Online Appendix

Dollar Funding Fragility and non-US Global Banks

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This Online Appendix has 7 sections. Section A derives the period 2 net worth of the bank (equation (13) of the text). Section B derives the optimal swap market position (equation (21) of the text) and the optimal euro and dollar loan portfolios (equations (22) and (23) of the text). Section C describes the computation of the bank default probability p_D. Section D derives the analytical results in Table 1 of the paper. Section E discusses other equilibria of the model than the equilibrium focused on in the text. Section F discusses the data used to calibrate the representative G-SIB bank balance sheet and the changes in bank balance sheet variables that accompany a decline in dollar funding in Figure 2 of the paper. Section G discusses sensitivity analysis.

A Period 2 Net Worth

We can write the period 2 net worth as

$$\begin{aligned} W_2 &= \left(1+i_0^{€,l}-d_2^{€}\right)L_1^{€}+\frac{1}{E_2}\left(1+i_0^{\$,l}-d_2^{\$}\right)L_1^{\$}-(1+i^s)B^{€}-(1+i_1^{€})B_1^{€,w} \\ &\quad -\frac{1}{E_2}(1+i_1^{\$})B_1^{\$,w}+S_1\left(1-\frac{F_1}{E_2}\right) \end{aligned} \tag{A.1}$$

The first two terms capture the gross returns on euro and dollar loans, the latter multiplied by $1/E_2$ to convert to euros. The last two terms on the first line subtract the gross return on retail euro liabilities and wholesale euro liabilities. The second line subtracts the gross return on wholesale dollar liabilities, converted to euros and adds the period profit from the swap market position.

We have

$$B_1^{\$,w}=L_1^{\$}-S_1 \tag{A.2}$$

$$B_1^{€,w}=-W_1+L_1^{€}-B^{€}+S_1 \tag{A.3}$$

Substituting these into (A.1), we have

$$\begin{aligned} W_2 &= \left(i_0^{€,l} - d_2^{€} - i_1^{€}\right) L_1^{€} + (i_1^{€} - i^s) B^{€} + (1 + i_1^{€}) W_1 \\ &\quad + \frac{1}{E_2}\left(i_0^{\$,l} - d_2^{\$} - i_1^{\$}\right) L_1^{\$} + \left(-1 - i_1^{€} + \frac{1}{E_2}(1 + i_1^{\$}) + 1 - \frac{F_1}{E_2}\right) S_1 \end{aligned} \tag{A.4}$$

The first term on the second line becomes $\left(i_0^{\$,l} - d_2^{\$} - i_1^{\$}\right) L_1^{\$}$ when linearizing around $e_2 = ln(E_2) = 0$ and an excess return $i_0^{\$,l} - d_2^{\$} - i_1^{\$}$ of zero. The second term on the second line becomes $(i_1^{\$} - i_1^{€} + e_1 - f_1)S_1$ when linearizing around $e_2 = i_1^{\$} = f_1 = 0$ and using that $e_1 = 0$.

This gives

$$\begin{aligned} W_2 &= \left(i_0^{€,l} - d_2^{€} - i_1^{€}\right) L_1^{€} + (i_1^{€} - i^s) B^{€} + (1 + i_1^{€}) W_1 \\ &\quad + \left(i_0^{\$,l} - d_2^{\$} - i_1^{\$}\right) L_1^{\$} + \left(e_1 - f_1 + i_1^{\$} - i_1^{€}\right) S_1 \end{aligned} \tag{A.5}$$

Substituting

$$W_1 = W_0 - (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1 - p_1^{€})(L_0^{€} - L_1^{€}) \tag{A.6}$$

we have

$$\begin{aligned} W_2 &= \left(i_0^{€,l} - i_1^{€} - d_2^{€}\right) L_1^{€} + \left(i_0^{\$,l} - i_1^{\$} - d_2^{\$}\right) L_1^{\$} + (1 + i_1^{€}) W_0 + (i_1^{€} - i^s) B^{€} \\ &\quad + \left(i_1^{\$} - i_1^{€} + e_1 - f_1\right) S_1 \\ &\quad -(1 + i_1^{€})(1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1 + i_1^{€})(1 - p_1^{€})(L_0^{€} - L_1^{€}) \end{aligned} \tag{A.7}$$

Linearizing the last line at $i_1^{€} = L_0^{\$} - L_1^{\$} = L_0^{€} - L_1^{€} = 0$, we have

$$\begin{aligned} W_2 &= \left(i_0^{€,l} - i_1^{€} - d_2^{€}\right) L_1^{€} + \left(i_0^{\$,l} - i_1^{\$} - d_2^{\$}\right) L_1^{\$} + (1 + i_1^{€}) W_0 + (i_1^{€} - i^s) B^{€} \\ &\quad + \left(i_1^{\$} - i_1^{€} + e_1 - f_1\right) S_1 - (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1 - p_1^{€})(L_0^{€} - L_1^{€}) \end{aligned} \tag{A.8}$$

This is equation (13) in the text. However, for the numerical solution we use (A.7).

B Optimal Decisions by Bank

The bank maximizes the Lagrangian

$$\begin{aligned} &E(W_2) - 0.5\gamma \frac{1}{W_0} var(W_2) - 0.5\eta S_1^2 \\ &-l_e\left(B_1^{€,w} - \bar{B}^{€}\right) - l_d\left(B_1^{\$,w} - \bar{B}^{\$}\right) - \mu_e\left(L_1^{€} - L_0^{€}\right) - \mu_d\left(L_1^{\$} - L_0^{\$}\right) \end{aligned} \tag{B.1}$$

Next substitute the expression (13) for W_2 as well as (A.2)-(A.3) and (A.6). Omitting terms that do not depend on $L_1^{\$}$, $L_1^{€}$ or S_1, the bank maximizes

$$\begin{aligned}
&\left(i_0^{€,l} - i_1^{€} - d\right) L_1^{€} + \left(i_0^{\$,l} - i_1^{\$} - d\right) L_1^{\$} \\
&+ \left(i_1^{\$} - i_1^{€} + e_1 - f_1\right) S_1 - (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1 - p_1^{€})(L_0^{€} - L_1^{€}) \\
&-0.5\gamma \frac{1}{W_0} \sigma^2 \left(L_1^{€}\right)^2 - 0.5\gamma \frac{1}{W_0} \sigma^2 \left(L_1^{\$}\right)^2 - 0.5\eta S_1^2 \\
&-l_e \left(L_1^{€} + S_1 - \bar{B}^{€}\right) - l_d \left(L_1^{\$} - S_1 - \bar{B}^{\$}\right) \\
&-l_e (1 - p_1^{€})(L_0^{€} - L_1^{€}) - l_e (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) \\
&-\mu_e \left(L_1^{€} - L_0^{€}\right) - \mu_d \left(L_1^{\$} - L_0^{\$}\right)
\end{aligned} \tag{B.2}$$

The first-order condition with respect to S_1 is

$$S_1 = \frac{\left(i_1^{\$} + l_d\right) - \left(i_1^{€} + l_e + f_1 - e_1\right)}{\eta} \tag{B.3}$$

This corresponds to equation (21) in the text.

The first-order conditions with respect to $L_1^{€}$ and $L_1^{\$}$ are

$$L_1^{€} = \frac{i_0^{€,l} - d - i_1^{€} + 1 - p_1^{€} - p_1^{€} l_e - \mu_e}{\gamma \sigma^2} W_0 \tag{B.4}$$

$$L_1^{\$} = \frac{i_0^{\$,l} - d - i_1^{\$} + 1 - p_1^{\$} - l_d + l_e (1 - p_1^{\$}) - \mu_d}{\gamma \sigma^2} W_0 \tag{B.5}$$

Next substitute the expressions for $p_1^{€}$ and $p_1^{\$}$. This gives

$$L_1^{€} = \frac{i_0^{€,l} - d - i_1^{€} - l_e - \mu_e + (1 + l_e)\nu_e L_0^{€}}{\gamma \sigma^2 + (1 + l_e)\nu_e W_0} W_0 \tag{B.6}$$

$$L_1^{\$} = \frac{i_0^{\$,l} - d - i_1^{\$} - l_d - \mu_d + (1 + l_e)\nu_d L_0^{\$}}{\gamma \sigma^2 + (1 + l_e)\nu_d W_0} W_0 \tag{B.7}$$

C Computation default probability

In this section we discuss how we compute the default probability p_D. There is default when $W_2 < 0$, which occurs when

$$\begin{aligned}
&\left(i_0^{€,l} - i_1^{€} - d_2^{€}\right) L_1^{€} + \left(i_0^{\$,l} - i_1^{\$} - d_2^{\$}\right) L_1^{\$} < -(1 + i_1^{€}) W_0 + (i^s - i_1^{€}) B^{€} \\
&+ \left(i_1^{€} - i_1^{\$} + f_1 - e_1\right) S_1 + (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) + (1 - p_1^{€})(L_0^{€} - L_1^{€})
\end{aligned} \tag{C.1}$$

We can write this as

$$X + Y > C \tag{C.2}$$

where

$$X = d_2^{€} L_1^{€} \tag{C.3}$$

$$Y = d_2^{\$} L_1^{\$} \tag{C.4}$$

and

$$\begin{aligned} C &= \left(i_0^{€,l} - i_1^{€}\right) L_1^{€} + \left(i_0^{\$,l} - i_1^{\$}\right) L_1^{\$} + (1 + i_1^{€}) W_0 + (i_1^{€} - i^s) B^{€} \\ &\quad + \left(i_1^{\$} - i_1^{€} + e_1 - f_1\right) S_1 - (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1 - p_1^{€})(L_0^{€} - L_1^{€}) \end{aligned} \tag{C.5}$$

We now consider two distributions for $d_2^{€}$ and $d_2^{\$}$. The first is a Gamma distribution. The second is a log normal distribution. In both cases we assume that their expectation is d and variance is σ^2.

C.1 Gamma Distributions

Here we assume that $d_2^{€}$ and $d_2^{\$}$ have a $Gamma(k, \theta)$ distribution, with $k = (d/\sigma)^2$ and $\theta = \sigma^2/d$. X has a $\Gamma(k_x, \theta_x)$ distribution, while Y has a $\Gamma(k_y, \theta_y)$ distribution, where

$$k_x = k \tag{C.6}$$

$$\theta_x = L_1^{€} \theta \tag{C.7}$$

$$k_y = k \tag{C.8}$$

$$\theta_y = L_1^{\$} \theta \tag{C.9}$$

The probability of default is then

$$p_D = Prob(X + Y > C) = 1 - Prob(X + Y < C) \tag{C.10}$$

To compute this, we need to derive the cdf of the sum of two $Gamma$ distributions. This is done as follows. We have

$$Prob(X+Y < C) = \int_0^C \int_0^{C-x} f_X(x) f_Y(y) dy dx = \int_0^C f_X(x) F_Y(C-x) dx \tag{C.11}$$

Here $f_X(x)$ and $f_Y(y)$ are the pdf of X and Y and $F_Y(y)$ is the cdf of Y. We compute this integral numerically with Matlab. We have

$$f_X(x) = \frac{1}{\Gamma(k_x)\theta_x^{k_x}} x^{k_x-1} e^{-x/\theta_x} \tag{C.12}$$

$$F_Y(C-x) = \frac{1}{\Gamma(k_y)} \gamma(k_y, (C-x)/\theta_y) \tag{C.13}$$

Here $\Gamma(.)$ is the gamma function and $\gamma(.,.)$ is the lower incomplete gamma function. The gamma function is simply $gamma(k)$ in Matlab. The lower incomplete gamma function is called $gammainc(.,.)$ in Matlab. However, it is scaled by $\Gamma(k)$ and its two elements are reversed. So in terms of Matlab notation, we have

$$F_Y(C-x) = gammainc((C-x)/\theta_y, k_y) \tag{C.14}$$

If we define a function "fun" in Matlab that is equal to $f_X(x)F_Y(C-x)$, we then compute the integral from 0 to C numerically by calling $integral(fun, 0, C)$.

C.2 Default Probability with Log Normal Distributions

We now assume that $d_2^{€}$ and $d_2^{\$}$ have log normal distributions. Specifically, $ln(d_2^{€})$ and $ln(d_2^{\$})$ both have $N(\mu, s^2)$ distributions, where

$$s^2 = ln\left(1 + \frac{\sigma^2}{d^2}\right) \tag{C.15}$$

$$\mu = ln(d) - 0.5s^2 \tag{C.16}$$

We need to compute

$$p_D = Prob(X + Y > C) = 1 - Prob(X + Y < C) \tag{C.17}$$

where $X = d_2^{€} L_1^{€}$ and $Y = d_2^{\$} L_1^{\$}$. $X + Y$ does not have a known distribution. We will follow the Fenton-Wilkinson approximation, where we approximate $Z = X+Y$ as also following a log normal distribution. The mean and variance are

$$E(Z) = \left(L_1^{€} + L_1^{\$}\right) d \tag{C.18}$$

$$var(Z) = \left(L_1^{€}\right)^2 \sigma^2 + \left(L_1^{\$}\right)^2 \sigma^2 \tag{C.19}$$

Then we approximate Z having a log normal distribution where $ln(Z)$ has a $N(\mu_Z, \sigma_Z^2)$ distribution, where

$$\sigma_Z^2 = ln\left(1 + \frac{var(Z)}{(E(Z))^2}\right) \tag{C.20}$$

$$\mu_Z = ln(E(Z)) - 0.5\sigma_Z^2 \tag{C.21}$$

Then the probability of default is

$$p_D = 1 - \Phi\left(\frac{ln(C) - \mu_Z}{\sigma_Z}\right) \tag{C.22}$$

D Analytical Results

D.1 Probability of Default

We start by showing that $\Delta p_D = 0$ to the first order when linearizing at the pre-shock equilibrium. The most important part of the argument is that $\Delta W_1 = 0$ when differentiating at the pre-shock equilibrium:

$$\Delta W_1 = (1 - p_1^{\$})\Delta L_1^{\$} + (L_0^{\$} - L_1^{\$})\Delta p_1^{\$} + (1 - p_1^{€})\Delta L_1^{€} + (L_0^{€} - L_1^{€})\Delta p_1^{€} \tag{D.1}$$

This is zero at the pre-shock equilibrium, where the asset prices are 1 and period 0 and 1 loans are the same.

