International Disaster Risk

- Supplementary Online Appendix -

NOT FOR PUBLICATION

Appendix A. Data

Appendix A.1. Macro-economic Data

Our macroeconomic series come from the quarterly database of the OECD. Our sample window starts in 1970:I and ends in 2010:IV. The following countries are in our sample: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, South Korea, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States. Data for Germany only starts in 1990:I.

We use the following series: real GDP Y, real private consumption expenditures C, employment N, employment in the business sector N_b, real investment (e.g the gross fixed capital formation) I, real private investment in the non-residential sector I_b, a productivity index Y/N, defined as real GDP divided by total employment, and a balance of payment measure of the current account CA/Y, expressed as a fraction of GDP.

These series are not available at the quarterly frequency for Austria, Greece, Hungary, and Turkey.

Table A.1 reports the standard deviations of these macroeconomic series for all countries in our sample. Table A.2 reports the within-country correlation of output and other macroeconomic aggregates. Table A.3 reports the cross-country correlation of each macroeconomic series with its U.S. counterpart.

Appendix A.2. Financial Data

Our financial series come from the monthly databases of the IMF, MSCI, and Datastream. From the IMF database, we extract nominal exchange rates s in foreign currency per U.S. dollar (when s increases, the U.S. dollar appreciates), nominal short term interest rates i, and consumer price indices. We use Treasury Bill rates whenever available, and money market rates otherwise. From the MSCI and Datastream databases, we extract stock market indices R^m. We compute real interest rates as nominal interest rates minus expected inflation, which we approximate using 12-month differences in log price indices. The maximum sample period is 1970:1–2010:12, but sample windows vary across countries.

There is no monthly CPI series for Australia and New Zealand. There is no MSCI index for Iceland, Luxembourg, and Slovakia.

Table A.4 reports summary statistics on exchange rates, interest rates, and market returns for all countries in our sample.

Table A.1: Business Cycles: Summary Statistics – OECD Countries

	$\sigma(\Delta y)$	$\sigma(\Delta c)/\sigma(\Delta y)$	$\sigma(\Delta n)/\sigma(\Delta y)$	$\sigma(\Delta n_b)/\sigma(\Delta y)$	$\sigma(\Delta i)/\sigma(\Delta y)$	$\sigma(\Delta i_b)/\sigma(\Delta y)$	$\sigma(\Delta(y-n))$	$\sigma(\Delta(ca-y))$
Australia	1.98	0.80	0.55	0.76	2.81	4.09	2.11	3.81
Austria	–	–	–	–	–	–	–	–
Belgium	1.26	0.85	0.45	0.59	3.17	3.60	–	6.61
Canada	1.65	0.99	0.71	0.93	2.80	3.73	1.29	4.48
Czech Republic	2.17	0.93	0.37	0.82	3.45	–	2.29	5.73
Denmark	1.95	1.19	0.54	–	3.96	5.26	–	–
Finland	2.97	0.87	0.53	0.57	2.69	4.08	2.78	8.90
France	1.21	0.99	0.93	0.54	2.21	2.88	1.01	2.65
Germany	1.68	1.14	0.38	–	2.75	3.20	1.59	5.24
Iceland	3.76	1.24	0.45	0.88	4.85	–	3.71	14.95
Ireland	2.90	0.94	0.58	0.66	3.66	6.89	2.39	9.55
Italy	1.70	0.91	0.60	0.64	–	–	1.70	3.70
Japan	2.31	1.03	0.33	0.36	1.89	2.57	2.21	2.98
Luxembourg	2.99	0.67	0.26	0.37	4.32	–	2.94	–
Mexico	2.87	1.18	–	–	3.25	–	–	4.29
Netherlands	2.37	0.85	0.30	0.60	4.12	4.39	2.43	5.11
New Zealand	5.48	0.63	0.25	–	1.93	3.22	4.41	6.44
Norway	2.54	1.11	0.54	–	4.74	6.46	2.58	16.32
Poland	2.43	1.02	0.73	0.72	3.91	–	–	4.32
Portugal	1.92	1.07	0.92	–	2.70	–	–	9.56
Slovakia	3.75	0.98	0.40	–	3.37	–	3.57	8.94
South Korea	3.51	1.16	0.42	0.43	3.56	4.49	3.13	8.78
Spain	1.58	0.96	1.02	–	2.91	–	–	5.91
Sweden	1.52	1.00	0.72	0.84	2.80	4.48	1.36	7.60
Switzerland	1.41	0.66	1.09	–	3.34	–	–	8.70
United Kingdom	1.93	1.13	0.42	0.55	2.89	5.86	1.76	3.44
United States	1.71	0.80	0.62	0.76	2.61	2.91	1.29	3.89

