal choice between the home produced composite and the foreign goods satisfy the standard Dixit-Stiglitz demand equations, so that the price of domestic consumption is given by $P_t = \left[(1-\gamma)(P_t^H)^{1-\eta} + \gamma(P_t^F)^{1-\eta}\right]^{\frac{1}{1-\eta}}$, where P_t^F is the domestic price of the foreign consumption aggregate C_t^F.

To ensure that larger foreign production does not depress the relative price of foreign goods, I assume that the foreign country consumes primarily its own goods. Thus, I let share of imports of domestic output in foreign consumption be decreasing in n, $\psi = \gamma/n$. This ensures that the terms of trade in the steady state equal 1. In the small open economy case, where $n \to \infty$, the share of home goods in foreign consumption approaches zero, $\psi \to 0$.

A.3 Intermediate Goods Firms

In each country there is continuum of local firms, producing a differentiated product using local labor. In the home country, these firms produce the varieties $Y_t^H(j)$ according to the production function,

$$Y_t^H(j) = A_t N_t(j),$$

where $N_t(j)$ is domestic labour input into the production of good j and A_t is aggregate technology, which I assume to be stationary. Each firm sets its prices on a staggered basis: With probability θ its current price remains fixed at last periods price and with probability $1-\theta$ it is optimally reset. The profit maximization problem of firm i is therefore,

$$\max_{P_t^H(i)} E_t \sum_{j=0}^{\infty} \theta^j Q_{t,t+j} \left[P_t^H(i) - (1-\tau)W_{t+j}^H(i)\right] Y_{t+j}(i), \tag{29}$$

where $\tau = \epsilon^{-1}$ is an employment subsidy designed to offset the inefficiently low output from monopolistic competition. $Q_{t,t+j}$ is the stochastic discount factor of domestic residents.

I assume that labour is perfectly substitutable between sectors, which implies that the wage paid in each sector, $W_t^H(j)$, must be the same in equilibrium. Finally, I define aggregate domestic output analogously to consumption $Y_t^H = \left(\int_0^1 Y_t^H(j)^{\frac{\epsilon-1}{\epsilon}} dj\right)^{\frac{\epsilon}{\epsilon-1}}$.

A.4 Government

Similar to the Dornbusch model, I assume that the government spends money on domestically produced goods only. In particular, government spending is the same composite good as

[22] In this case the home economy is equivalent to the model in Christiano, Eichenbaum, and Rebelo [2011].

C_t^H, $G_t = \left(\int_0^1 G_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right)^{\frac{\epsilon}{\epsilon-1}}$. Furthermore, I assume that the government chooses among varieties to maximize the aggregator G_t. This assumption greatly simplifies the derivation of the New Keynesian Phillips Curve.

Government purchases are financed by lump-sum taxation and Ricardian equivalence holds in this economy. Subject to the no-Ponzi scheme condition, the government must satisfy the budget constraint,

$$B_0 = \sum_{t=0}^{\infty} \left(\prod_{s=0}^{t} \frac{1}{R_s}\right) G_t - \sum_{t=0}^{\infty} \left(\prod_{s=0}^{t} \frac{1}{R_s}\right) T_t, \tag{30}$$

where T_t are lump-sum taxes and B_0 are initial government assets. The steady-state share of government spending in output is given by $g = \bar{G}/\bar{Y}$.

The central bank conducts monetary policy according to a simple Taylor rule, subject to the zero interest rate floor,

$$R_{t+1} = \max \left\{ \beta^{-1} E_t \left(\frac{P_t^H}{P_{t-1}^H} \right)^{\phi_\pi}, 1 \right\}, \tag{31}$$

where $\phi_\pi > 1$ to satisfy the Taylor principle. Note that the central bank is responding to the inflation of domestically produced goods (the PPI), not the inflation rate of consumption goods (the CPI).

A.5 Prices and Market Clearing

The terms of trade are defined as the ratio between import prices (in domestic currency) and export prices,

$$S_t = \frac{P_t^F}{P_t^H}. \tag{32}$$

I assume that the the law of one price holds among individual goods. This defines the nominal exchange rate as ratio of the domestic currency price of good j to the foreign currency price of good j,

$$\mathcal{E}_t = \frac{P_t^H(j)}{P_t^{H*}(j)} = \frac{P_t^F}{P_t^{F*}}. \tag{33}$$

The Backus-Smith condition (Backus and Smith [1993]) in this model is subject to a reduced form friction F_t. Thus, consumption at home relative to abroad is proportional to the ratio of the real exchange rate λ_t and the friction F_t,

$$\left(\frac{C_t^*}{C_t}\right)^{-\sigma} = \lambda_t / F_t. \tag{34}$$

In equilibrium the market clearing conditions for home goods,

$$Y_t(j) = C_t^H(j) + C_t^{H*}(i) + G_t(j) \ \ \forall \ j, \tag{35}$$

as well as for foreign goods have to be satisfied. The definition of the equilibrium in this model is then as follows.