We have

$$p_D = Prob(W_2 < 0) = Prob\left(d_2^{€} L_1^{€} + d_2^{\$} L_1^{\$} > C\right) \tag{D.2}$$

where

$$\begin{aligned} C &= \left(i_0^{€,l} - i_1^{€}\right) L_1^{€} + \left(i_0^{\$,l} - i_1^{\$}\right) L_1^{\$} + (1 + i_1^{€})W_0 + (i_1^{€} - i^s)B^{€} \\ &\quad + \left(i_1^{\$} - i_1^{€} + e_1 - f_1\right) S_1 - (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1 - p_1^{€})(L_0^{€} - L_1^{€}) \end{aligned} \tag{D.3}$$

Linearizing $d_2^{€} L_1^{€} + d_2^{\$} L_1^{\$}$ at pre-shock loan levels and $d_2^{€} = d_2^{\$} = d$, we can write the probability of default as

$$p_D = Prob\left(\left(d_2^{€} - d\right) L_0^{€} + \left(d_2^{\$} - d\right) L_0^{\$} > C - dL_1^{€} - dL_1^{\$}\right) \tag{D.4}$$

The left hand side has an exogenous stochastic distribution that is unaffected by the shock. It therefore follows that this probability depends on $C - dL_1^{€} - dL_1^{\$}$. This is equal to

$$\begin{aligned} &\left(i_0^{€,l} - d - i_1^{€}\right) L_1^{€} + \left(i_0^{\$,l} - d - i_1^{\$}\right) L_1^{\$} + (1 + i_1^{€})W_0 + (i_1^{€} - i^s)B^{€} \\ &+ \left(i_1^{\$} - i_1^{€} + e_1 - f_1\right) S_1 - (1 - p_1^{\$})(L_0^{\$} - L_1^{\$}) - (1 - p_1^{€})(L_0^{€} - L_1^{€}) \end{aligned} \tag{D.5}$$

This term does not change to the first-order due to the shock, so that $\Delta p_D = 0$. We have already discussed that the last two terms, associated with the change in

W_1, do not change to the first-order. Also, when $\Delta p_D = 0$, the euro and dollar borrowing rates do not change to the first order. Now consider changes in euro and dollar lending. For example, for euro lending this term is

$$\left(i_0^{€,l} - d - i_0^{€}\right) \Delta L_1^{€} = \gamma \sigma^2 L_0^{€} \frac{1}{W_0} \Delta L_1^{€} \tag{D.6}$$

This term is third-order as $\Delta L_1^{€}$ is multiplied by σ^2. So we ignore this. The only term left is the one involving synthetic dollar borrowing. Its first-order change is

$$-\left(f_0 - e_0\right) \Delta S_1 - S_0 \Delta \left(f_1 - e_1\right) \tag{D.7}$$

But this is also zero since the pre-shock CIP deviation $f_0 - e_0$ is zero and also $S_0 = 0$. It follows that $\Delta p_D = 0$ to the first order, so that also $\Delta i_1^{€} = \Delta i_1^{\$} = 0$.

D.2 Linearization

Differentiating (22)-(23) at the pre-shock equilibrium, using that $\Delta i_1^{€} = \Delta i_1^{\$} = 0$, we have

$$\Delta L_1^{€} = \frac{W_0}{\gamma \sigma^2 + \nu W_0} \left(-\Delta l_e - \Delta \mu_e\right) \tag{D.8}$$

$$\Delta L_1^{\$} = \frac{W_0}{\gamma \sigma^2 + \nu W_0} \left(-\Delta l_d - \Delta \mu_d\right) \tag{D.9}$$

From the swap market clearing condition we have

$$\Delta(f_1 - e_1) = 0.5 \eta \epsilon^u + 0.5 \left(\Delta l_d - \Delta l_e\right) \tag{D.10}$$

$$\Delta S_1 = -0.5 \epsilon^u + 0.5 \frac{1}{\eta} \left(\Delta l_d - \Delta l_e\right) \tag{D.11}$$

where $\epsilon^u = \Delta u$.

Using that $\Delta W_1 = 0$, we have

$$\Delta B_1^{€,w} = \Delta L_1^{€} + \Delta S_1 \tag{D.12}$$

$$\Delta B_1^{\$,w} = \Delta L_1^{\$} - \Delta S_1 \tag{D.13}$$

We consider 4 scenarios: dollar liquidity shocks without and with slackness in the euro borrowing constraint and u-shocks without and with slackness in the dollar borrowing constraint. In all the equilibria $\Delta \mu_e = \Delta \mu_d = 0$ as banks do not wish to increase lending.

D.3 Dollar Liquidity Shock without Euro Slackness

In the equilibrium derived below both dollar and euro lending drop, so that $\Delta L_1^{€}$ and $\Delta L_1^{\$}$ are negative. Dollar and euro borrowing constraints hold with equality. Therefore $\Delta B_1^{€,w} = 0$ and $\Delta B_1^{\$,w} = -\epsilon^b$. These constraints bind, so that Δl_e and Δl_d are positive. We must compute $\Delta L_1^{€}$ and $\Delta L_1^{\$}$ as well as Δl_e and Δl_d.

We solve Δl_e and Δl_d by setting $\Delta B_1^{€,w} = 0$ and $\Delta B_1^{\$,w} = -\epsilon^b$. This implies

$$\Delta L_1^{€} + \Delta S_1 = 0 \tag{D.14}$$

$$\Delta L_1^{\$} - \Delta S_1 = -\epsilon^b \tag{D.15}$$

It is convenient to add and subtract these equations:

$$\Delta L_1^{€} + \Delta L_1^{\$} = -\epsilon^b \tag{D.16}$$

$$\Delta L_1^{€} - \Delta L_1^{\$} + 2\Delta S_1 = \epsilon^b \tag{D.17}$$

These two equations imply

$$\Delta l_d + \Delta l_e = \frac{\gamma\sigma^2 + \nu W_0}{W_0}\epsilon^b \tag{D.18}$$

$$\Delta l_d - \Delta l_e = \frac{\gamma\sigma^2 + \nu W_0}{W_0 + \frac{1}{\eta}(\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.19}$$

Adding and subtracting gives

$$\Delta l_d = 0.5(\gamma\sigma^2 + \nu W_0)\left(\frac{1}{W_0} + \frac{1}{W_0 + \frac{1}{\eta}(\gamma\sigma^2 + \nu W_0)}\right)\epsilon^b \tag{D.20}$$

$$\Delta l_e = 0.5(\gamma\sigma^2 + \nu W_0)\left(\frac{1}{W_0} - \frac{1}{W_0 + \frac{1}{\eta}(\gamma\sigma^2 + \nu W_0)}\right)\epsilon^b \tag{D.21}$$

It follows that

$$\Delta L_1^{€} = -\frac{0.5(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + (\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.22}$$

$$\Delta L_1^{\$} = -\frac{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + (\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.23}$$

These results also imply that

$$\Delta(f_1 - e_1) = \frac{0.5\eta(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + (\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.24}$$

$$\Delta S_1 = \frac{0.5(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + (\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.25}$$

D.4 Dollar Liquidity Shock with Euro Slackness

In the equilibrium with euro slackness we have $\Delta l_e = 0$ and $\Delta B_1^{€,w} > 0$. In the equilibrium derived below the dollar borrowing constraint still holds with an equality, so that $\Delta B_1^{\$,w} = -\epsilon^b$ and $\Delta l_d > 0$.

We solve for $\Delta l_d > 0$ by imposing the dollar borrowing constraint with an equality. This implies $\Delta L_1^{\$} - \Delta S_1 = -\epsilon^b$, so that

$$\frac{-W_0}{\gamma\sigma^2 + \nu W_0}\Delta l_d - 0.5\frac{1}{\eta}\Delta l_d = -\epsilon^b \tag{D.26}$$

and

$$\Delta l_d = \frac{\eta(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.27}$$

We have

$$\Delta L_1^{\$} = -\frac{\eta W_0}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.28}$$

$$\Delta S_1 = \frac{0.5(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.29}$$

We also have

$$\Delta L_1^{€} = 0 \tag{D.30}$$

$$\Delta B_1^{€,w} = \frac{0.5(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.31}$$

The CIP deviation is

$$\Delta(f_1 - e_1) = \frac{0.5\eta(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^b \tag{D.32}$$

D.5 u-shock without Dollar Slackness

In the equilibrium below wholesale euro borrowing drops, so that $\Delta l_e = 0$. The dollar borrowing constraint binds, so that $\Delta l_d > 0$ needs to be solved.

We solve Δl_d by setting $\Delta B_1^{\$,w} = 0$. This implies

$$\Delta L_1^{\$} - \Delta S_1 = 0 \tag{D.33}$$

This implies

$$-\frac{W_0}{\gamma\sigma^2 + \nu W_0}\Delta l_d + 0.5\epsilon^u - 0.5\frac{1}{\eta}\Delta l_d = 0 \tag{D.34}$$

This implies

$$\Delta l_d = \frac{0.5\eta(\gamma\sigma^2 + \nu W_0)}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^u \tag{D.35}$$

We then have

$$\Delta L_1^{\$} = -\frac{0.5\eta W_0}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^u \tag{D.36}$$

We have

$$\Delta L_1^{€} = 0 \tag{D.37}$$

$$\Delta B_1^{\$,w} = 0 \tag{D.38}$$

$$\Delta B_1^{€,w} = \Delta S_1 = -\frac{0.5\eta W_0}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^u \tag{D.39}$$

The change in the CIP deviation is

$$\Delta(f_1 - e_1) = 0.5\eta\epsilon^u + 0.5\Delta l_d = 0.5\eta\frac{\eta W_0 + (\gamma\sigma^2 + \nu W_0)}{\eta W_0 + 0.5(\gamma\sigma^2 + \nu W_0)}\epsilon^u \tag{D.40}$$

D.6 u-shock with Dollar Slackness

When there is dollar slackness we have $\Delta l_d = 0$. It still remains the case that $\Delta l_e = 0$ as euro borrowing falls. It is easily checked that with no changes in Lagrange multipliers, $\Delta L_1^{€} = \Delta L_1^{\$} = 0$.

We have $\Delta S_1 = -0.5\epsilon^u$, $\Delta B_1^{€,w} = -0.5\epsilon^u$ and $\Delta B_1^{\$,w} = 0.5\epsilon^u$. The CIP deviation rises by $\Delta(f_1 - e_1) = 0.5\eta\epsilon^u$.

E Equilibria

There can be both rollover and non-rollover equilibria.

E.1 Rollover Equilibria

For the benchmark parameterization in the paper, Figure A1 shows a mapping of the probability of default p_D into itself. The value of p_D on the horizontal axis is the assumed value of p_D by the wholesale lenders. This determines the interest rates on wholesale dollar and euro funding. The implied actual default probability is on the vertical axis. These must be equal in order for an equilibrium to exist. Figure A1 is drawn assuming that neither of the two shocks analyzed in the paper apply, so that $\bar{B}^{\$} = B_0^{\$,w}$, $\bar{B}^{€} = B_0^{€,w}$ and $u = 0$.

There are two solutions. We focus on the equilibrium with a low value of p_D, which is 0.005 or 50 basis points. We refer to this as the pre-shock equilibrium. But there is a second equilibrium with high value of $p_D = 0.107$. This means that without either of the shocks considered in the paper, it is possible to have a self-fulfilling shock that raises the probability of default. Intuitively, a higher probability of default raises wholesale dollar and euro interest rates, which lowers net worth at time 2, which indeed raises the probability of default. However, the higher default equilibrium is unstable. Raising the assumed default probability slightly beyond that of the higher default equilibrium implies that the actual default probability is even higher. Similarly, lowering the assumed default probability slightly implies that the actual default probability is even lower. We should also say that for $\nu < 0.0135$, the higher default fixed point does not even exist.

As discussed in Section 4.2 of the paper, a dollar liquidity shock shifts the blue line upward. This raises the probability of default in the stable equilibrium. When the shock is large enough, the blue line no longer crosses the red line, so that a rollover equilibrium no longer exists. However non-rollover equilibria do exist, to which we turn now.

E.2 Non-Rollover Equilibria

In non-rollover equilibria none of the period 0 wholesale lending is rolled over into period 1. These equilibria can take one of two forms. One is a standard bank-run equilibrium. This type of equilibrium is familiar from the bank-run literature. If wholesale funding is not rolled over, the bank is forced to liquidate assets. When the losses from liquidation are high enough that the bank is unable to pay the period 0 wholesale lenders, the bank defaults in period 1. In that case, we do not even reach period 2. The other case is where it is possible for the bank to liquidate enough assets in period 1 to pay the period 0 wholesale lenders, but doing so implies losses from liquidating assets that are large enough that $W_2 < 0$ even under the most favorable scenario, where $d_2^{\$} = d_2^{€} = 0$. In that case period 2 default is certain, $p_D = 1$, and it is indeed not optimal for wholesale lenders to provide any funding in period 1. In this case bank default is delayed to period 2.

E.2.1 Bank-Run Equilibrium

First consider a regular bank-run equilibrium. Assume that wholesale lenders do not roll over their lending, so that $B_1^{\$,w} = B_1^{€,w} = 0$. In order to pay the period 0 wholesale lenders, the bank must sell enough loans to pay the principal $B_0 = B_0^{\$,w} + B_0^{€,w}$. Note that the interest has already been deducted to pay dividends to bank shareholders. A bank-run equilibrium is feasible when for all possible values of $L_1^{\$}$ between 0 and $L_0^{\$}$ and $L_1^{€}$ between 0 and $L_0^{€}$ the bank is unable to repay the period 0 wholesale debt of B_0. This happens when

$$p_1^{\$}\left(L_0^{\$} - L_1^{\$}\right) + p_1^{€}\left(L_0^{€} - L_1^{€}\right) < B_0 \tag{E.1}$$

Let $x^e = L_0^{€} - L_1^{€}$ be euro loans sold and $x^d = L_0^{\$} - L_1^{\$}$ dollar loans sold. Note that $0 \leq x^e \leq L_0^{€}$ and $0 \leq x^d \leq L_0^{\$}$. Also note that $p_1^{\$} = 1 - \nu x^d$ and $p_1^{€} = 1 - \nu x^e$.

It follows that there exists a period 1 bank-run equilibrium when

$$x^d - \nu(x^d)^2 + x^e - \nu(x^e)^2 < B_0 \tag{E.2}$$

for all $0 \leq x^e \leq L_0^{€}$ and $0 \leq x^d \leq L_0^{\$}$. For our benchmark parameterization (without any shocks) we find that this is the case when $\nu > 0.0195$.