Notes: This table reports, for each country, the standard deviation of log real GDP y, along with the standard deviations of log real private consumption expenditures c, log employment n, log employment in the business sector n_b, log real investment (e.g gross fixed capital formation) i, log real private investment in the non-residential sector i_b. All these volatility measures are reported in percentage of the standard deviation of y. The table also reports the standard deviation of a log productivity index $y-n$, defined as real GDP divided by total employment, as well as the standard deviation of the current account $ca-y$, expressed as a fraction of GDP. Standard deviations are annualized (i.e, multiplied by 2) and reported in percentages. The maximum sample period is 1970.I–2010.IV, but sample windows vary across countries. Data come from the OECD database, available on Datastream.

Table A.2: Business Cycles: Within-Country Correlations – OECD Countries

	$Corr(\Delta c, \Delta y)$	$Corr(\Delta n, \Delta y)$	$Corr(\Delta n_b, \Delta y)$	$Corr(\Delta i, \Delta y)$	$Corr(\Delta i_b, \Delta y)$
Australia	0.38	0.15	0.10	0.48	0.32
Belgium	0.69	0.37	0.34	0.53	0.38
Canada	0.61	0.63	0.55	0.52	0.41
Czech Republic	0.35	0.32	0.31	0.41	–
Denmark	0.52	0.33	–	0.59	0.50
Finland	0.52	0.35	0.36	0.61	0.54
France	0.61	0.08	0.53	0.69	0.64
Germany	0.34	0.33	–	0.75	0.71
Iceland	0.49	0.25	0.13	0.32	–
Ireland	0.43	0.55	0.57	0.46	0.34
Italy	0.52	0.22	0.23	–	–
Japan	0.74	0.30	0.29	0.71	0.50
Luxembourg	0.23	0.19	0.20	0.24	–
Mexico	0.78	–	–	0.73	–
Netherlands	0.38	0.24	0.20	0.58	0.44
New Zealand	0.48	0.19	–	0.38	0.28
Norway	0.24	0.14	–	-0.03	-0.08
Poland	0.09	0.15	0.16	0.48	–
Portugal	0.59	0.06	–	0.73	–
Slovakia	0.13	0.38	–	0.37	–
South Korea	0.61	0.45	0.49	0.44	0.42
Spain	0.66	0.56	–	0.68	–
Sweden	0.56	0.44	0.47	0.68	0.52
Switzerland	0.61	0.29	–	0.51	–
United Kingdom	0.67	0.41	0.41	0.36	0.17
United States	0.66	0.59	0.67	0.75	0.62

Notes: This table reports, for each country, the correlation between the log real GDP y and log real private consumption expenditures c, log employment n, log employment in the business sector n_b, log real investment (e.g gross fixed capital formation) i, log real private investment in the non-residential sector i_b. The maximum sample period is 1970.I–2010.IV, but sample windows vary across countries. Data come from the OECD database, available on Datastream.

Table A.3: Business Cycles: Cross-Country Correlations – OECD Countries

	$(\Delta y, \Delta y^{US})$	$(\Delta c, \Delta c^{US})$	$(\Delta n, \Delta n^{US})$	$(\Delta n_b, \Delta n_b^{US})$	$(\Delta i, \Delta i^{US})$	$(\Delta i_b, \Delta i_b^{US})$	$(\Delta(y-n), \Delta(y-n)^{US})$	$(\Delta(ca-y), \Delta(ca-y)^{US})$
Australia	0.31	0.16	0.17	0.20	0.18	0.17	0.22	0.61
Belgium	0.32	0.17	0.20	0.19	0.07	0.15	–	-0.28
Canada	0.51	0.35	0.60	0.57	0.40	0.44	0.14	-0.64
Czech Republic	0.21	-0.01	0.16	0.11	0.17	–	0.11	0.28
Denmark	0.32	0.32	0.41	–	0.22	0.13	–	–
Finland	0.10	0.11	0.19	0.17	0.12	0.10	-0.11	-0.66
France	0.35	0.23	0.04	0.26	0.33	0.34	0.06	-0.05
Germany	0.45	0.12	0.15	–	0.34	0.52	0.15	-0.56
Iceland	0.13	0.17	0.26	0.15	0.33	–	-0.00	0.46
Ireland	0.21	0.34	0.34	0.39	0.34	0.21	0.07	-0.22
Italy	0.27	0.21	-0.01	0.02	–	–	-0.05	0.15
Japan	0.31	0.27	0.21	0.23	0.26	0.25	0.05	-0.77
Luxembourg	0.21	0.03	-0.00	0.15	0.02	–	0.01	–
Mexico	0.24	0.09	–	–	0.15	–	–	-0.40
Netherlands	0.27	0.11	0.25	0.33	0.16	0.15	0.11	-0.52
New Zealand	0.29	0.09	0.16	–	0.21	0.22	0.15	0.17
Norway	0.22	0.11	0.15	–	0.10	0.06	0.14	-0.72
Poland	0.31	0.01	0.10	0.07	0.30	–	–	0.28
Portugal	0.24	0.03	-0.01	–	0.18	–	–	0.37
Slovakia	0.30	0.06	0.28	–	0.12	–	0.19	0.36
South Korea	0.19	0.16	0.21	0.16	0.08	0.11	0.08	-0.49
Spain	0.19	0.32	0.27	–	0.20	–	–	0.49
Sweden	0.28	0.13	0.10	0.06	0.24	0.31	0.15	-0.79
Switzerland	0.28	0.22	0.03	–	0.30	–	–	-0.69
United Kingdom	0.36	0.30	0.38	0.48	0.26	0.19	0.15	0.40
United States	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes: This table reports, for each country, the correlation between the log real GDP y, log real private consumption expenditures c, log employment n, log employment in the business sector n_b, log real investment (e.g gross fixed capital formation) i, log real private investment in the non-residential sector i_b, log productivity index $y-n$, defined as real GDP divided by total employment, $ca-y$, expressed as a fraction of GDP, and their counterparts in the U.S.. The maximum sample period is 1970.I–2009.IV, but sample windows vary across countries. Data come from the OECD database, available on Datastream.