Definition 1 (Equilibrium)**.** *The equilibrium is a sequence,*

$$\{C_t^H(i), C_t^F, N_t(i), Y_t(i), D_t, G_t(i), T_t, W_t^H, P_t^H(i), P_t^{H*}, P_t^F, P_t^*, R_{t+1}, R_{t+1}^*, S_t, \mathcal{E}_t\}_{t=0}^{\infty},$$

such that for given $\{C_t^*, G_t, \beta_t, \chi_t, A_t\}_{t=0}^{\infty}$ *and given initial assets* $\{D_0, B_0\}$ *the maximization problems for the domestic and foreign households and firms are satisfied; the government satisfies its budget constraint* (30) *and allocates spending to maximize* G_t*; the domestic nominal interest rate follows the Taylor rule* (31)*; the foreign real interest rate is determined by the foreign Euler equation* (28)*; the Backus-Smith condition* (34) *is satisfied; domestic and foreign prices satisfy the law of one price* (33)*; and the market clearing conditions for the home and foreign goods are satisfied.*

B Backus-Smith with Wedge: An Example

Following Bodenstein [2008], consider a two country economy with limited enforcement of international contracts. In particular, they can only be enforced through threat of exclusion from asset markets in the future. Let V_t denote the home countries value from financial autarky. Then the incentive compatibility constraint must satisfy,

$$E_t \sum_{s=0}^{\infty} \beta^s u(c_{t+s}) \geq V_t \ \ \forall t$$

Denote the Lagrange multiplier on this constraint by μ_t. Then the objective function of the home agent can be rewritten as

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[u(c_t) + \mu_t \left(E_t \sum_{s=0}^{\infty} \beta^s u(c_{t+s}) - V_t \right) \right] = E_0 \sum_{t=0}^{\infty} \beta^t \left[M_t u(c_t) + \mu_t \left(u(c_{t+s}) - V_t \right) \right]$$

where $M_{t+1} = M_t + \mu_t$ and $M_0 = 1$. The first order conditions for the domestic household are,

$$\lambda_t P_t = [M_t + \mu_t] \, u'(c_t)$$

where P_t is the price of consumption, and

$$Q_{t,t+1} = \beta \frac{\lambda_{t+1}}{\lambda_t}$$

is the home agents SDF. Absent arbitrage opportunities, the home and foreign SDF are equal, which implies (given symmetric initial conditions)

$$\frac{u'(c_t^*)}{u'(c_t)} = \lambda_t \frac{M_{t+1}}{M_{t+1}^*}$$

where λ_t is the real exchange rate and M_{t+1}^* analogously defined for the foreign country. Log-linearizing this equation yields,

$$\sigma(\hat{c}_t - \hat{c}_t^*) = \hat{\lambda}_t - \hat{f}_t$$

where $\hat{f}_t = \hat{m}_{t+1} - \hat{m}_{t+1}^*$, which is the expression (1) in the baseline model.

C Solution Method for Baseline Model

The zero lower bound on nominal interest rates makes this model piecewise linear. In particular, let $x_t = \begin{pmatrix}\hat{y}_t & \hat{c}_t & \hat{\pi}_t & \hat{s}_t & \hat{r}_{t+1}\end{pmatrix}'$ be the vector of endogenous variables and $\upsilon_t = \begin{pmatrix}\hat{g}_t & \hat{\beta}_t & \hat{c}_t^*\end{pmatrix}'$ be the vector of exogenous variables. So long as the liquidity trap does not bind, we can write the system of equations as

$$Ax_t = BE_t x_{t+1} + F\upsilon_t. \tag{36}$$

Given the stochastic process in Example 1, its unique solution when the zero lower bound does not bind is

$$x_t = D\upsilon_t,$$

where $D = (I - A^{-1}B\text{diag}(p))^{-1}A^{-1}F$. Because there are no endogenous state variables in this model, a shock in period t causes an immediate jump in x_t to the new equilibrium. If at $t+1$ the shock disappears then the economy jumps back to the steady state. On the other hand, if the shock remains at the same value, then $x_{t+1} = x_t$. In particular, the fiscal multiplier outside the liquidity trap is the D_{11} element in the matrix D scaled by g^{-1}, the inverse of the government's share in output. Because the system of equations is linear, this multiplier is independent of the size of government spending.