E.2.2 Delayed Default

Now consider non-rollover equilibria where default is delayed till period 2. In the benchmark parameterization these may occur when $\nu < 0.0195$, so that the period 1 bank-run equilibrium can be avoided. The bank is still able to repay the period 0 wholesale lenders when none of the credit is rolled over to period 1. But liquidating these loans leads to losses, which can lead to $W_2 < 0$, even in the most favorable case when there is no default on bank loans in period 2. Since $p_D = 1$, again none of the wholesale lending is rolled over in period 1. But default is postponed to period 2.

Since there is no rollover in period 1, $B_1^{€,w} = B_1^{\$,w} = 0$. After log linearizing with respect to the exchange rate and considering the best case scenario where $d_2^{€} = d_2^{\$} = 0$, (A.1) becomes

$$W_2 = \left(1 + i_0^{€,l}\right) L_1^{€} + \left(1 + i_0^{\$,l} - e_2\right) L_1^{\$} - (1 + i^s)B^{€} + S_1\left(e_2 - f_1\right) \tag{E.3}$$

Since there is no wholesale dollar debt, we have $S_1 = L_1^{\$}$, so that

$$W_2 = \left(1 + i_0^{€,l}\right) L_1^{€} + \left(1 + i_0^{\$,l} - (f_1 - e_1)\right) L_1^{\$} - (1 + i^s)B^{€} \tag{E.4}$$

The bank has limited decision space. It can choose $L_1^{€}$ and $L_1^{\$}$, but it must satisfy the constraint that it sells sufficient assets to repay all period 0 wholesale debt:

$$p_1^{\$}\left(L_0^{\$} - L_1^{\$}\right) + p_1^{€}\left(L_0^{€} - L_1^{€}\right) = B_0 \tag{E.5}$$

Also, while the bank takes $f_1 - e_1$ as given, in equilibrium $S_1 + S_1^{US} = 0$, so that $f_1 - e_1 = \eta S_1 = \eta L_1^{\$}$.

We can check numerically whether W_2 is always negative by varying $L_1^{\$}$ from 0 to $L_0^{\$}$, then solving $L_1^{€}$ from (E.5), and then substituting the result into (E.4). Solving for $L_1^{€}$ from (E.5) can be done as follows. Define x^d and x^e as before. We vary x^d from 0 to $L_0^{\$}$ and use that $L_1^{\$} = L_0^{\$} - x^d$. For a given x^d, we solve x^e from

$$x^d - \nu(x^d)^2 + x^e - \nu(x^e)^2 = B_0 \tag{E.6}$$

We can write

$$\nu(x^e)^2 - x^e + B_0 + \nu(x^d)^2 - x^d = 0 \tag{E.7}$$

For a given x^d, there is only a solution when

$$4\nu\left(B_0 + \nu(x^d)^2 - x^d\right) < 1 \tag{E.8}$$

The solution is then

$$x^e = \frac{1 \pm \sqrt{1 - 4\nu\left(B_0 + \nu(x^d)^2 - x^d\right)}}{2\nu} \tag{E.9}$$

We will apply the minus sign as a lower value of x^e implies a higher value of $L_1^{€}$ and therefore a higher value of W_2 in (E.4). We also need to check that x^e is between 0 and $L_0^{€}$. We then need to check for which values of ν we always have $W_2 < 0$, no matter what value of x^d we choose between 0 and $L_0^{\$}$. For our benchmark parameters we find numerically that this is the case for values of ν between 0.0126 and 0.0195.

F Bank balance sheets and event study

We discuss some details behind the construction of bank balance sheets, which are used for the calibration exercise in Section 4 of the paper and for the event study in Figure 2 of the paper.

F.1 Balance Sheet Data

We collect balance sheet data from 40 non-US and non-Chinese G-SIB banks. As part of the BIS annual G-SIB assessment that has been conducted every year since 2013, the BIS collects data from a set of the largest banks in the world. These 40 banks are the non-US and non-Chinese banks that have been included in the BIS G-SIB Main Sample every year from 2013 to 2022.[1] These 40 banks are headquartered in 14 countries.

Define $D_{B,c,t}$ as deposits at G-SIB banks in country c, where $D_{B,c,t} = \sum_{i=1}^{I} D_{i,c,t}$ and $D_{i,c,t}$ are deposits at G-SIB bank i in country c and I is the total number of G-SIB banks headquartered in country c. These deposit data are taken from the S&P Capital IQ data.

$C^{USD}_{B,c,t}$ and $L^{USD}_{B,c,t}$ are the USD denominated claims and liabilities for the G-SIB banks in country c, where $C^{USD}_{B,c,t} = m_c C^{USD}_{c,t}$ and $L^{USD}_{B,c,t} = m_c L^{USD}_{c,t}$. $C^{USD}_{c,t}$ and $L^{USD}_{c,t}$ are the dollar denominated claims and liabilities for all banks in country c from the BIS, and m_c is the share that is held by the G-SIB banks.

The USD denominated claims and liabilities at the country-level, $C^{USD}_{c,t}$ and $L^{USD}_{c,t}$, are calculated from the BIS International Banking Statistics following the method described in Aldasoro and Ehlers (2018). From the Locational Banking

[1]The names of these banks, along with the stock exchange and ticker for the publicly traded ones are: ANZ Group Holdings Limited (ASX:ANZ), Banco Bilbao Vizcaya Argentaria, S.A. (BME:BBVA), Banco Santander, S.A. (BME:SAN), Bank of Montreal (TSX:BMO), Barclays PLC (LSE:BARC), BNP Paribas SA (ENXTPA:BNP), CaixaBank, S.A. (BME:CABK), Canadian Imperial Bank of Commerce (TSX:CM), Commerzbank AG (XTRA:CBK), Commonwealth Bank of Australia (ASX:CBA), Coöperatieve Rabobank U.A., Crédit Agricole S.A. (ENXTPA:ACA), Crédit Mutuel Group, Credit Suisse Group AG (SWX:CSGN), Danske Bank A/S (CPSE:DANSKE), DBS Group Holdings Ltd (SGX:D05), Deutsche Bank Aktiengesellschaft (XTRA:DBK), DZ BANK AG, Deutsche Zentral-Genossenschaftsbank Frankfurt am Main , Groupe BPCE, HSBC Holdings plc (LSE:HSBA), ING Groep N.V. (ENXTAM:INGA), Intesa Sanpaolo S.p.A. (BIT:ISP), Lloyds Banking Group plc (LSE:LLOY), Mitsubishi UFJ Financial Group, Inc. (TSE:8306), Mizuho Financial Group, Inc. (TSE:8411), National Australia Bank Limited (ASX:NAB), NatWest Group plc (LSE:NWG), Nordea Bank Abp (HLSE:NDA FI), Royal Bank of Canada (TSX:RY), Société Générale Société anonyme (ENXTPA:GLE), Standard Chartered PLC (LSE:STAN), State Bank of India (NSEI:SBIN), Sumitomo Mitsui Financial Group, Inc. (TSE:8316), Sumitomo Mitsui Trust Group, Inc. (TSE:8309), The Bank of Nova Scotia (TSX:BNS), The Norinchukin Bank, The Toronto-Dominion Bank (TSX:TD), UBS Group AG (SWX:UBSG), UniCredit S.p.A. (BIT:UCG), Westpac Banking Corporation (ASX:WBC)

Statistics by Nationality we can observe the USD claims and liabilities of banks headquartered in country c. This includes both local and cross-border holdings by the bank in the headquarter country as well as local USD claims and liabilities of foreign affiliates, and excludes intragroup holdings. This however does not include the local USD claims and liabilities of affiliates in the United States. So to this data from the Locational Banking Statistics by Nationality we add local claims and liabilities in the local currency by the bank's affiliates in the United States from the BIS Consolidated Banking Statistics.

The shares m_c are calculated as follows. Let $C^F_{i,c,t}$ and $L^F_{i,c,t}$ be cross-jurisdictional claims and liabilities of G-SIB bank i in country c. We observe these data for every year from 2013 to 2022. Summing these across the G-SIB banks in a country, we have $C^F_{B,c,t} = \sum_{i=1}^{I} C^F_{i,c,t}$ and $L^F_{B,c,t} = \sum_{i=1}^{I} L^F_{i,c,t}$. We can observe foreign claims and liabilities at the country level from the BIS (denominated in all currencies), $C^F_{c,t}$ and $L^F_{c,t}$. When observing these foreign claims and liabilities from the BIS, we can observe if a claim or liability is with a domestic counterparty, foreign counterparty, or unallocated. We assume that the claims and liabilities with an unallocated counterparty are 50% foreign and 50% domestic.

From this we can calculate $m^C_{c,t} = \frac{C^F_{B,c,t}}{C^F_{c,t}}$ and $m^L_{c,t} = \frac{L^F_{B,c,t}}{L^F_{c,t}}$ for every year 2013-2022. Our shares are $m_c = \frac{1}{2}\frac{1}{10}\sum_{t=2013}^{2022}\left(m^C_{c,t} + m^L_{c,t}\right)$.[2]

$C^{nonUSD}_{B,c,t}$ are non-USD denominated claims for the G-SIB banks in country c. It is computed as a residual: $C^{nonUSD}_{B,c,t} = A_{B,c,t} - C^{USD}_{B,c,t}$. Total assets of G-SIB banks in country c are $A_{B,c,t} = \sum_{i=1}^{I} A_{i,c,t}$, where $A_{i,c,t}$ is the total assets of G-SIB bank i.

$L^{nonUSD}_{B,c,t}$ are non-USD denominated wholesale liabilities for the G-SIB banks in country c. It is also computed as a residual: $L^{nonUSD}_{B,c,t} = L_{B,c,t} - D_{B,c,t} - L^{USD}_{B,c,t}$. Total bank liabilities of G-SIB banks in country c are $L_{B,c,t} = \sum_{i=1}^{I} L_{i,c,t}$, where $L_{i,c,t}$ is total liabilities of G-SIB bank i.

The net worth of G-SIB banks in country c is then $N_{B,c,t} = A_{B,c,t} - L_{B,c,t}$. FX swaps/bank assets are $S_{B,c,t} = \frac{C^{USD}_{B,c,t} - L^{USD}_{B,c,t}}{A_{B,c,t}}$.

[2]We can compute these shares every year from 2013 to 2022. They do not show an upward or downward trend over time, so we simply compute one share and apply it throughout our sample.

F.2 Event Study Figure 2

The event study graphs in Figure 2 present the responses of seven bank balance sheet variables: deposits, USD claims, USD liabilities, non-USD claims, non-USD liabilities, net worth, and FX swaps/bank assets. The figure also presents the CIP deviation and the probability of default (EDF).

The CIP deviation is the 3-month OIS CIP deviation from Bloomberg. The graph in Figure 2 reports the average of these CIP deviations across our 22 events.

The EDF (expected default frequency) is observed at the bank level and is obtained from Moody's Analytics. The EDF series $EDF_{B,c,t}$ at the country level is the average EDF across the G-SIB banks in the country. The EDF graph in Figure 2 is the average of these country-level EDFs across our 22 events.

We calculate $\frac{s_c D_{B,c,t}}{hp\left(s_c D_{B,c,t}\right)}$, where s_c is the nominal exchange rate in local currency per USD and hp refers to the HP trend. We normalize this series to have a value of zero in the quarter T=0 of an event in country c. The graph of retail deposits in Figure 2 is the average of these normalized $\frac{s_c D_{B,c,t}}{hp\left(s_c D_{B,c,t}\right)}$ across our 22 events. The same is done for USD claims and liabilities, non-USD claims and wholesale liabilities, and net worth. USD assets and liabilities and net worth are not converted to the local currency.

For FX swaps/bank assets, we do not scale by the HP trend. We do normalize the series to have a value of zero in the quarter T=0 of an event in country c. The graph of FX swaps/bank assets in Figure 2 is the average of these normalized $S_{B,c,t}$ across our 22 events.

G Sensitivity Analysis and Extensions

We now consider sensitivity analysis and extensions. Figures A2 through A10 illustrate how changing various parameters affect the response of variables to a dollar liquidity shock.

G.1 Role of $\nu_e = \nu_d$

In the paper, we set $\nu = \nu_e = \nu_d = 0.2$. In Figure A2 we vary ν from 0 to 0.3. Unless we lower ν below 0.01, this has very little effect on the results. The only variable that is affected substantially for values above 0.01 is the probability

of default. When the euro borrowing constraint is binding, it rises in response to the dollar liquidity shock as we raise ν. This is natural as a higher cost of asset liquidation lowers net worth, which raises the probability of default. At the extreme where ν approaches zero, so that assets can be sold without cost, the drop in dollar borrowing leads to an almost equal drop in dollar loans, while the swap market position is only slightly above zero. Naturally, in that case the CIP deviation is largely unaffected. But beyond this rather extreme case where both dollar and euro assets are perfectly liquid, we find that ν mainly affects net worth and the probability of default and only when the euro borrowing constraint binds.

G.2 Role of η

In the paper we set $\eta = 0.0025$. In Figure A3 we vary η from 0 to 0.01. We see that the only variable that is substantially affected is the CIP deviation. Over this range, the increase in the CIP deviation varies from 0 to 51 basis points with a binding euro borrowing constraint and from 0 to 117 basis points without a binding euro borrowing constraint.

G.3 Difference between ν_e and ν_d

So far we have assumed that $\nu_e = \nu_d = 0.2$. We now vary $\nu_d - \nu_e$ while keeping their average value equal to 0.2. Perhaps not surprisingly, this has a significant effect on the results, as shown in Figure A4.

One extreme involves $\nu_d = 0$ and $\nu_e = 0.4$. Then there is no cost to liquidating dollar loans, but a very high cost to liquidating euro loans. The opposite extreme case involves $\nu_d = 0.4$ and $\nu_e = 0$.

Consider the two extremes in turn. When $\nu_d = 0$ and $\nu_e = 0.4$ there is no cost to liquidating dollar loans. Banks then naturally sell dollar loans by an amount close to the drop in dollar borrowing. They do so even when the euro borrowing constraint does not bind. Dollar assets and liabilities then drop equally and the swap market position remains zero. The CIP deviation is therefore also unaffected by the shock.

When $\nu_d = 0.4$ and $\nu_e = 0$, the cost of selling dollar loans is so high that banks will not sell any dollar loans. When the euro borrowing constraint binds they will instead sell euro loans, which they can do without any cost. But this creates a

larger net long dollar position on the balance sheet. This leads to a larger demand for dollar swaps and a larger increase in the CIP deviation.

The probability of bank default actually rises most when $\nu_e = \nu_d = 0.2$ and the euro borrowing constraint binds. This is because in the two extreme cases banks avoid losses associated with selling loans. For example, when $\nu_d = 0.4$ and $\nu_e = 0$, there is no cost associated with selling euro loans, while banks avoid selling dollar loans as this is too costly.