Table A.5 reports the fraction of total variances explained by the first four principal components of return volatilities. We consider four samples. The first sample comprises all OECD countries except Iceland, Luxembourg, and Slovakia. The second sample focuses on OECD countries for which we have such volatility data for our entire time-window. Countries in this sample are: Australia, Austria, Belgium, Canada, Denmark, France, Germany, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, and United States. The third sample focuses on G7 countries. The fourth sample uses option-implied volatilities on equity indices VIX (United States), VDAX (Germany), SMI (Switzerland), CAC (France), BEL (Belgium), AEX (Netherlands), currencies (U.S. Dollar to UK pound, U.S. Dollar to Japanese yen), along with a U.S. bond index (1 month).

Figure A.1 reports time-series of option-implied market volatility in the U.S., Germany, Switzerland and France. We use the following option-based indices: VIX (United States), VDAX (Germany), SMI (Switzerland), CAC (France), BEL (Belgium), AEX (Netherlands), currencies (U.S. Dollar to UK pound, U.S. Dollar to Japanese yen), along with a U.S. bond index (1 month).

Table A.4: Asset Prices: Summary Statistics – OECD Countries

	$\sigma(\Delta s)$	$\bar{i}$	$\sigma(i)$	$\overline{R^m}$	$\sigma(R^m)$	$\sigma(\Delta q)$	$\bar{r}$	$\sigma(r)$	$\overline{R^m - i}$	$\sigma(R^m - i)$	SR	$(\Delta q, \Delta c - \Delta c^{\star})$
Australia	10.78	8.09	3.78	9.64	20.23	10.75	2.43	3.70	1.56	21.25	0.07	-0.01
Austria	11.01	6.25	2.14	6.89	20.82	11.09	2.12	2.31				
Belgium	11.17	6.55	3.42	9.58	18.53	11.27	2.64	2.80	3.01	18.52	0.16	0.15
Canada	6.19	6.74	3.93	9.94	17.16	6.32	2.41	2.82	3.18	17.24	0.18	0.08
Czech Republic	12.29	5.70	4.11	10.83	25.91	12.16	0.83	2.23	8.55	25.27	0.34	0.06
Denmark	10.83	8.36	5.26	11.96	17.98	10.99	3.56	3.70	4.18	19.14	0.22	0.18
Finland	10.00	7.64	4.90	9.89	32.24	10.21	3.85	3.22				0.07
France	10.88	7.09	3.93	9.68	20.42	10.87	2.38	2.67	2.51	20.46	0.12	0.06
Germany	11.09	4.98	2.57	7.43	20.00	11.06	1.59	1.06	4.89	19.91	0.25	-0.08
Greece	10.02	11.54	7.74	9.72	34.01	11.63	2.81	3.67	-0.79	33.91	-0.02	
Hungary	10.54	16.14	9.09	17.31	34.63	11.19	3.49	3.32	4.48	34.40	0.13	
Iceland	13.71	12.35	7.39			13.39	4.53	4.62				0.28
Ireland	10.22	7.98	4.84	2.56	22.56	8.69	0.42	2.05	8.56	20.11	0.43	0.24
Italy	10.13	9.24	5.49	7.81	23.42	10.16	2.19	3.45	2.26	23.71	0.10	0.16
Japan	10.87	2.86	2.39	5.72	18.73	11.16	-0.05	3.03	2.84	18.70	0.15	-0.00
Luxembourg	11.17	6.03	2.68			11.25	3.76	1.77				0.06
Mexico	19.70	28.34	26.49	27.46	27.51	15.45	6.75	14.42	7.56	27.03	0.28	-0.00
Netherlands	11.14	6.29	2.84	9.92	18.41	11.37	2.23	3.69				0.13
New Zealand	11.59	9.25	5.36	4.53	19.13	11.65	3.62	4.43	-2.94	19.24	-0.15	-0.11
Norway	10.21	8.26	3.92	10.83	25.77	10.33	3.25	3.58				0.10
Poland	41.78	16.86	13.80	18.42	42.26	20.42	3.02	6.18	4.78	42.40	0.11	0.01
Portugal	10.75	11.85	5.74	4.59	20.97	11.83	2.19	3.42	-0.03	21.51	-0.00	0.25
Slovakia	9.74	5.66	1.97			10.07	-0.08	2.46				0.08
South Korea	11.35	10.46	5.97	9.30	31.28	11.35	4.15	4.74				-0.02