The liquidity trap is somewhat more difficult to handle. When the economy is at the zero lower bound at time t, the system of equations may be written as follows,

$$A^* x_t = BE_t x_{t+1} + C^* + F\upsilon_t, \tag{37}$$

where A^* is the same matrix as A except that the A_{53}^* entry is equal to zero whereas $A_{53} = -\phi$. This reflects that in the liquidity trap, the nominal interest rate is bounded at zero and does respond to changes in the inflation rate. Instead, the log-linearized nominal interest rate is equal to $-\bar{r}$, which is captured in the C_{51}^* element of the vector C^*. All other elements of this vector are zero.

If the law of motion is given by equation (37) for all $t = 0, 1, ...$, then there is no unique solution to this system of equations because the economy violates the Taylor principle. To avoid this case I require that the economy must ultimately exit the liquidity trap with probability 1. This will imply that in the limit, the law of motion must satisfy equation (36) (rather than (37)), which we know has a unique solution. Given the stochastic process I have assumed, $\lim_{j\to\infty} \text{Prob}\left[\upsilon_{t+j} = \mathbf{0} | \upsilon_t \neq \mathbf{0}\right] = 1$. We therefore know that, in the limit, any shock that causes the zero bound to bind will disappear with probability one. Since we exit the liquidity trap with probability 1, the Taylor principle will hold asymptotically and there will be a unique solution to this problem.

Now suppose that at time t, the shocks υ_t are such that the zero lower bound binds. Suppose the endogenous variables take on the value x_t. We then know that with probability p, $\upsilon_{t+1} = \upsilon_t$. In this case, the economy at $t+1$ looks just like the economy at t. Thus, $x_{t+1} = x_t$ and the liquidity trap will remain binding at $t+1$. With probability $1-p$, $\upsilon_{t+1} = \mathbf{0}$. Since the economy exits the liquidity trap, the solution is simply given by (C), $x_t = \mathbf{0}$. Quite intuitively, without shocks the economy jumps back to the steady state. Using this logic, I solve equation (36) forward, to obtain,

$$x_t = E^* + D^* \upsilon_t,$$

where $D^* = (I - A^{*-1}B\text{diag}(p))^{-1}A^{*-1}F$ and $E^* = (I - A^{*-1}B\text{diag}(p))^{-1}A^{*-1}C^*$.

The fiscal multiplier in the liquidity trap is now the D^*_{11} element in the matrix D scaled by g^{-1}, the inverse of the government's share in output. Note however, that here fiscal policy is conditional on the liquidity trap. When the economy exits the liquidity trap, then the entire vector υ_t becomes zero, including the government spending shock. Furthermore, government spending must be small enough such that the economy does not exit the liquidity trap. Theoretically at least, this is defensible because it cleanly isolates fiscal policy in the liquidity trap.

D Large Open Economy

In this section I derive fiscal multipliers for the frictionless model in a large open economy. Let $\psi = \gamma/n$ be the import share of the foreign country, where n is the relative size of the foreign country. Define the function

$$z(\phi) = \frac{\kappa\nu(\phi - p)}{(1-\beta p)(1-p) + \kappa(\phi - p)}. \tag{38}$$

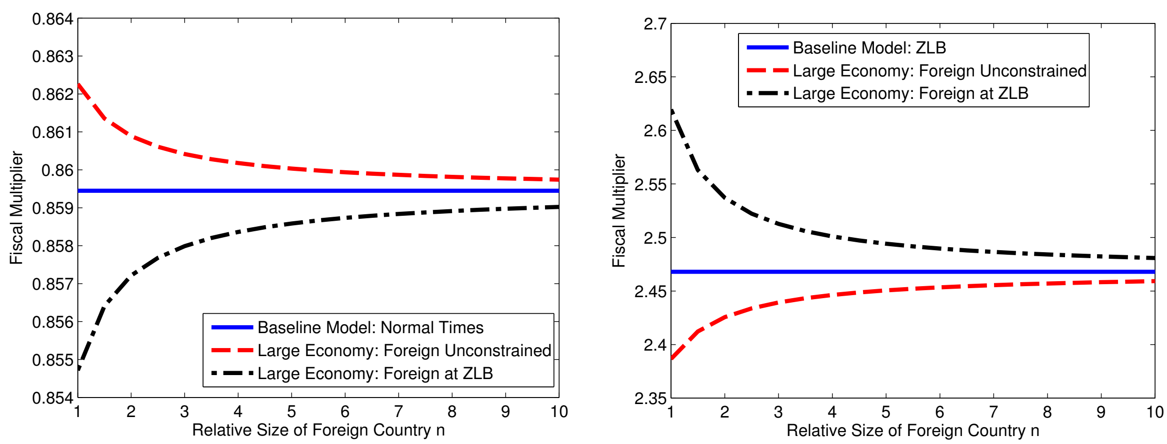
Then the fiscal multiplier in the open economy is given by