G.4 Pre-shock Synthetic Dollar Position

Next we consider some extensions. We first vary the pre-shock synthetic dollar position of banks. So far we set it equal to zero in the pre-shock equilibrium. Table 2 of the paper shows that in 2022 dollar assets of non-US banks were about \$0.8T higher than dollar liabilities. If this net dollar position is hedged, it implies that non-US banks hold \$0.8T in dollar swaps, which is 1.7% of all bank assets. On average over the 2003-2022 sample the swap position was 1% of bank assets.

Defining δ as the pre-shock ratio of the swap market position relative to assets, we will vary δ from -0.05 to 0.05 (-5 to +5%). If we take the average ratio in the sample for each country, the 5th percentile across the countries is -0.05, while the 95th percentile is 0.05. So this captures well the variation across countries. We vary δ by changing $L_0^{\$}$ and $L_0^{€}$ relative to their values in Table 3. Holding $B_0^{\$,w}$ equal to its value in Table 3 of the paper, we set $L_0^{\$} = B_0^{\$,w} + \delta K$ and $L_0^{€} = K - L_0^{\$}$, where K is the size of the balance sheet that we hold constant at 47.5. Figure A5 shows that this has virtually no effect on any of the variables. The drop in dollar and euro lending that occurs when the euro borrowing constraint binds remains the same. Percentage wise they vary with δ as $L_0^{\$}$ is higher and $L_0^{€}$ is lower as we raise δ. The absolute changes in dollar lending are virtually identical across δ.

Intuitively, If $\delta > 0$, then $S_0 > 0$, so that the bank has a positive swap position and is borrowing dollars synthetically. The dollar liquidity shock has two offsetting effects. First, it raises the CIP deviation. This reduces profits and net worth since banks are borrowing dollars synthetically. Second, the shock raises the swap market position further. This raises profits as the CIP deviation is negative to start with. The latter is needed to generate $S_0 > 0$ and is achieved by lowering u in the pre-shock equilibrium. These two effects offset each other.

Now assume $\delta < 0$, so that $S_0 < 0$. Banks then lend dollars synthetically.

Then the higher CIP deviation raises bank profits. But the increase in the swap market position lowers bank profits as the CIP deviation is positive to start with. The latter is needed to induce $S_0 < 0$ and is achieved by raising u in the pre-shock equilibrium. These two effects again cancel each other.

G.5 Risk Aversion Wholesale Dollar and Euro Lenders

We have assumed that wholesale lenders are risk neutral, so that the interest rates on wholesale dollar and euro funding are equal to the safe rate plus the probability of bank default. We now extend the model to make wholesale lenders risk-averse. Consider wholesale euro lenders. Let their wealth be $W^{l,€}$ and let P_2 be the period 2 payment per euro of wholesale lending to the bank. This is equal to $1 + i_1^€$ with probability $1 - p_D$ and 0 with probability p_D. They earn an interest of i^s on safe euro assets.

When the euro wholesale lenders allocate $A_1^{€,w}$ to bank lending, the portfolio return is

$$R_2^{p,l} = 1 + i^s + \frac{A_1^{€,w}}{W_1^{l,€}} \left(P_2 - 1 - i^s\right) \tag{G.10}$$

Lenders maximize

$$ER_2^{p,l} - 0.5\gamma_e var(R_2^{p,l}) \tag{G.11}$$

This implies maximizing

$$\frac{A_1^{€,w}}{W_1^{l,€}} \left(E(P_2) - 1 - i^s\right) - 0.5\gamma_e \left(\frac{A_1^{€,w}}{W_1^{l,€}}\right)^2 var(P_2) \tag{G.12}$$

This implies

$$A_1^{€,w} = \frac{(E(P_2) - 1 - i^s)W_1^{l,€}}{\gamma_e var(P_2)} \tag{G.13}$$

We have

$$E(P_2) = \left(1 + i_1^€\right)(1 - p_D) \tag{G.14}$$

and

$$var(P_2) = E(P_2^2) - (E(P_2))^2 = (1-p_D)\left(1 + i_1^€\right)^2 - (1-p_D)^2\left(1 + i_1^€\right)^2 = \left(1 + i_1^€\right)^2 p_D(1-p_D) \tag{G.15}$$

To summarize, we have

$$A_1^{€,w} = \frac{\left[\left(1 + i_1^€\right)(1 - p_D) - 1 - i^s\right] W^{l,€}}{\gamma_e \left(1 + i_1^€\right)^2 p_D(1 - p_D)} \tag{G.16}$$

Analogously, for wholesale dollar lenders we have

$$A_1^{\$,w} = \frac{\left[\left(1+i_1^{\$}\right)(1-p_D) - 1 - i^s\right] W^{l,\$}}{\gamma_d \left(1+i_1^{\$}\right)^2 p_D(1-p_D)} \tag{G.17}$$

In the calibration, we set $W^{l,€} = B_0^{€,w}$ and $W^{l,\$} = B_0^{\$,w}$. The market equilibrium conditions for short-term wholesale funding are $A_1^{€,w} = B_1^{€,w}$ and $A_1^{\$,w} = B_1^{\$,w}$, which can be written as

$$\left(1+i_1^{€}\right)(1-p_D) - 1 - i^s = \gamma_e \left(1+i_1^{€}\right)^2 p_D(1-p_D)\frac{B_1^{€,w}}{B_0^{€,w}} \tag{G.18}$$

$$\left(1+i_1^{\$}\right)(1-p_D) - 1 - i^s = \gamma_d (1+i_1^{\$})^2 p_D(1-p_D)\frac{B_1^{\$,w}}{B_0^{\$,w}} \tag{G.19}$$

This replaces the equations $i_1^{€} = i_1^{\$} = i^s + p_D$.

With this extension, both the first and second moments associated with bank default affect the interest rates. We vary risk aversion of these lenders from 0 to 2. Figure A6 shows that this has virtually no effect on the results.

G.6 Bailout of Wholesale Lenders

We consider an extension where there is a partial bailout of euro and dollar wholesale lenders in case of bank default. A fraction $bail_e$ of obligations to euro wholesale lenders will be bailed out by the government in period 2 in case of default. Separately, we also consider the case where a fraction $bail_d$ of obligations to dollar lenders are bailed out in case of default. Assuming risk neutrality, the lenders then demand interest rates $i_1^{€} = i^s + p_D(1 - bail_e)$ and $i_1^{\$} = i^s + p_D(1 - bail_d)$. We vary $bail_e$ from 0 to 1 in Figure A7 and we vary $bail_d$ from 0 to 1 in Figure A8. When it is 1, there is a complete bailout in case of default, so that wholesale lending becomes risk-free. Figures A7 and A8 show that this parameter also has no effect on the impact of the dollar liquidity shock on variables.

However, these bailout parameters do affect the pre-shock CIP deviation. In the main analysis, where $bail_e = bail_d = 0$, the pre-shock CIP deviation is zero. A higher value of $bail_e$ implies a larger pre-shock CIP deviation, while a higher $bail_d$ implies a lower (negative) pre-shock CIP deviation. Intuitively, a higher $bail_e$ lowers the wholesale euro borrowing rate for banks. This makes it cheaper to borrow dollars synthetically. The resulting larger demand for dollar swaps by banks raises

the pre-shock CIP deviation. A higher $bail_d$ lowers the wholesale dollar borrowing rate for banks. This makes CIP arbitrage more attractive, which involves borrowing wholesale dollars and lending dollars synthetically. The resulting larger supply of dollar swaps lowers the pre-shock CIP deviation.

G.7 Binding Pre-shock Dollar Borrowing Constraint

In the main analysis the dollar borrowing constraint does not strictly bind in the pre-shock equilibrium, so that $l_d = 0$. We now consider positive values of l_d by raising $i_0^{\$,l}$. As discussed in Appendix B, there is a one-to-one relationship between l_d and $i_0^{\$,l}$. A higher dollar lending rate makes it more attractive for banks to borrow dollars, which causes the dollar borrowing constraint to bind. By varying $i_0^{\$,l}$ we vary l_d in the pre-shock equilibrium from 0 to 0.02. The results are shown in Figure A9.

Raising l_d raises the effective pre-shock dollar funding rate, which makes it more attractive for banks to borrow dollars synthetically. This raises the pre-shock swap rate and CIP deviation. As we vary l_d from 0 to 0.02 the pre-shock CIP deviation varies from 0 to 100 basis points.[3] Nonetheless, Figure A8 shows that the response of variables to a dollar liquidity shock is again unaffected.

G.8 Mixture of Dollar Liquidity Shock and External Dollar Shortage Shock

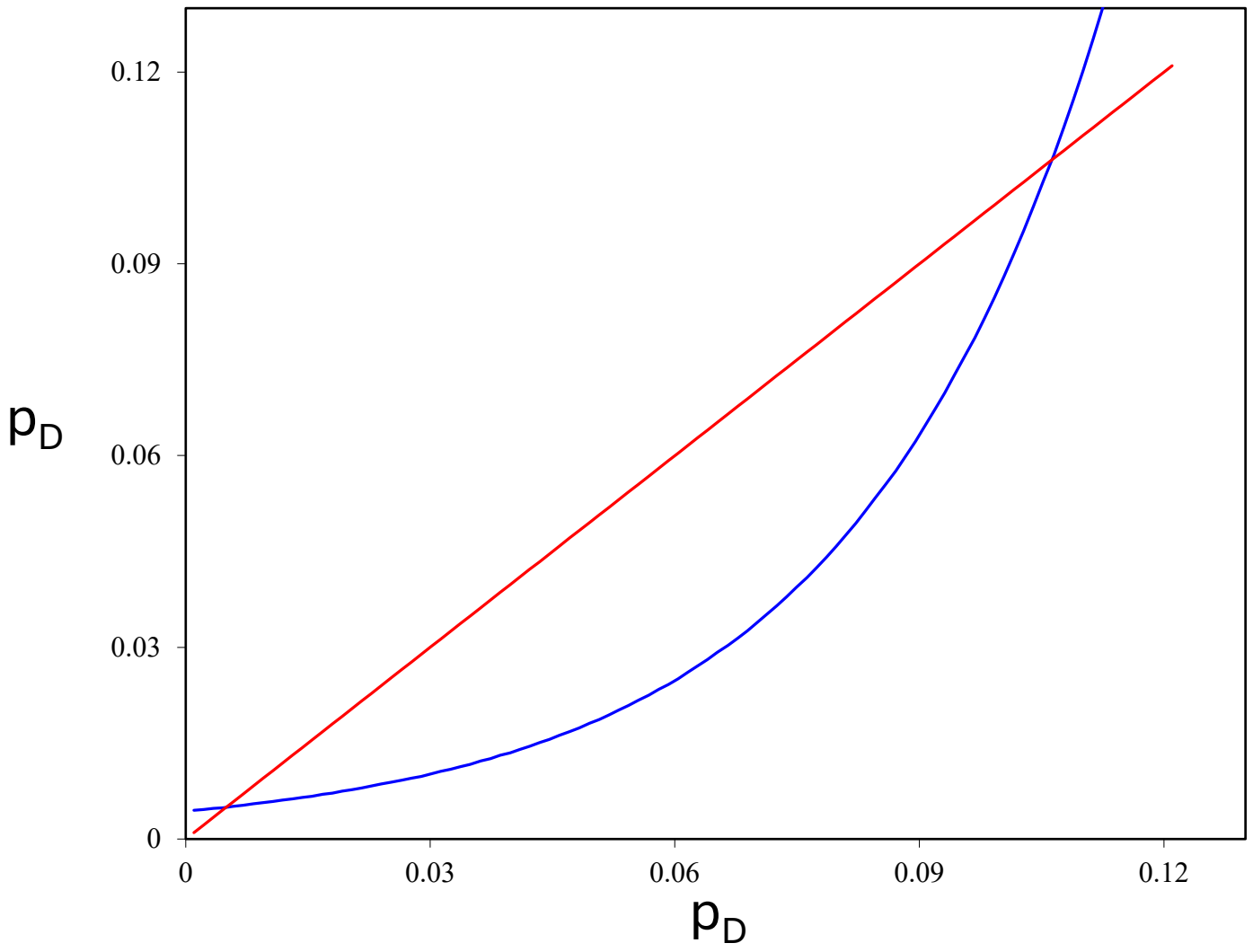
In reality, the two types of dollar funding shocks that we have discussed often occur in combination. In Figure A10 we consider the following scenario. We continue to assume a dollar liquidity shock of 15.8%, while at the same time varying ϵ^u from 0 to 2.

We have seen that external dollar shortage shocks on their own mainly impact the CIP deviation. They have little effect on the balance sheet and the probability of default. It is therefore not surprising that when combining the two shocks, the only variable that is affected is the CIP deviation. The larger the external dollar shortage shock that we mix with a given dollar liquidity shock, the bigger the rise

[3] We also raise u in the pre-shock equilibrium (so far set at 0). The higher swap rate causes US banks to sell dollar swaps. To equilibrate the swap market, we raise u, so that non-banks agents buy more dollar swaps. See Appendix B for further details.

in the CIP deviation.