Spain	10.50	8.93	6.03	10.54	21.06	10.63	1.63	5.15	5.55	22.07	0.25	0.27
Sweden	10.89	7.08	4.09	14.10	22.68	11.07	2.06	3.35	7.00	22.65	0.31	0.23
Switzerland	12.02	2.95	2.41	7.47	16.84	12.10	0.85	1.59	6.03	16.72	0.36	0.09
Turkey	22.80	49.92	31.95	43.67	51.25	24.10	15.35	23.43	-11.20	54.17	-0.21	
United Kingdom	10.06	7.78	3.66	11.07	19.61	10.37	1.61	4.37	3.27	19.59	0.17	0.14

Notes: This table reports, for each country, the standard deviation of changes in nominal exchange rates $\sigma(\Delta s)$, the average $\bar{i}$ and standard deviation $\sigma(i)$ of nominal Treasury Bill rates, the average $\overline{R^m}$ and standard deviation $\sigma(R^m)$ of MSCI stock market returns. The table also reports the following sets of moments for real variables: the standard deviation of changes in real exchange rates $\sigma(\Delta q)$, the average $\bar{r}$ and standard deviation $\sigma(r)$ of nominal Treasury Bill rates, the average $\overline{R^m - i}$, standard deviation $\sigma(R^m - i)$, and Sharpe ratios SR of MSCI stock market excess returns. The last column reports the correlation $(\Delta q, \Delta c - \Delta c^{\star}$ between real changes in exchange rates and relative consumption growth at quarterly frequency. Averages and standard deviations are annualized (e.g multiplied by 12 and $\sqrt{12}$ respectively) and reported in percentages. Data are monthly (except for consumption). The maximum sample period is 1970:1–2010:12, but sample windows vary across countries. Data come from the IMF and MSCI databases, available on Datastream.

Table A.5: Volatility Indices: Principal Components

% Var. explained by Factors	1	2	3	4
Realized Vol, 27 countries	40.99	16.49	8.17	6.28
Realized Vol, 15 countries	42.95	9.10	7.55	5.94
Realized Vol, 7 countries	47.41	15.17	11.23	9.59
Implied Vol, 9 series	90.19	7.12	1.32	0.67

Notes: This table reports the fraction of total variances explained by the first four principal components of return volatilities. We consider three samples. The first sample comprises all OECD countries for which we have MSCI equity returns at daily frequency. We build monthly volatility series by computing standard deviations of daily equity returns over each calendar month. Countries in this sample are all the countries in Table A.4 except Iceland, Luxembourg, and Slovakia. The second sample focuses on OECD countries for which we have such volatility data for all our time-window. Countries in this sample are: Australia, Austria, Belgium, Canada, Denmark, France, Germany, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, and United States. The third sample focuses on G7 countries. The fourth sample uses option-implied volatilities on equity indices VIX (United States), VDAX (Germany), SMI (Switzerland), CAC (France), BEL (Belgium), AEX (Netherlands), currencies (U.S. Dollar to UK pound, U.S. Dollar to Japanese yen), along with a U.S. bond index (1 month). Monthly Data. Realized equity return volatilities in 27 or 15 OECD countries, 1/1970–12/2009. Implied Volatilities on bond, equity and currency returns, 1/1995–12/2009