$$\mu_n = \frac{(1-p)(1-\beta p) + \kappa(\phi - p)}{(1-p)(1-\beta p) + \kappa(\phi - p)\left\{1 + (1-s_g)\frac{\nu}{\sigma}\left[1 + \gamma(2-\gamma-\psi)(\sigma\eta - 1)\right]\right\} - \gamma\psi\Delta_n}, \tag{39}$$

where the new term in the denominator is defined as,

$$\Delta_n = \frac{z(\phi)z(\phi^*)\left[(1-\beta p)(1-p)+\kappa(\phi-p)\right]\left[\frac{1-s_g}{\sigma}(2-\gamma-\psi)(\sigma\eta-1)\right]^2}{1+z(\phi^*)\frac{1-s_g}{\sigma}\left[1+\psi(2-\gamma-\psi)(\sigma\eta-1)\right]}. \tag{40}$$

When interest rates are positive in both countries, $z(\phi) > 0$ and $z(\phi^*) > 0$, so that $\Delta_n > 0$. This implies that the fiscal multiplier is larger in the large open economy than in the small open economy. Intuitively, the improvement in the terms of trade (due to domestic fiscal expansion) raises demand for foreign products and thus foreign inflation. In response, the foreign central bank raises nominal interest rates such that real rates rise, which mitigates the improvement in the terms of trade. As a result, there is less crowding out of domestic production and the multiplier is higher. This is illustrated in Figure 3(a).



(a) Domestic Fiscal Multiplier: Normal Times

(b) Domestic Fiscal Multiplier: ZLB

Figure 3: Domestic fiscal multipliers in normal times (left panel) and at the ZLB (right panel). Both panels show results from (a) the baseline model (small open economy), (b) when the foreign country is unconstrained and (c) when the foreign country it is at the ZLB. The import share γ is set to 0.15.

Figure 3(a) also shows that the fiscal multiplier is smaller when the home country is unconstrained but the foreign country is at the ZLB. The logic follows from the preceding argument, except that the foreign central bank does not raise nominal interest rates. Consequently, foreign real rates will fall which further amplifies the improvement in the terms of trade and crowds out domestic production.

Figure 3(b) illustrates the case when both countries are at the ZLB. In this case, $z(\phi) < 0$ and $z(\phi^*) < 0$, so that $\Delta_n > 0$, and the fiscal multiplier is larger than in the baseline model. The logic is similar to above, except that at the ZLB a fiscal expansion generates a deterioration in the terms of trade and thus deflation in the foreign country. If the foreign country is at the ZLB, then its real rates rise which precipitates a further deterioration in the terms of trade and amplifies the fiscal multiplier. Only if the foreign country is unconstrained will domestic real rates fall and cushion the deterioration in the terms of trade, which will result in a smaller fiscal multiplier.

Note that for reasonable parameters the spillovers are small. Intuitively, Δ_n is multiplied by $\gamma\psi$ which is very small for reasonable import shares and country sizes. Figure 3 illustrates this for the baseline calibration when $n = 3$ and $\gamma = 0.15$, which is reasonable for the US. (European parameters generate even smaller spillovers given their smaller country size.)

E The Nature of Inflation Surprises

To investigate the nature of inflation surprises, I first test whether they add predictive power to a simple autoregressive model. In particular, denote the forecasted value for inflation by $\hat{\pi}_t^f$, the announced value by $\hat{\pi}_t^a$, and the revised value for inflation by $\hat{\pi}_t^r$.[23] The inflation surprise is then defined as $\hat{\pi}_t^s = \hat{\pi}_t^a - \hat{\pi}_t^f$. In Figure 4 I plot the residuals from a regression of revised inflation, $\hat{\pi}_t^r$, on 24 of its own lagged values agains the residuals from a regression of inflation surprises $\hat{\pi}_t^s$ on 24 lagged values of revised inflation.[24] If inflation surprises added all the missing information to make a perfect forecast for inflation then these residuals should be perfectly correlated, i.e. line up on the 45 degree line. If however, inflation surprises are contaminated by measurement error, then there will be an attenuation bias, which will reduce the correlation. I find that the correlation between the residuals are 0.71 for headline inflation and 0.65 for core inflation, which is consistent with the notion that inflation surprises contains news about macroeconomic conditions, and are only somewhat contaminated by measurement error.