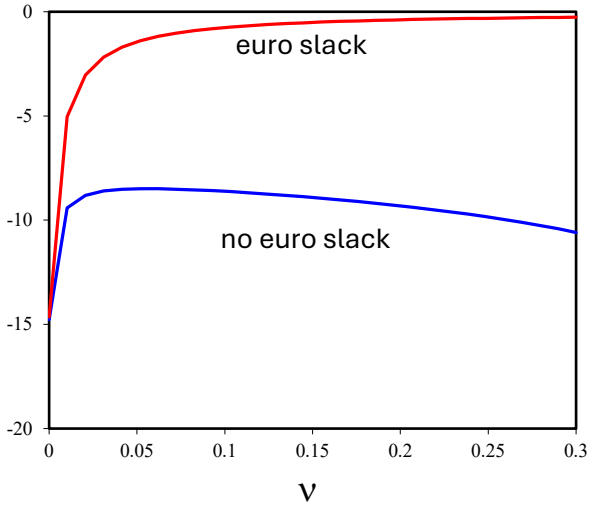
Figure A1 Multiple Equilibria*



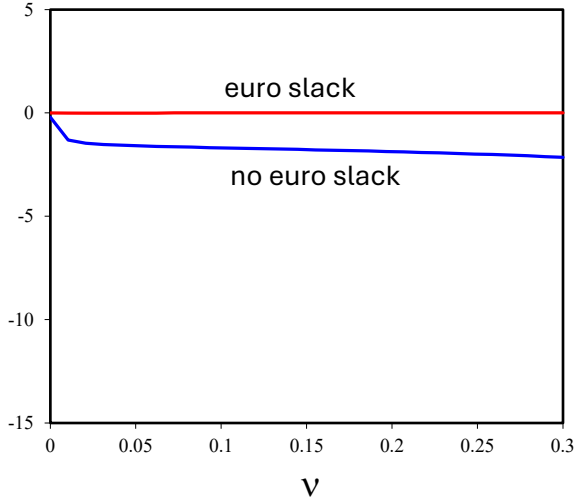
*The horizontal axis is the conjectured probability of default that determines the interest rates on euro and dollar wholesale funding. The vertical axis shows the implied probability of default. The two points on the intersection with the 45 degree line represent an equilibrium where the conjectured and actual probability of bank default are equal. The graph is based on the benchmark parameterization in the paper, without any shocks. In the lower equilibrium the default probability is 0.005 or 50 basis points. In the higher equilibrium it is 0.107 or 10.7 percent

Figure A2 Dollar Liquidity Shock: Role of ν

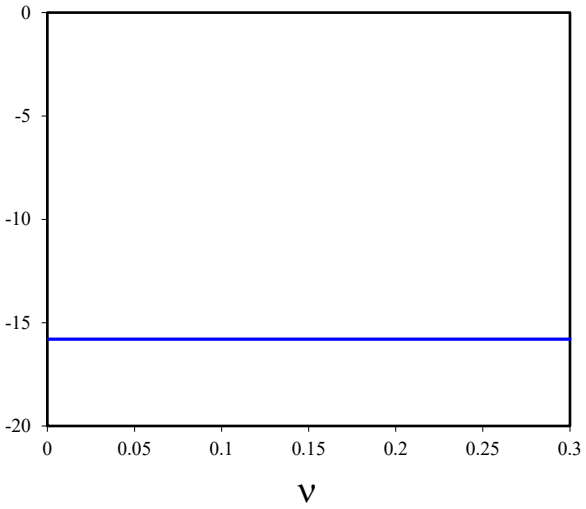
A. % change dollar lending



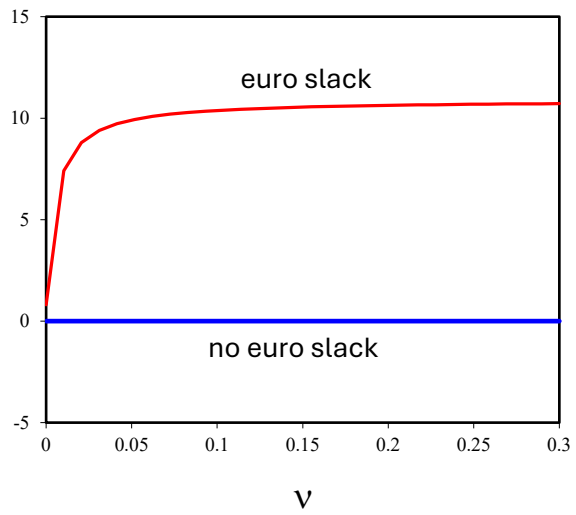
B. % change euro lending



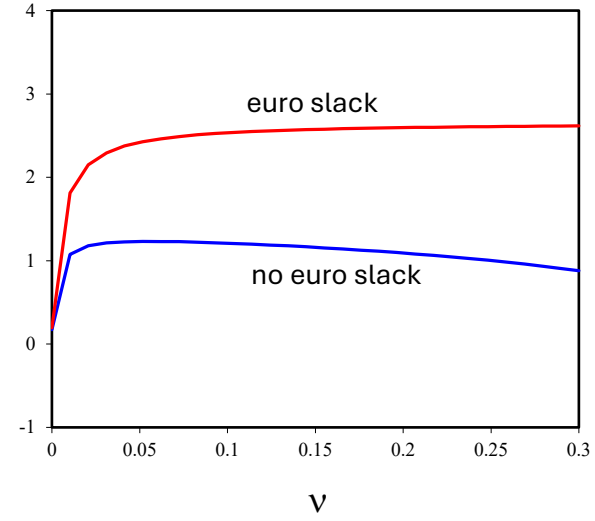
C. % change dollar borrowing



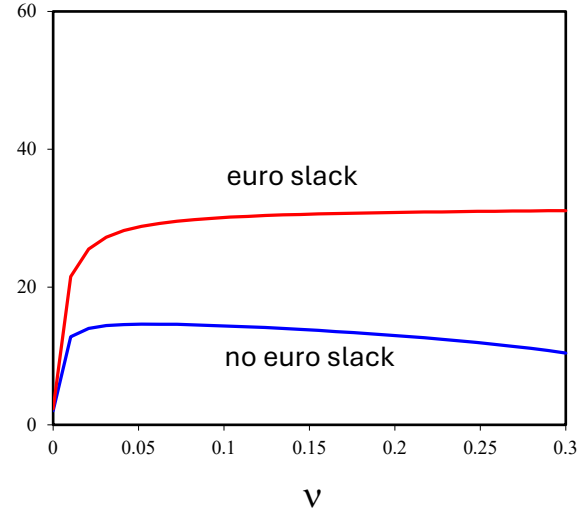
D. % change euro borrowing



E. Δ swaps as % of bank assets



F. change CIP deviation (bps)



G. change prob. default (bps)

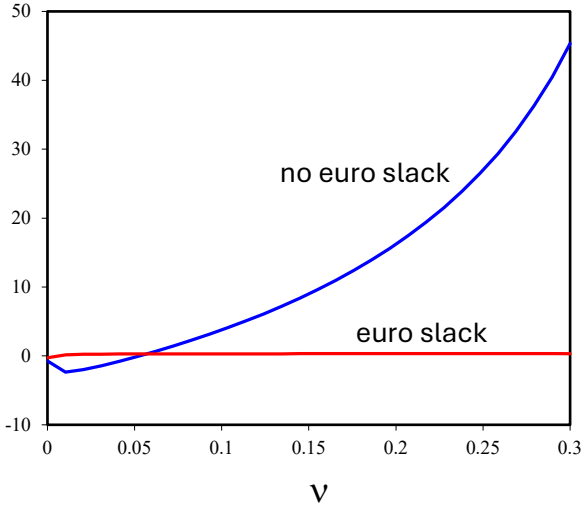
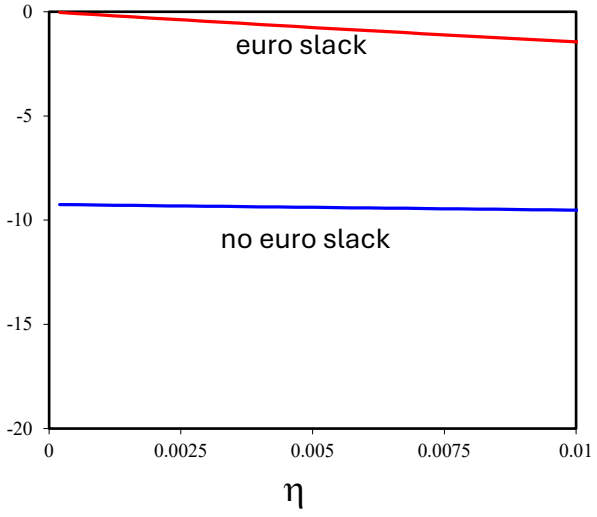
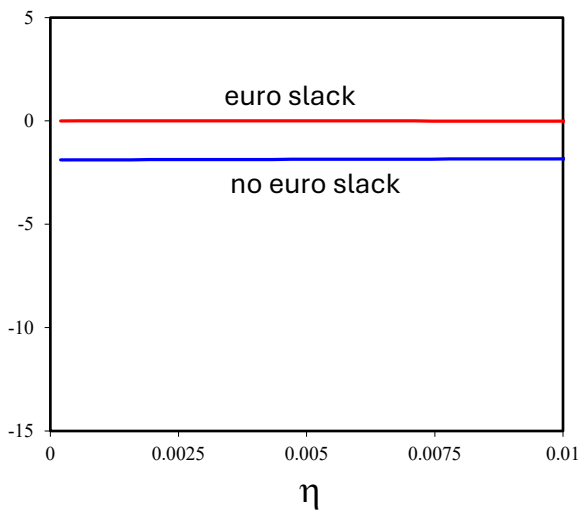


Figure A3 Dollar Liquidity Shock: Role of η

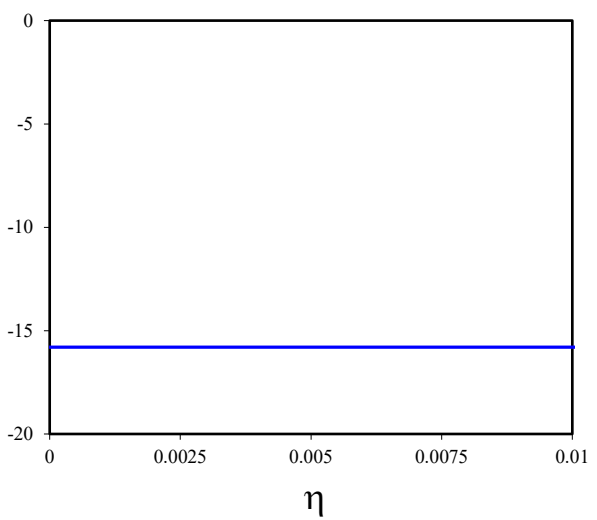
A. % change dollar lending



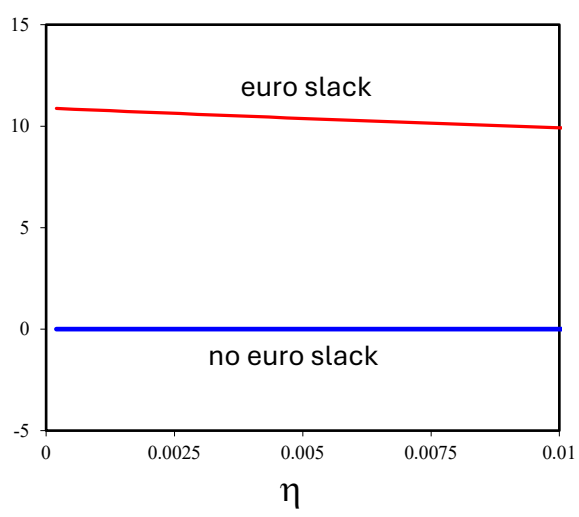
B. % change euro lending



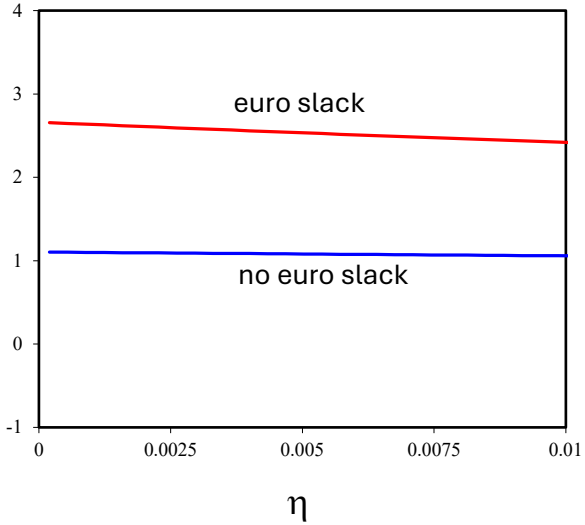
C. % change dollar borrowing



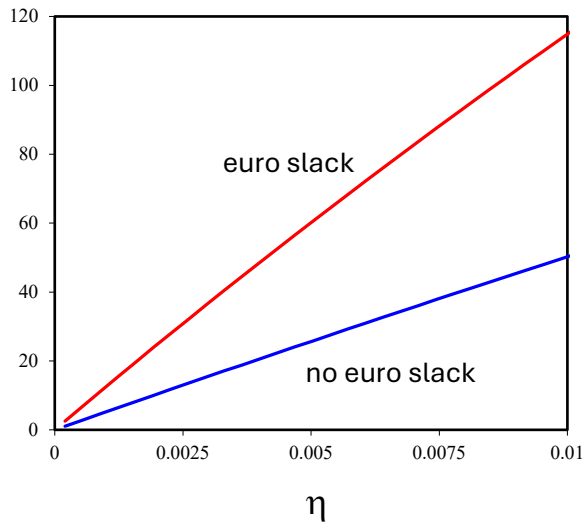
D. % change euro borrowing



E. Δ swaps as % of bank assets



F. change CIP deviation (bps)



G. change prob. default (bps)

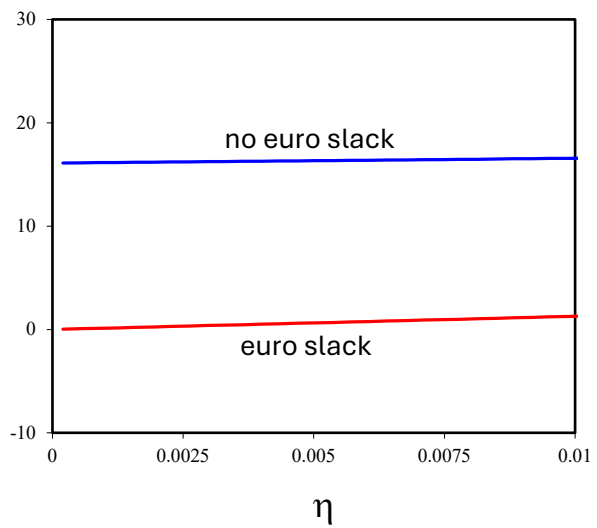
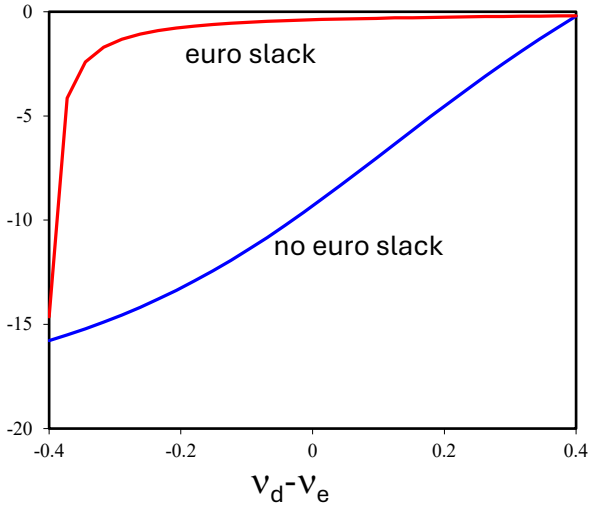
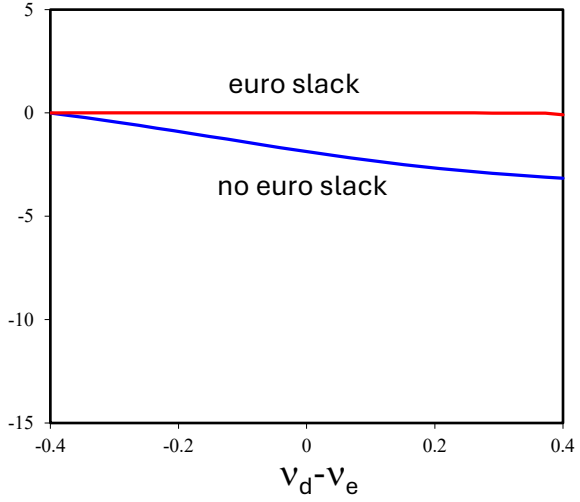