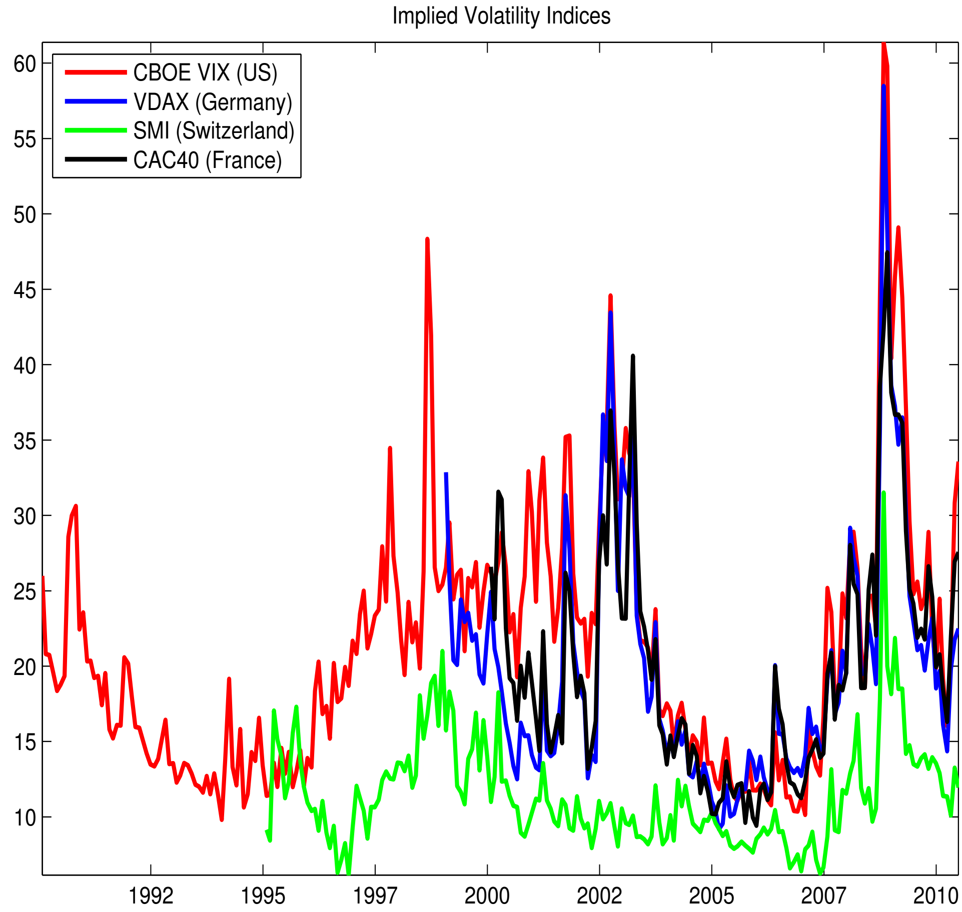

Figure A.1: Option-Implied Stock Market Volatility

This figure plots time-series of option-implied stock market volatility in the U.S., Germany, Switzerland and France.

Appendix B. VARs

Following Bloom (2009), our VARs contain the following variables in order: market returns, volatility, and the macroeconomic series under study. We obtain similar results when we add consumer price indices and short-term interest rates. To obtain stationary series, we use differences in log variables. To account for seasonality, we use 12 lags for monthly series when computing these log differences. For variables expressed in percentages (market returns and interest rates), we do not take logs. We obtain similar results when using HP filters on levels.

We use 12 lags in the estimation of our monthly VARs. We use a simple Cholesky decomposition to obtain structural residuals. Volatility series are ordered after market returns to focus on a volatility shock that is orthogonal to market returns. Standard errors on impulse response functions are obtained by bootstrapping 500 times the VAR residuals. Standard errors correspond to 5 and 95 percentiles.

Figures B.2 and B.3 report the impulse response functions of industrial production and unemployment rates to a shock on average volatility. Each panel focuses on a different country. Dotted lines correspond to standard errors.