Headline inflation surprises over this sub-sample are somewhat predictable based on past levels of (revised) headline inflation: The p-value on the Wald exclusion test of 24 lags of headline inflation is 0.036. While this may reflect some information in revised headline inflation that wasn't available at the time the forecast is made, I make the conservative choice and purge headline inflation surprises of this correlation. In addition, I control for time and country fixed effects from both headline and core inflation surprises to derive a series of "true," uncorrelated surprises, which I denote $\tilde{\pi}_t^s$. The correlation between the true inflation surprises, $\tilde{\pi}_t^s$, and the original inflation surprise series, $\hat{\pi}_t^s$, is 0.85 for both headline inflation and core inflation, which suggests that the economic difference between these two series is small. Indeed, all results reported in this section are quantitatively robust to using the original inflation surprise series.[25]

To determine the likely source of inflation surprises, I construct impulse response functions for inflation, unemployment, and central bank nominal interest rates, given a 1% point true inflation surprise. I first regressed true inflation surprises on 24 lags of past inflation, true inflation surprises, unemployment, and central bank rates, and I could not reject that

[23]Not all countries in this sample revise initial CPI releases. For these countries, $\hat{\pi}_t^r = \hat{\pi}_t^a$.

[24]The regressions also include country and time fixed effects.

[25]For headline inflation surprises, the 95% confidence intervals will be larger, but the effects described below are still significant at the 5% level. For core inflation surprises the results reported below strengthen in both magnitude and significance.

(a) Headline Inflation Surprises

(b) Core Inflation Surprises

Figure 4: Correlation between residuals from a regression of inflation, $\hat{\pi}_t^r$, on 24 of its lagged values and residuals from a regression of inflation surprises, $\hat{\pi}_t^s = \hat{\pi}_t^a - \hat{\pi}_t^f$, on 24 lagged values of inflation, $\hat{\pi}_t^r$. The left panel shows the correlation when headline inflation is used, the right panel when core inflation is used.

true inflation surprises are unpredictable at the 5% significance level. This is consistent with true inflation surprises being exogenous with respect to past realizations these variables, which allows me to construct IRFs by regressing the outcome variables on 24 lags of true inflation surprises, controlling for country and time fixed effects,

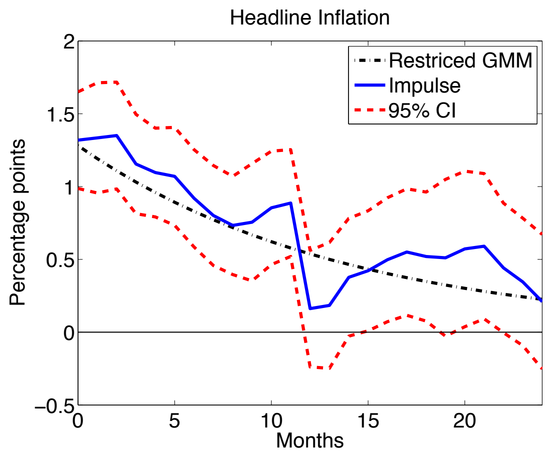
$$y_{i,t} = \gamma_i + \delta_t + \sum_{k=0}^{24} \beta_k \tilde{\pi}_{i,t-k}^s + e_{i,t}, \tag{41}$$

and then plotting the coefficients $\{\beta_k\}_{k=0}^{24}$ and associated HAC two-standard-error bands in Figure 5. The impulse responses for inflation display a significant increase in inflation for at least a year, and appear to follow an AR(1) process.

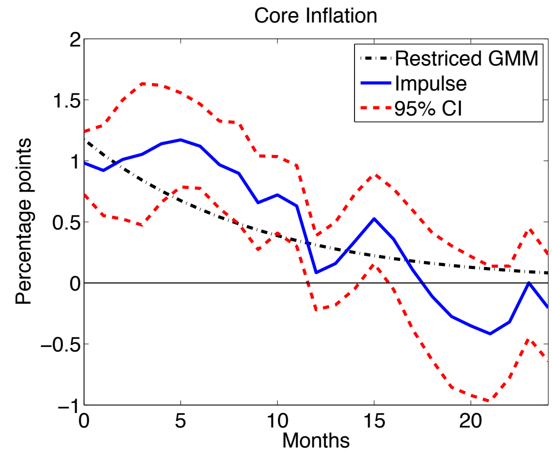
Unemployment is also below average after the inflation surprise occurred. The peak response is a 0.5% points decline in unemployment after a 1% point headline inflation surprise and a 1.5% point decline after a 1% point core inflation surprise. This suggests that the source of the inflation surprise is in fact an unexpected demand shock. While the effect may seem large, it requires a large real shock to generate a 1% point inflation surprise, given the flatness of the Phillips curve in recent times.[26]

The increase of central bank policy rates after inflation surprises further supports the

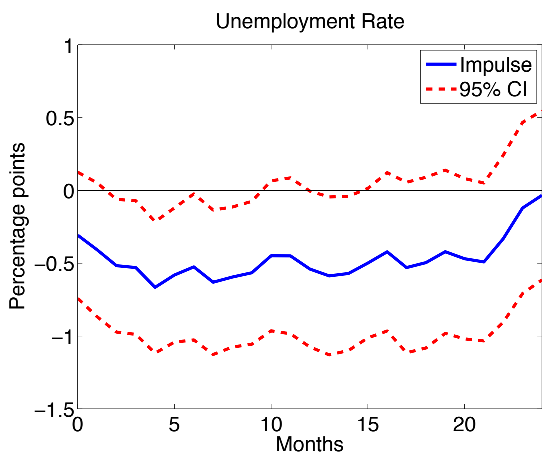
[26]See e.g. Altig, Christiano, Eichenbaum, and Lindé [2010] and Hall [2011].