Figure A4 Dollar Liquidity Shock: ν_d-ν_e , keep ν_d+ν_e=0.4

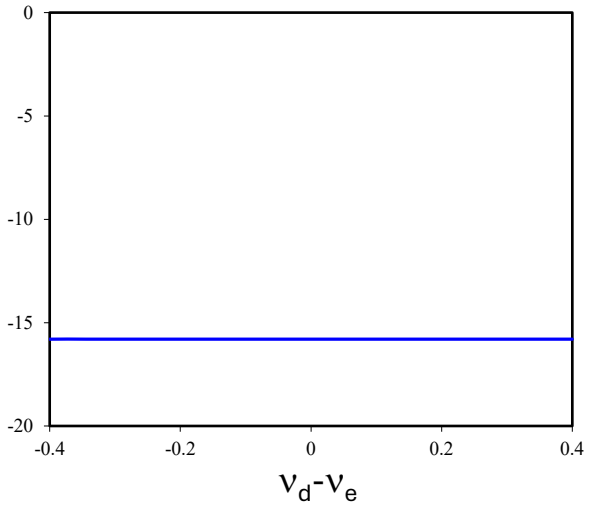
A. % change dollar lending



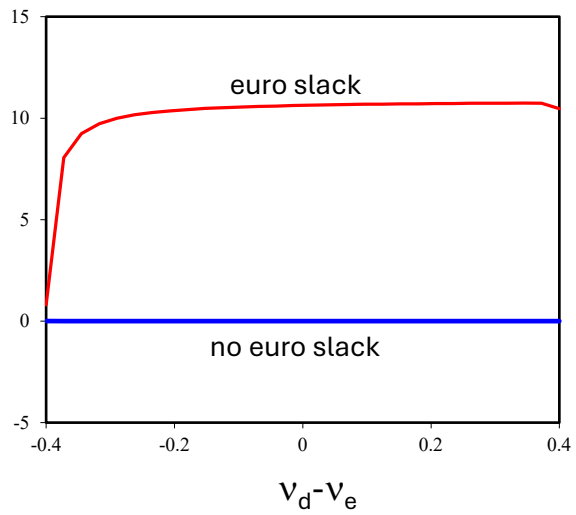
B. % change euro lending



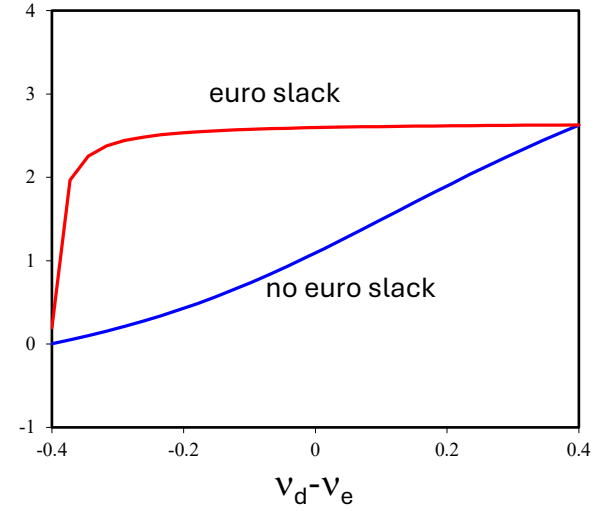
C. % change dollar borrowing



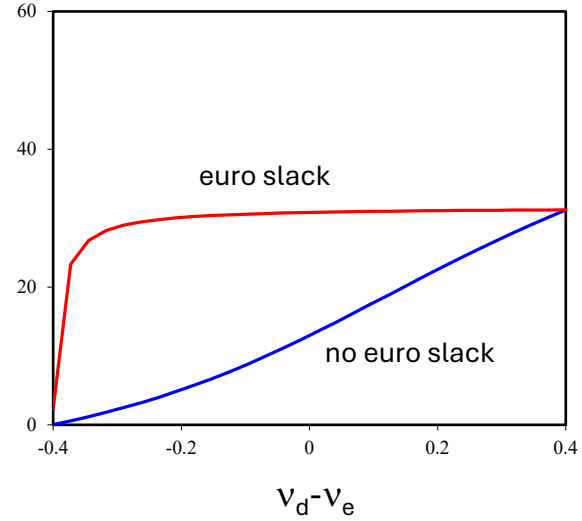
D. % change euro borrowing



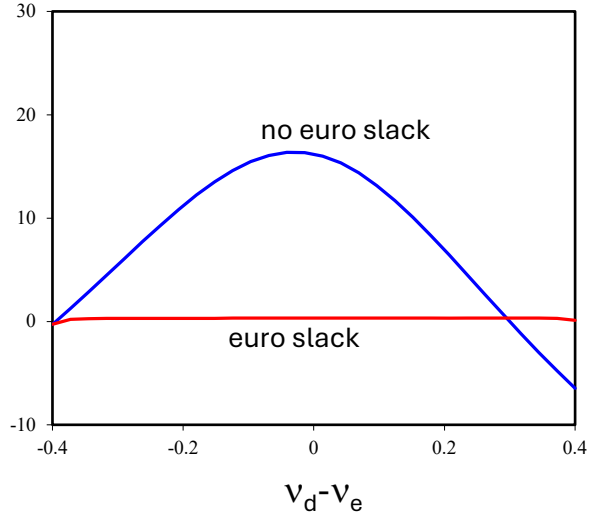
E. Δ swaps as % of bank assets



F. change CIP deviation (bps)



G. change prob. default (bps)



H. pre-shock CIP (bps)

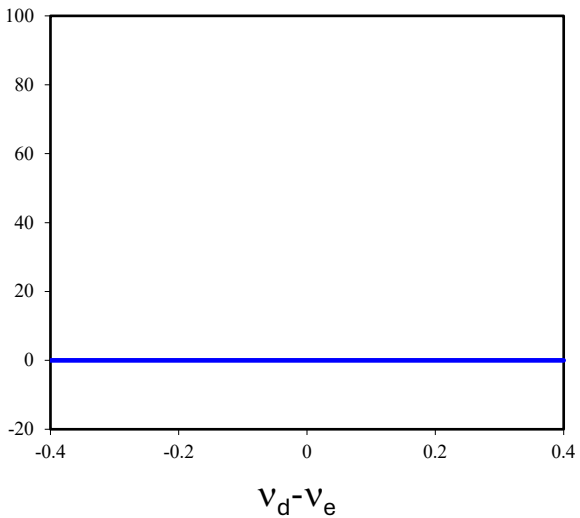
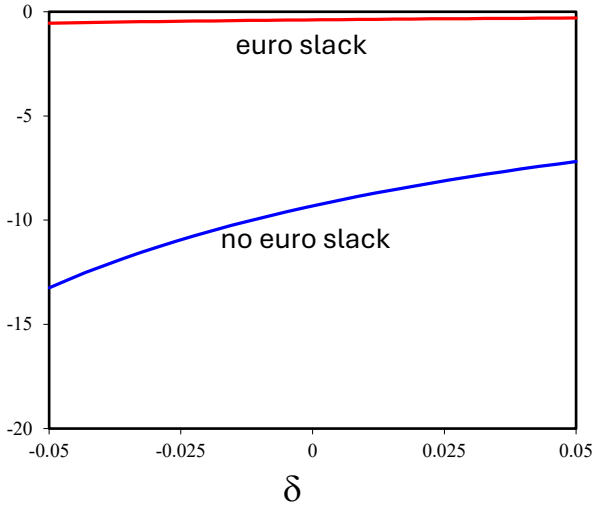
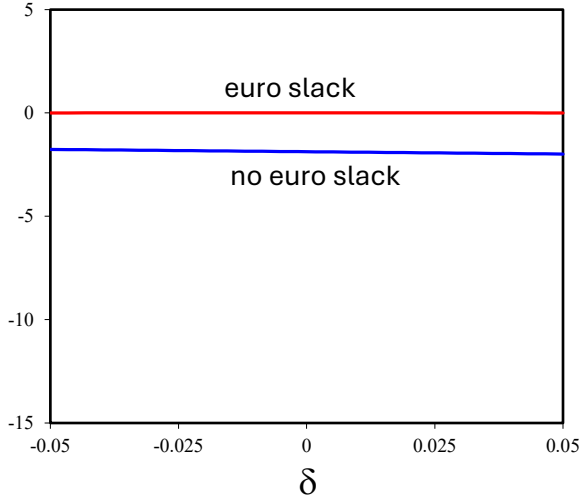