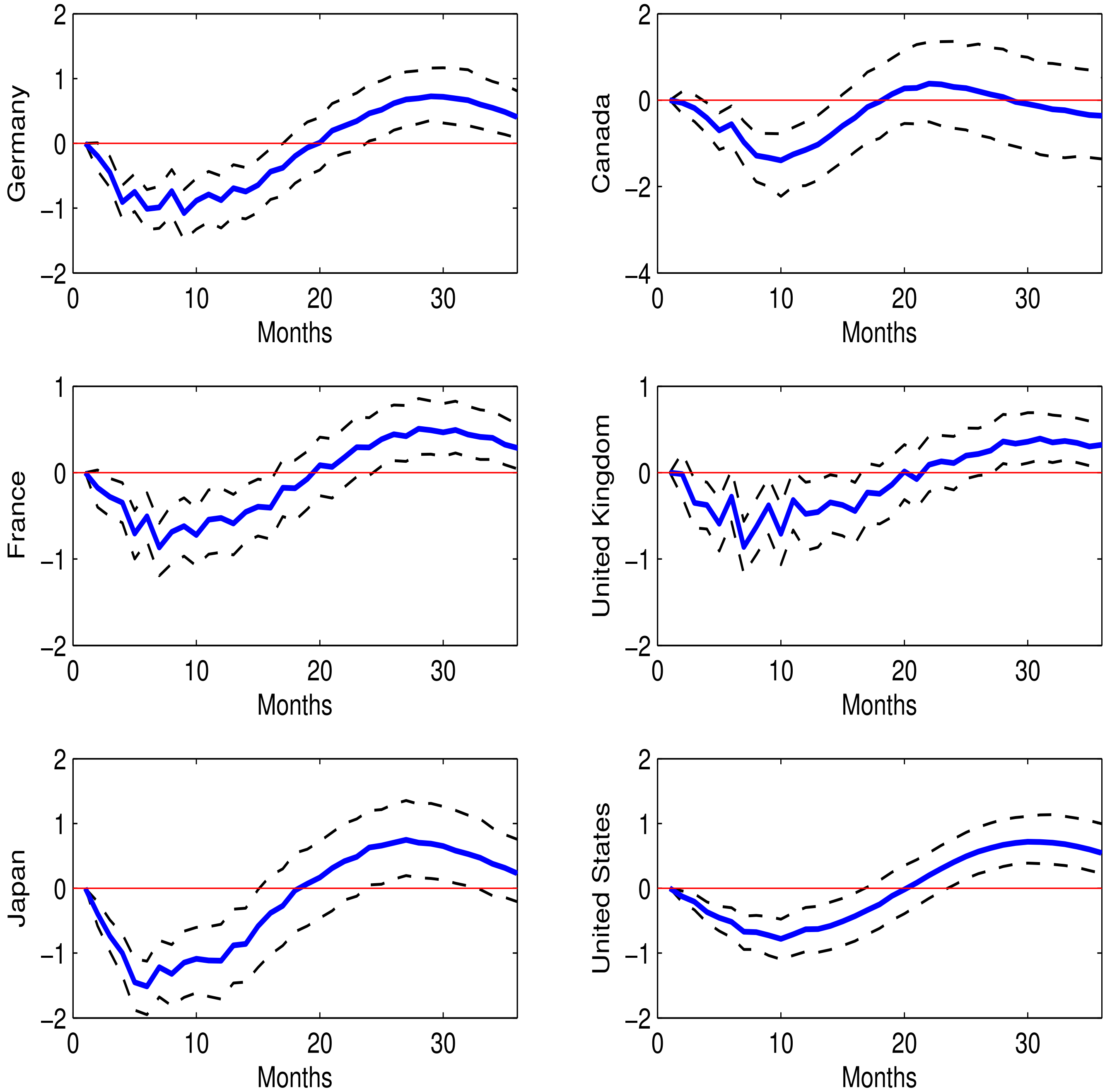

Figure B.2: Response of Industrial Production to a Shock on Average Realized Volatility

This figure plots the impulse response functions of industrial production to a one-standard deviation shock on average volatility in the following G7 countries: Canada, France, Germany, Japan, United Kingdom, and United States. Data are monthly. The sample is 1970.1 – 2009.12, except for the United Kingdom (1971.1 – 2009.12) and Canada (1995.1 – 2009.12). Volatility measures correspond to the standard deviations of equity returns over calendar months. The average volatility is the mean of these different standard deviations over the G7 countries. VARs contain the following variables: market returns, volatility, and industrial production.