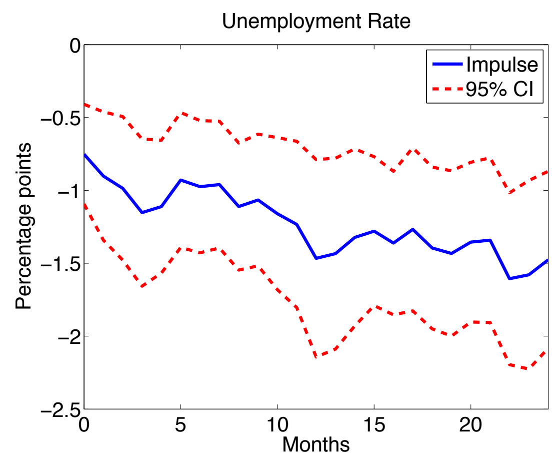
(a) Headline Infl. Surprise → Headline Inflation



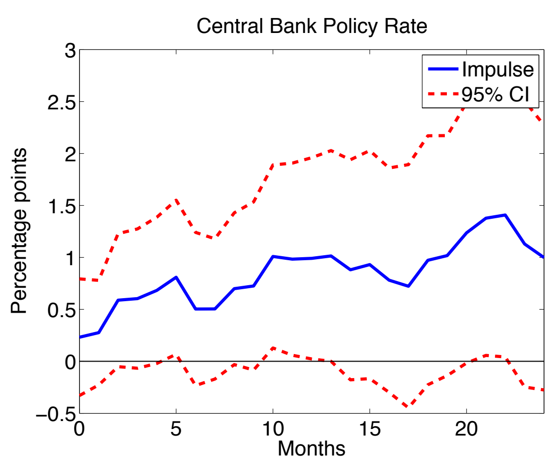
(b) Core Infl. Surprise → Core Inflation



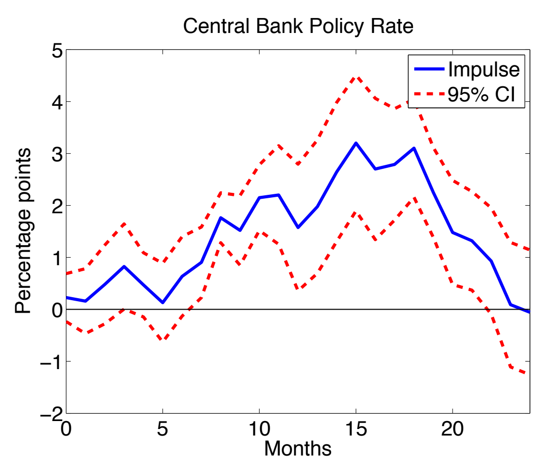
(c) Headline Infl. Surprise → Unemployment



(d) Core Infl. Surprise → Unemployment



(e) Headline Infl. Surprise → Nom. Policy Rates



(f) Core Infl. Surprise → Nom. Policy Rates

Figure 5: Impulse Response Functions for inflation, unemployment, and central bank nominal interest rates. Left side shows impulses for headline inflation surprises, right side shows impulses for core inflation surprises.

demand shock hypothesis, since unemployment falls even though the central bank tightens monetary policy.[27] I therefore conclude, that the evidence is consistent with inflation surprises being caused by demand shocks, a novel finding to the best of my knowledge.

[27] Estimation of the central bank response excludes periods marked as liquidity trap.

F Supplemental Tables for Empirical Section

Table 4: Price Indices used for Inflation Surprises

Economy	Headline	Core
USA	CPI Headline NSA	CPI Core NSA
UK	CPI EU Harmonized NSA	CPI Ex Energy Food Alcohol & Tobacco NSA
EUZ	Eurozone MUICP All Items NSA	Eurozone MUICP Core NSA
JAP	CPI Nationwide	CPI Nationwide Ex Fresh Food
CAN	STCA Canada CPI NSA	STCA Canada CPI Ex the 8 Most Volatile Components and Indirect Taxes NSA
SWE	Sweden CPI Headline	-
NOR	Norway CPI	Norway CPI Underlying (CPI-ATE)
CHE	Switzerland CPI	-

Table 5: Inflation Surprises (YoY)