Figure A5 Dollar Liquidity Shock: Role of δ

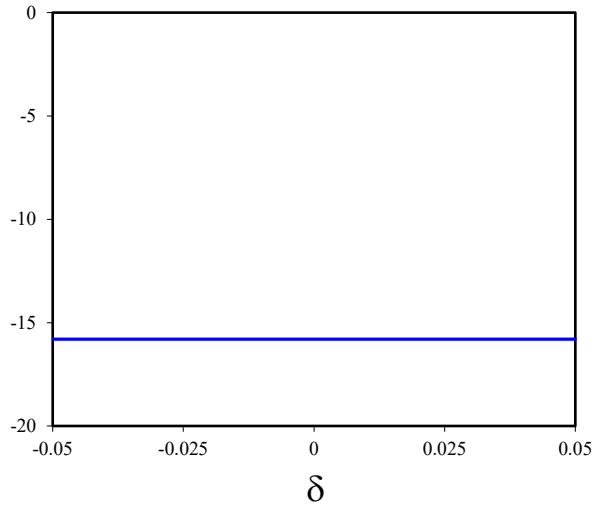
A. % change dollar lending



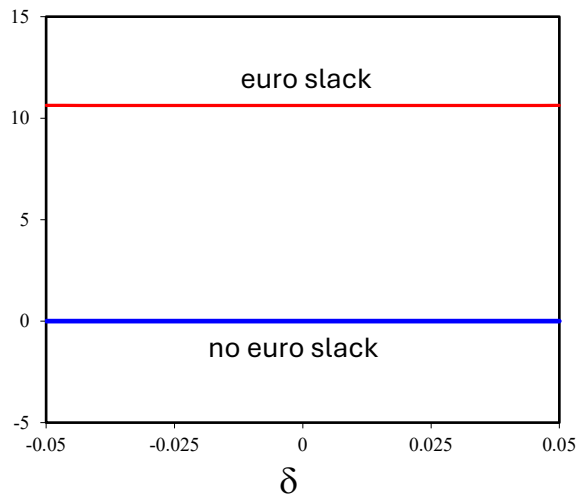
B. % change euro lending



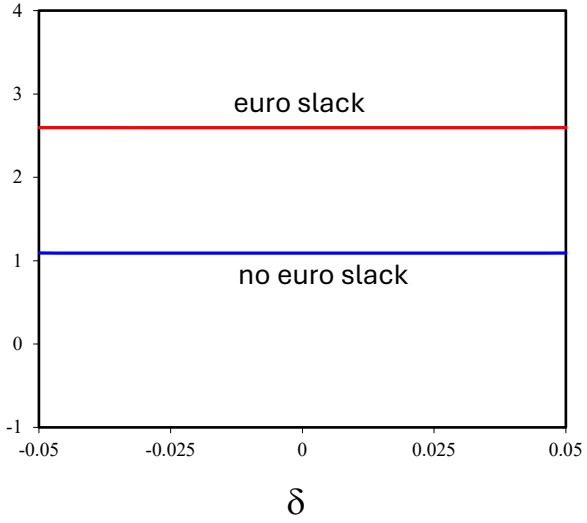
C. % change dollar borrowing



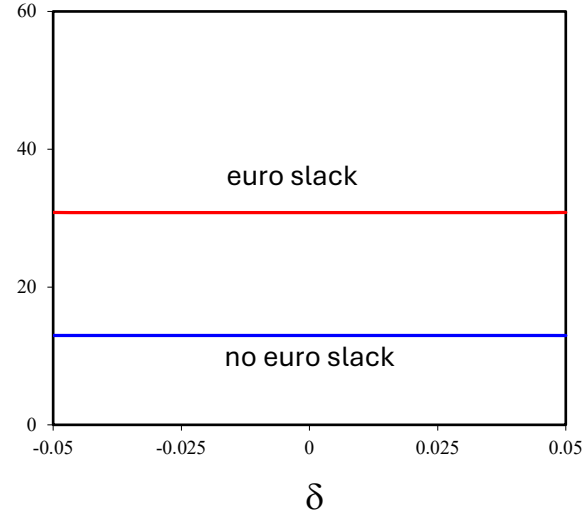
D. % change euro borrowing



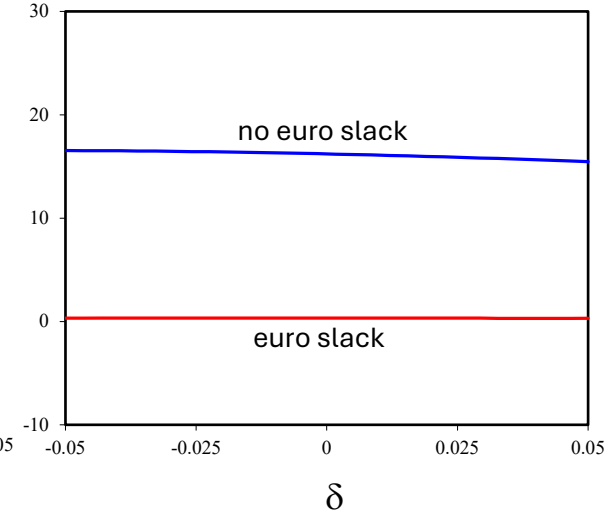
E. Δ swaps as % of bank assets



F. change CIP deviation (bps)



G. change prob. default (bps)



H. pre-shock CIP (bps)

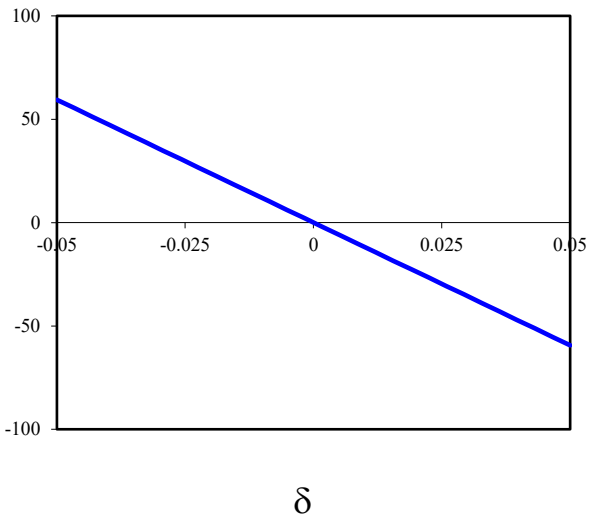
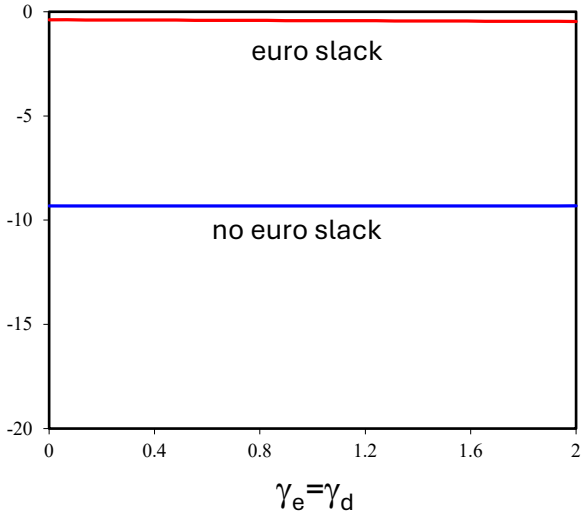
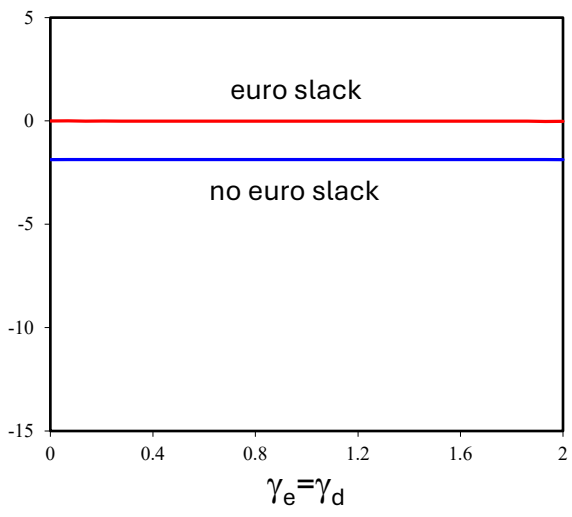