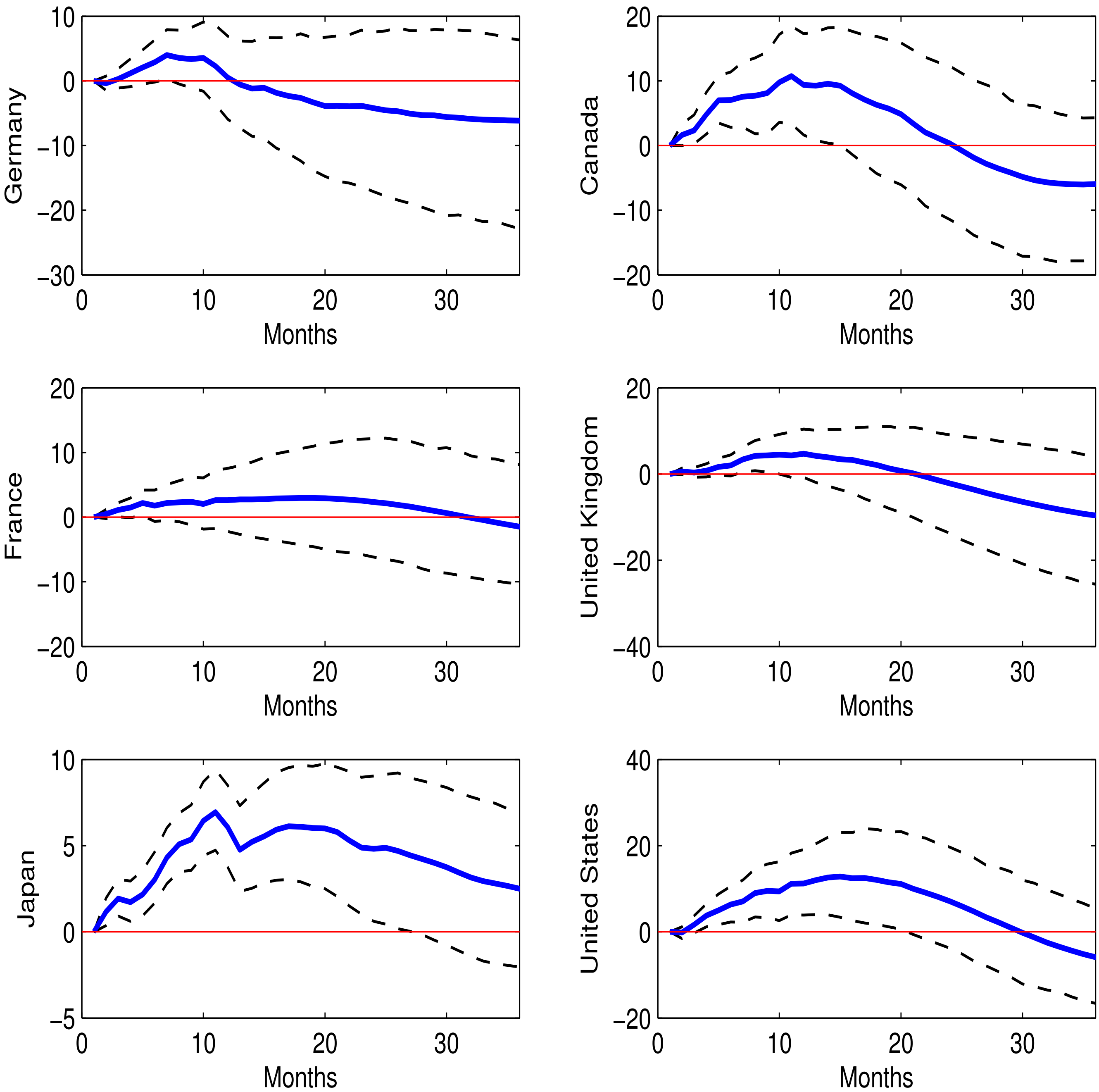

Figure B.3: Response of Unemployment to a Shock on Average Realized Volatility

This figure plots the impulse response functions of unemployment rates to a one-standard deviation shock on average volatility in the following G7 countries: Canada, France, Germany, Japan, United Kingdom, and United States. Data are monthly. The sample is 1970.1 – 2009.12, except for France (1978.1 – 2009.12) and Germany (1992.1 – 2009.12). Volatility measures correspond to the standard deviations of equity returns over calendar months. The average volatility is the mean of these different standard deviations over the G7 countries. VARs contain the following variables: market returns, volatility, and unemployment rates.

Appendix C. Computational Method

The method used to solve the model is exactly as in Gourio (2009). Given parameter values, we apply this method to solve for each country's allocation. We then obtain the stochastic discount factor for each country, then compute asset prices in each country and finally the exchange rate as the ratio of the stochastic discount factors.