Variable	Mean	Std. Dev.	Min.	Max.	N
Pooled	-0.003	0.199	-0.9	1	925
USA	0.021	0.198	-0.4	0.5	84
UK	0.032	0.181	-0.4	0.6	80
EUZ	-0.002	0.061	-0.1	0.2	110
EUZ (flash)	-0.004	0.109	-0.3	0.3	95
JAP	0.012	0.107	-0.3	0.2	99
CAN	-0.01	0.242	-0.75	0.6	120
CHE	-0.04	0.213	-0.55	0.6	120
SWE	-0.016	0.21	-0.8	0.5	120
NOR	0	0.325	-0.9	1	97

Table 6: Core Inflation Surprises (YoY)

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Pooled	-0.014	0.178	-0.8	0.9	476
USA	-0.06	0.193	-0.8	0.3	84
UK	-0.005	0.184	-0.3	0.55	53
EUZ	-0.032	0.123	-0.4	0.2	61
JAP	0.016	0.12	-0.3	0.9	99
CAN	0.01	0.191	-0.5	0.775	97
NOR	-0.023	0.223	-0.55	0.5	82

Table 7: Percentage Change in Exchange Rate after Inflation Announcements

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Pooled	0.003	0.145	-0.812	0.796	486
USD	0.015	0.119	-0.365	0.398	61
GBP	0.004	0.132	-0.352	0.357	61
EUR	-0.001	0.061	-0.213	0.17	61
JPY	-0.019	0.107	-0.545	0.101	60
CAD	0.032	0.137	-0.378	0.616	61
CHF	0.01	0.07	-0.158	0.201	60
SEK	-0.015	0.201	-0.812	0.796	61
NOK	0	0.238	-0.503	0.688	61

G Taylor Rule Estimation

I estimate the following quarterly regression model for each country in my sample (except for Japan) via OLS:

$$r_t^* = \alpha + \rho r_{t-1}^* + \phi_\pi \pi_{t+1}^e + \phi_{gy} \Delta y_{t+1}^e + \phi_x x_t^e + \epsilon_t.$$

Here π_t^e, Δy_t^e, and x_t^e are real time forecasts on year-on-year inflation, output growth and the output gap respectively. The former two data series are from Consensus Economics, the latter from the OECD. The OECD output gap data is in real time only from 2003 onwards. Since the purpose of these equation is to forecast it is permissible to use the OLS estimates.

While the baseline model did not feature interest rate smoothing or a response to the output gap, the relationship between the fiscal multiplier and the terms of trade response in the liquidity trap is independent of the monetary policy rule. Thus my identification strategy for the fiscal multiplier in the liquidity trap is unaffected by the switch to the above rule, which better matches the data (see Coibion and Gorodnichenko [2011]).

I estimate this equation using data from the first quarter in 1992, up until the fourth quarter of 2007 (if available). The results are tabulated in Appendix Table 9. I then generate dynamic forecast up until the first quarter of 2010, which I plot in Appendix Figure 6. I then set the liquidity trap dummy equal to 1 if

1. based on historical Central Bank behavior, the predicted unconstrained interest rate at t, r_t^*, is below zero, $r_t^* < 0$.

2. the policy rate at t is the minimum among all observed policy rates in the sample $r_t = \min(\{r_s\}_{s=1}^T)$.

The additional second condition is necessary, because it rules out that interest rates will be subsequently cut or were previously at a lower level, which violates the premise of a lower bound on interest rates. The episodes that are thus classified as liquidity traps are tabulated in Appendix Table 8.

Table 8: Episodes Classified as Liquidity Traps

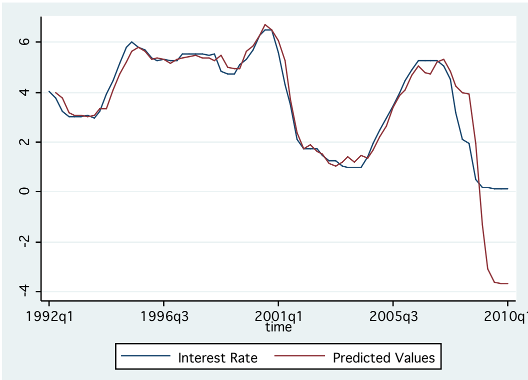
Economy	**In the Liquidity Trap**
USA	Jan 2009 - Jan 2010
UK	April 2009 - Jan 2010
EUZ	April 2009 - Jan 2010
JAP	Dec 2008 - Jan 2010
	Beginning of Sample - June 2006
CAN	May 2009 - Jan 2010
CHE	April 2009 - Jan 2010
SWE	July 2009 - Jan 2010
NOR	-