Figure A6 Dollar Liquidity Shock: Role of $\gamma_e=\gamma_d$

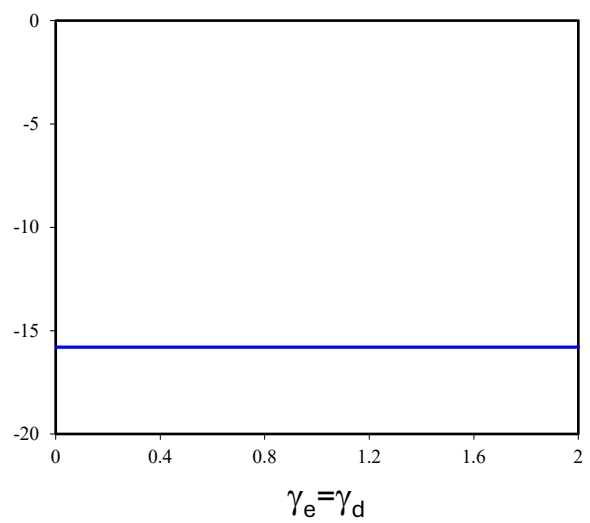
A. % change dollar lending



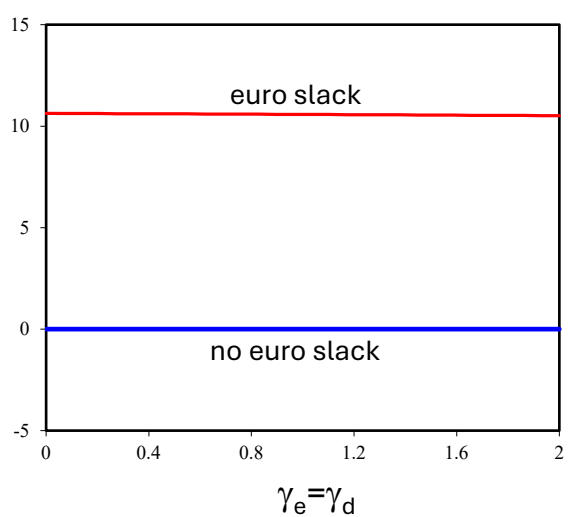
B. % change euro lending



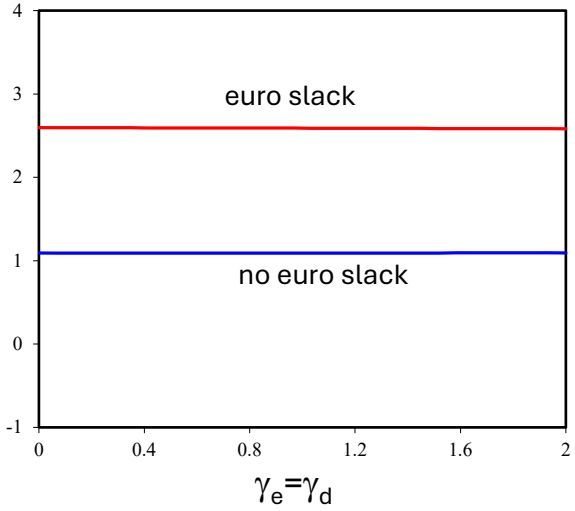
C. % change dollar borrowing



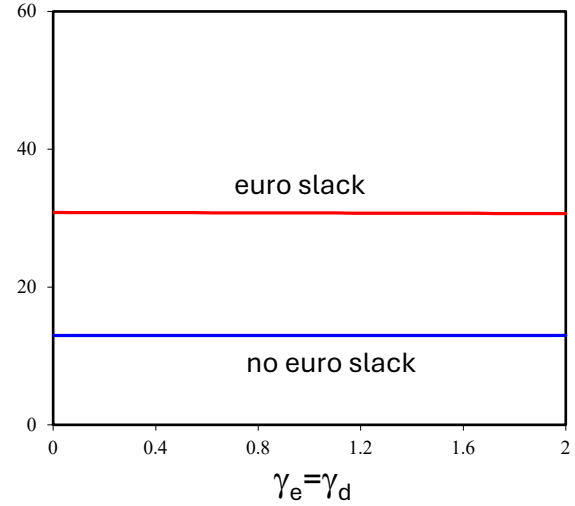
D. % change euro borrowing



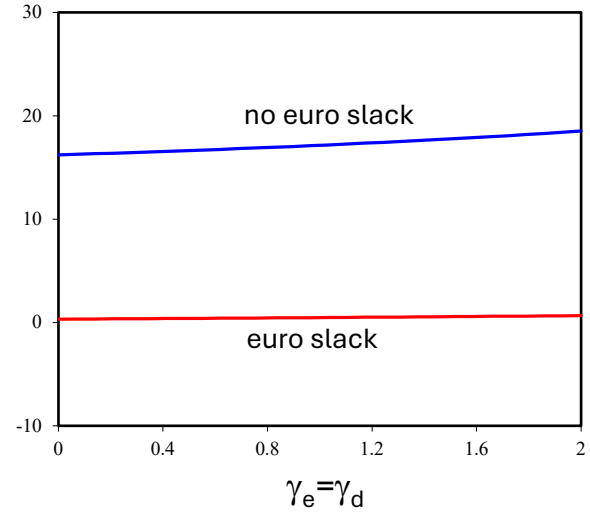
E. Δ swaps as % of bank assets



F. change CIP deviation (bps)



G. change prob. default (bps)



H. pre-shock CIP (bps)

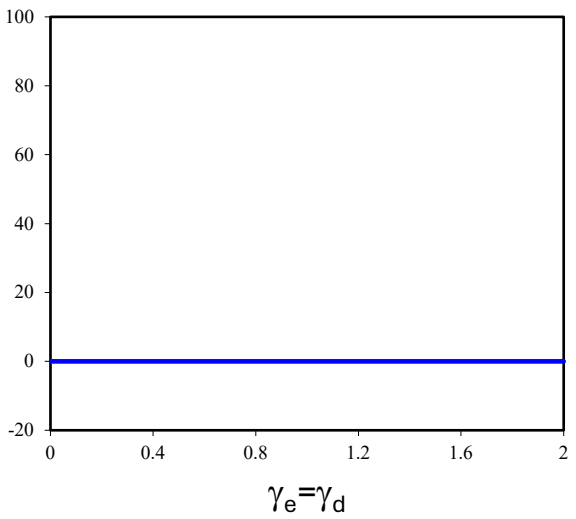


Figure A7 Dollar Liquidity Shock: Role of $bail_e$

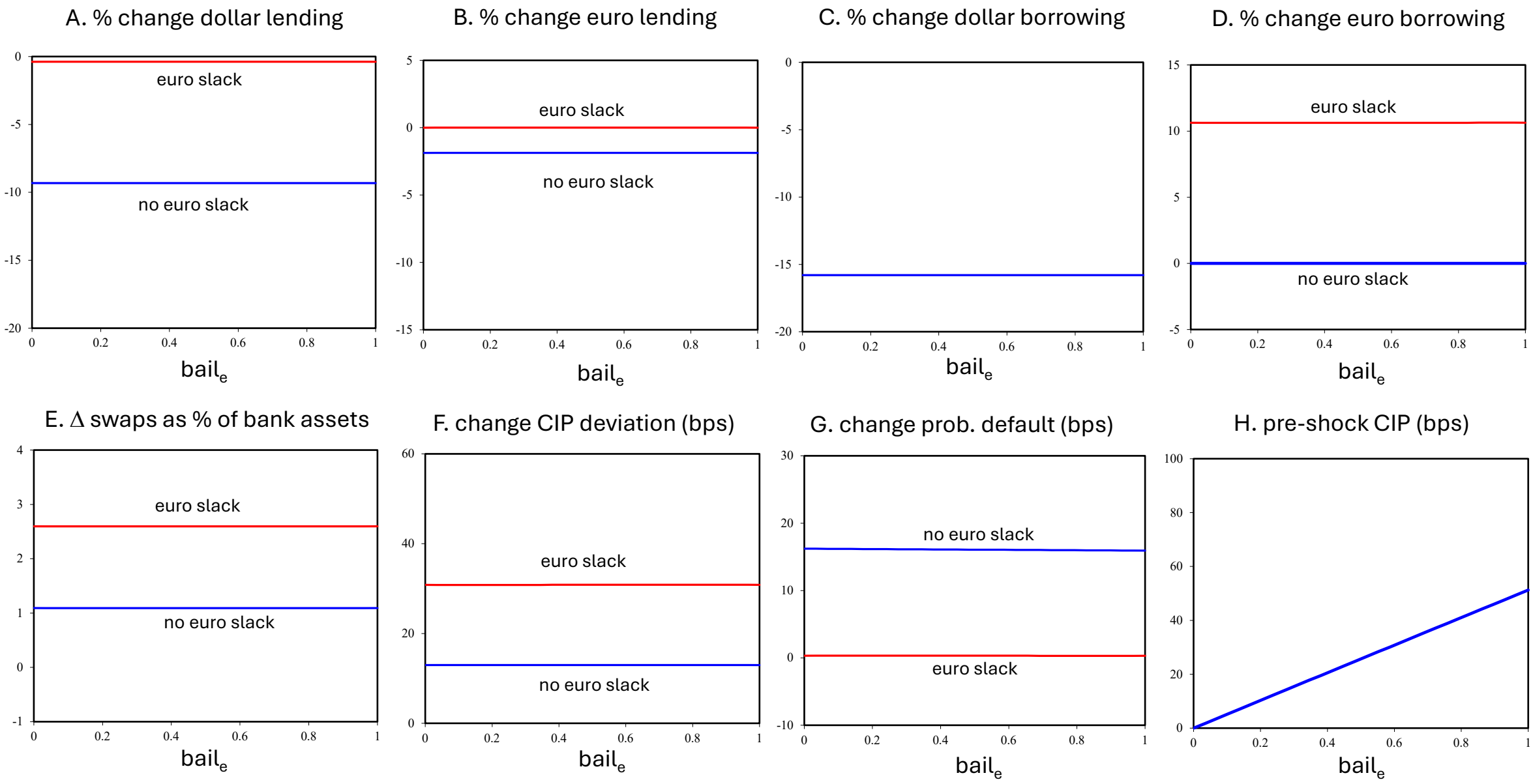


Figure A8 Dollar Liquidity Shock: Role of $bail_d$

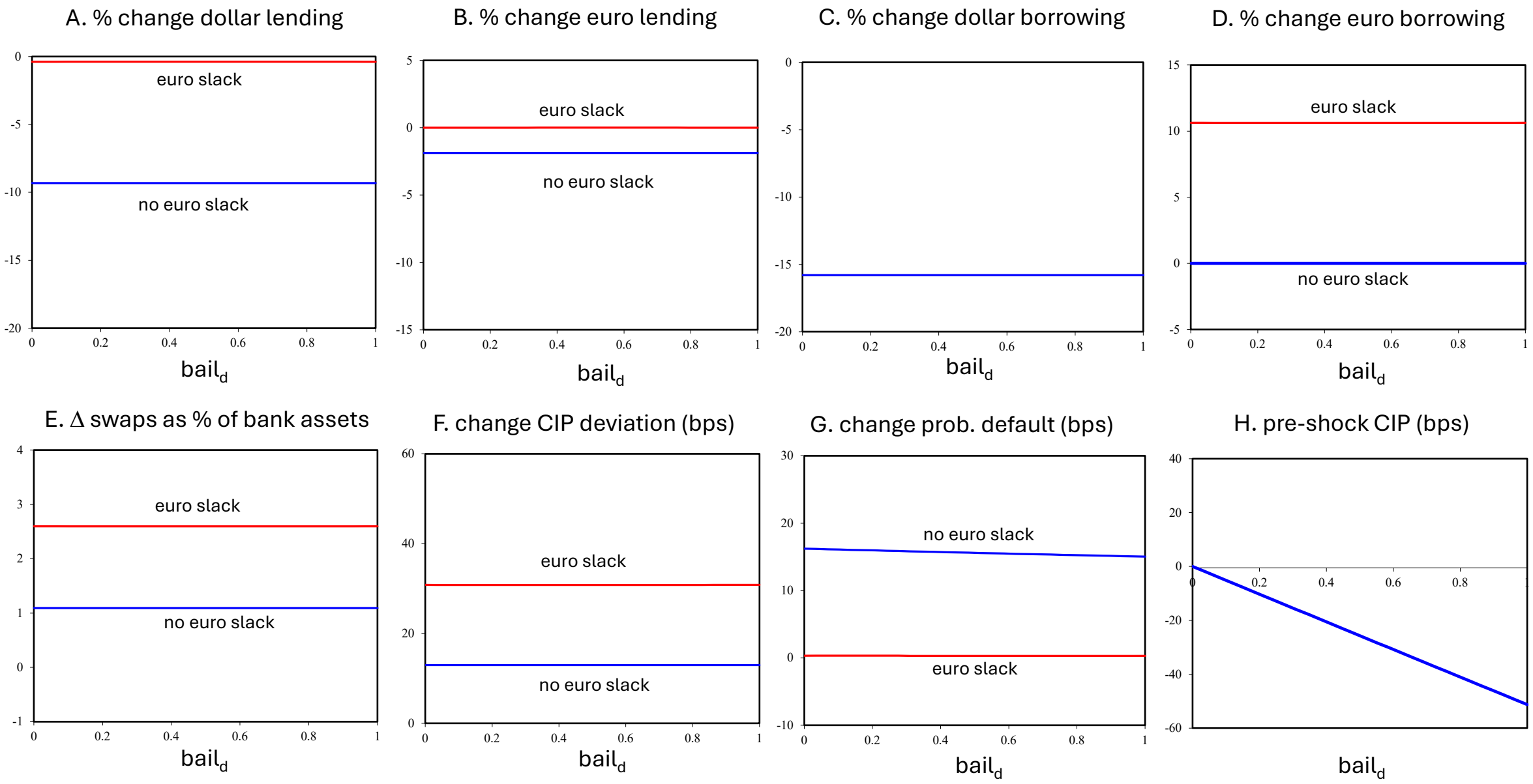


Figure A9 Dollar Liquidity Shock: Role of Pre-Shock l_d

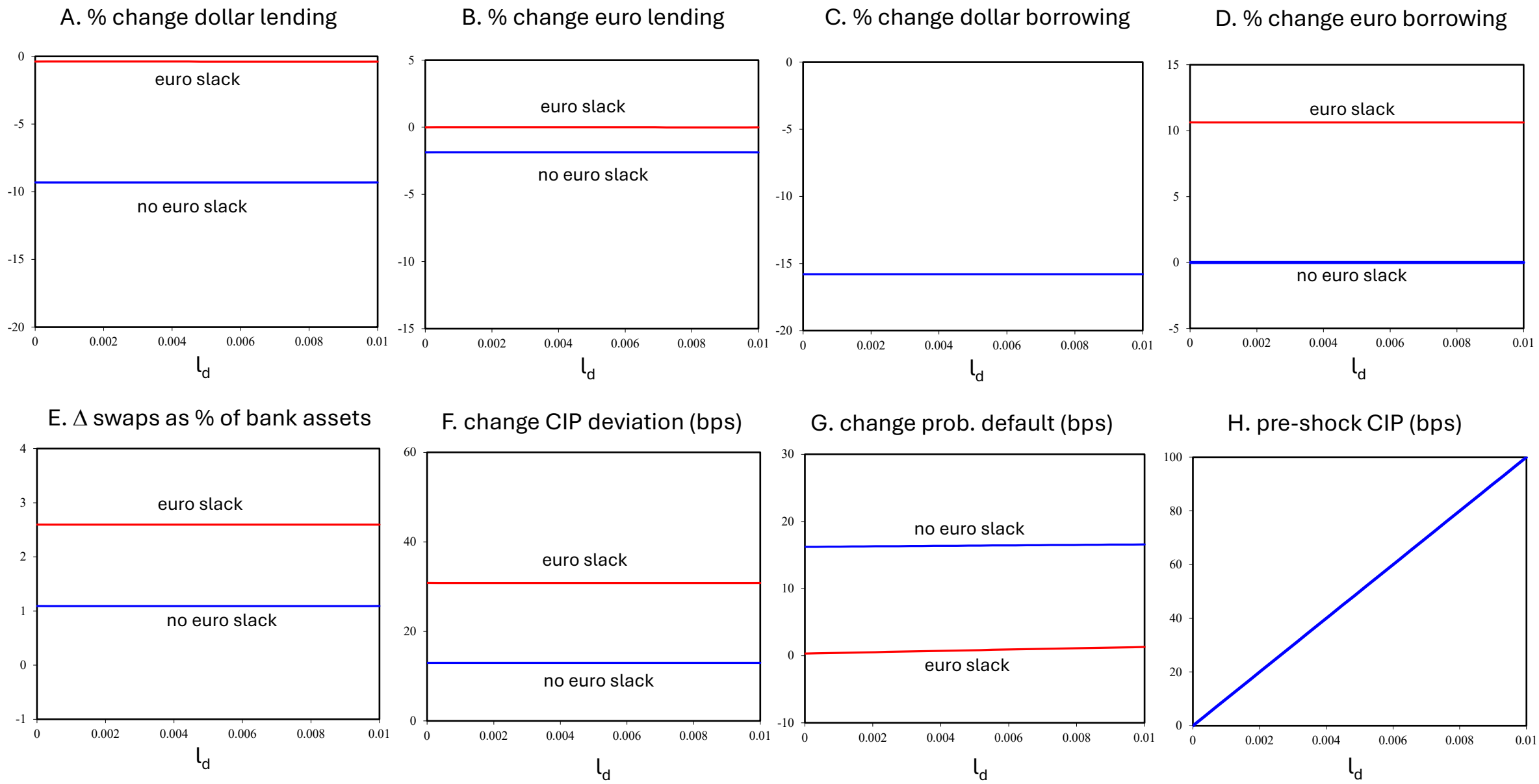
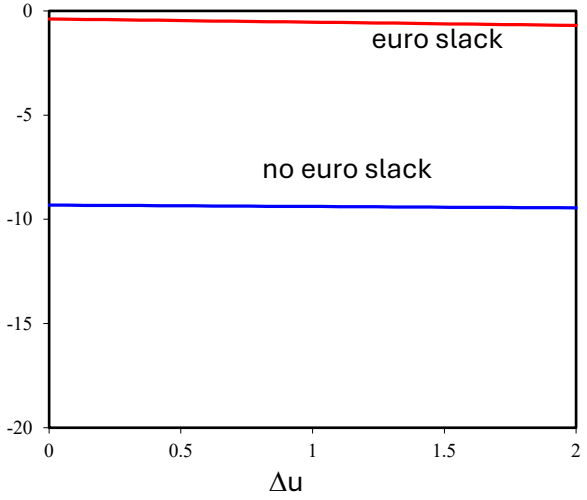
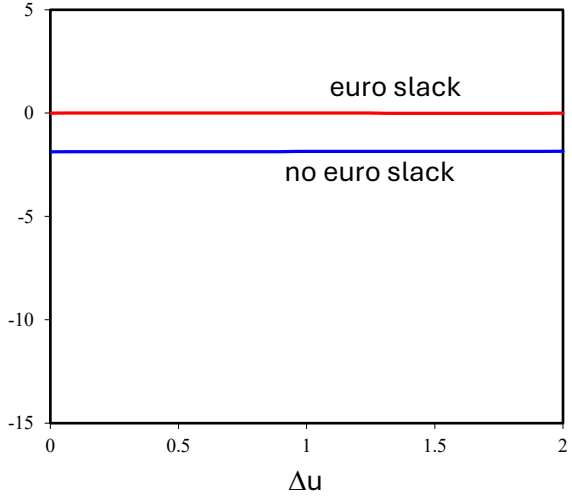


Figure A10 Mixture of Dollar Liquidity Shock and U-shock*

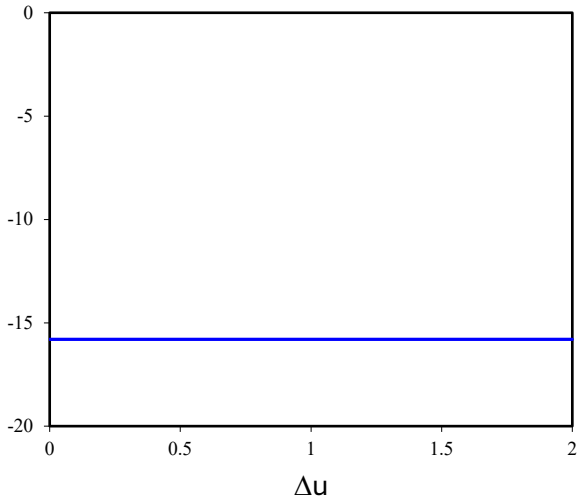
A. % change dollar lending



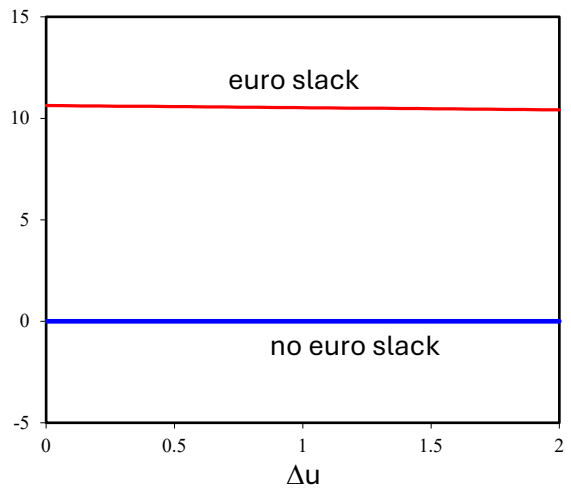
B. % change euro lending



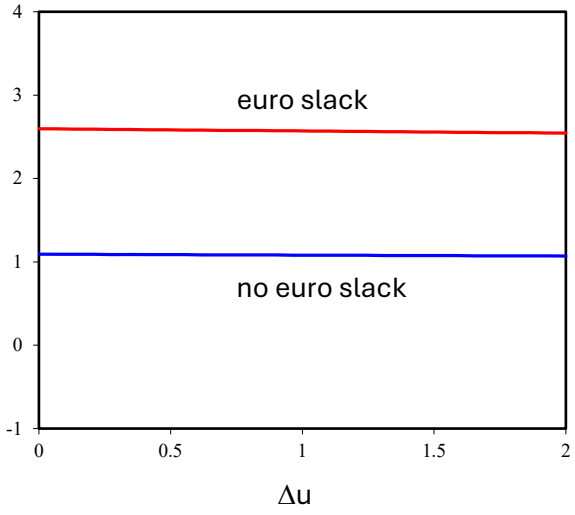
C. % change dollar borrowing



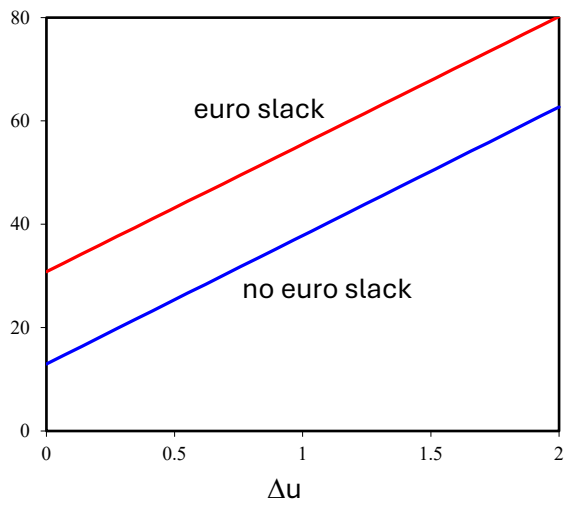
D. % change euro borrowing



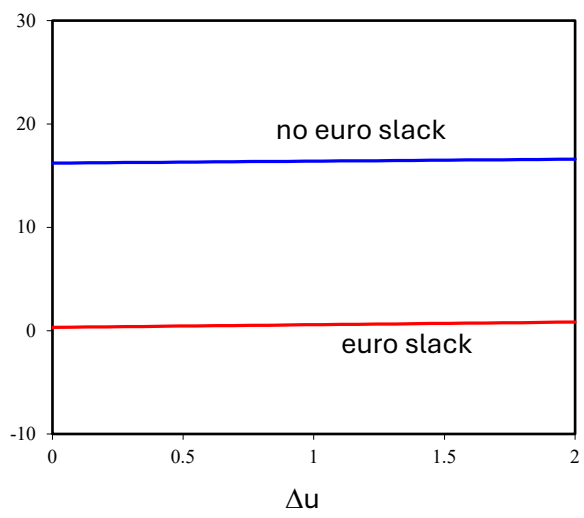
E. Δ swaps as % of bank assets



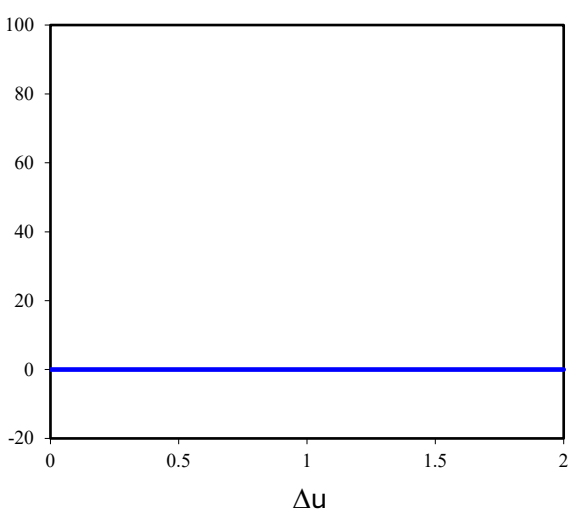
F. change CIP deviation (bps)



G. change prob. default (bps)



H. pre-shock CIP (bps)



*The shock is a drop in dollar borrowing by 15.8% plus a u-shock of Δu.