Table 9: Taylor rule estimates

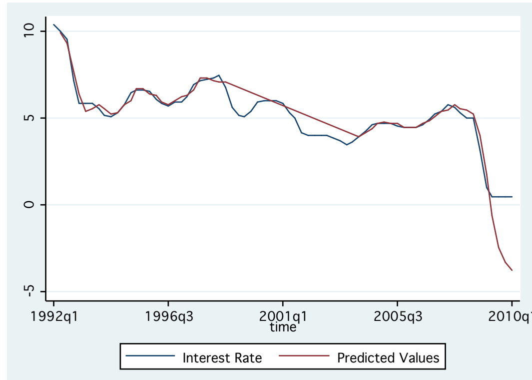
	(1) USA	(2) UK	(3) EUZ	(4) CAN	(5) CHE	(6) SWE	(7) NOR
Lagged Interest Rate	0.931***	0.973***	0.846***	0.914***	0.905***	0.938***	0.958***
	(0.0410)	(0.0404)	(0.0808)	(0.0510)	(0.0397)	(0.0373)	(0.0764)
Inflation Forecast	0.275***	0.150	0.175	-0.0717	-0.0585	0.303***	0.239**
	(0.0813)	(0.110)	(0.187)	(0.141)	(0.0895)	(0.0555)	(0.117)
Growth Forecast	0.234***	0.302***	0.349***	0.299***	0.425***	0.222***	0.107
	(0.0642)	(0.0701)	(0.0831)	(0.102)	(0.0716)	(0.0504)	(0.190)
Contemporaneous Output Gap	0.119**	0.0861	0.0229	0.0502	-0.0729	0.0117	0.156**
	(0.0463)	(0.0526)	(0.0812)	(0.0730)	(0.0429)	(0.0278)	(0.0698)
Constant	-1.114***	-0.834***	-0.587	-0.369	-0.571***	-0.904***	-0.760
	(0.275)	(0.265)	(0.388)	(0.526)	(0.150)	(0.201)	(0.840)
Observations	63	42	35	63	35	53	38
R^2	0.968	0.970	0.969	0.819	0.967	0.978	0.932

Robust standard errors in parentheses

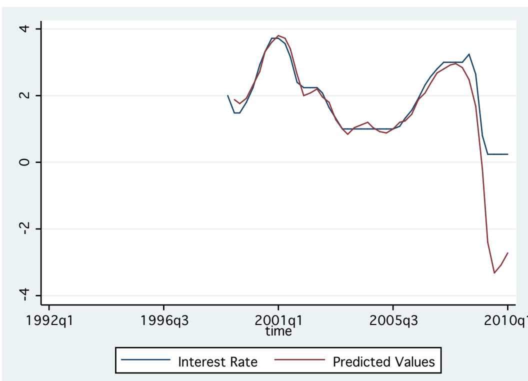
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$



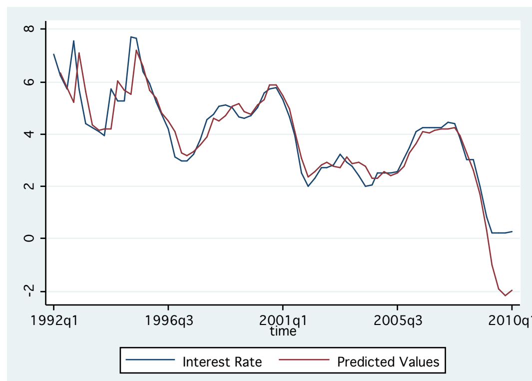
(a) USA



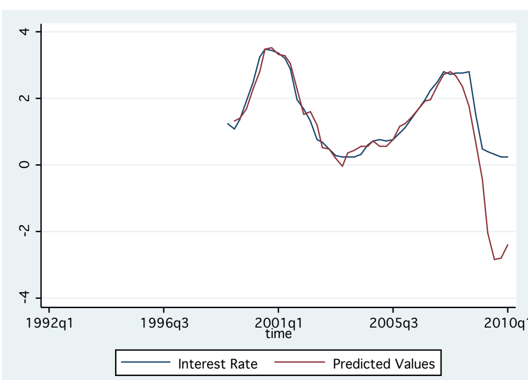
(b) UK



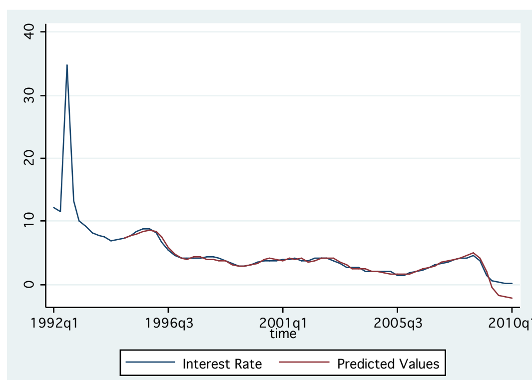
(c) EUZ



(d) CAN



(e) CHE



(f) SWE

Figure 6: Predicted Policy Rates from Taylor Rule Estimates