Specifically, the Bellman equation for each country is

$$\begin{aligned}
W(K,z,p) &= \max_{C,I,N}\left\{\left(C^{\upsilon}(1-N)^{1-\upsilon}\right)^{1-\gamma}+\beta\left(E_{p',z',x'}W(K',z',p')^{\frac{1-\theta}{1-\gamma}}\right)^{\frac{1-\gamma}{1-\theta}}\right\}, \\
s.t. &: C+I\leq z^{1-\alpha}K^{\alpha}N^{1-\alpha}, \\
K' &= \left((1-\delta)K+\phi\left(\frac{I}{K}\right)K\right)(1-x'b_k), \\
\log z' &= \log z+\mu+\sigma\varepsilon'+x'\log(1-b_{tfp}).
\end{aligned}$$

This can be simplified as follows: write $W(K,z,p)=z^{\upsilon(1-\gamma)}g(k,p)$ with

$$\begin{aligned}
g(k,p) &= \max_{c,i,N}\left\{\begin{array}{c} c^{\upsilon(1-\gamma)}(1-N)^{(1-\upsilon)(1-\gamma)} \\ +\beta e^{\mu\upsilon(1-\gamma)}\left(E_{p',\varepsilon',x'}e^{\sigma\varepsilon'\upsilon(1-\theta)}\left(1-x'b_{tfp}\right)^{\upsilon(1-\theta)}g\left(k',p'\right)^{\frac{1-\theta}{1-\gamma}}\right)^{\frac{1-\gamma}{1-\theta}}\end{array}\right\}, \\
s.t. &: c+i=k^{\alpha}N^{1-\alpha}, \\
k' &= \frac{(1-x'b_k)\left((1-\delta)k+\phi\left(\frac{i}{k}\right)k\right)}{e^{\mu+\sigma\varepsilon'}\left(1-x'b_{tfp}\right)}.
\end{aligned}$$

Because we take a power $\frac{1}{1-\gamma}$ of the value function, the max needs to be transformed in a min if $\gamma>1$.

This Bellman equation can then be easily solved by discretizing i and k. (See Gourio (2009) for details.) Given g, we have the value (utility) function $V(K,z,p)=W(K,z,p)^{\frac{1}{1-\gamma}}=z^{\upsilon}g(k,p)^{\frac{1}{1-\gamma}}$. We also obtain the policy functions $C=zc(k,p)$, $I=zi(k,p)$, $N=N(k,p)$, and the output policy function $Y=zk^{\alpha}N(k,p)^{1-\alpha}$. Because these policy functions are defined on a discrete grid, we use interpolation in the simulations and impulse responses to obtain more accurate results. (Linear or spline interpolations yield nearly the same results.)

We next obtain the stochastic discount factor, which is given by the standard formula:

$$M_{t,t+1}=\beta\left(\frac{C_{t+1}}{C_t}\right)^{\upsilon(1-\gamma)-1}\left(\frac{1-N_{t+1}}{1-N_t}\right)^{(1-\upsilon)(1-\gamma)}\left(\frac{V_{t+1}}{E_t\left(V_{t+1}^{1-\theta}\right)^{\frac{1}{1-\theta}}}\right)^{\gamma-\theta},$$

and hence the SDF between two states $s=(k,p)$ and $s'=(k',p')$ is:

$$\begin{aligned} M(s,s',\varepsilon',x') &= \beta\left(\frac{z'c(k',p')}{zc(k,p)}\right)^{\upsilon(1-\gamma)-1}\left(\frac{1-N(k',p')}{1-N(k,p)}\right)^{(1-\upsilon)(1-\gamma)}\left(\frac{z'^{\upsilon}g(k',p')^{\frac{1}{1-\gamma}}}{E_{z',p',x'}\left(z'^{\upsilon(1-\theta)}g(k',p')^{\frac{1-\theta}{1-\gamma}}\right)^{\frac{1}{1-\theta}}}\right)^{\gamma-\theta} \\ &= \beta\left(\frac{z'}{z}\right)^{(\gamma-\theta)\upsilon+\upsilon(1-\gamma)-1}\left(\frac{c(k',p')}{c(k,p)}\right)^{\upsilon(1-\gamma)-1}\times ... \\ & \quad ...\left(\frac{1-N(k',p')}{1-N(k,p)}\right)^{(1-\upsilon)(1-\gamma)}\left(\frac{g(k',p')^{\frac{1}{1-\gamma}}}{E_{z',p',x'}\left(\left(\frac{z'}{z}\right)^{\upsilon(1-\theta)}g(k',p')^{\frac{1-\theta}{1-\gamma}}\right)^{\frac{1}{1-\theta}}}\right)^{\gamma-\theta}. \end{aligned}$$

Computing the expectation of this discount factor gives us the risk-free rate, $R_f(k,p)$. The equity is simply a claim to the stream $\{D_t\}$, with $D_t = Y_t^{\lambda}$. Let P_t denote its price, which satisfies the standard recursion:

$$P_t = E_t\left(M_{t,t+1}\left(P_{t+1}+D_{t+1}\right)\right).$$

Note that D_t can be written as $D_t = z_t^{\lambda} d(k_t,p_t)$. Hence, we can rewrite the firm value recursion as: $P_t = z_t^{\lambda} f(k_t,p_t)$, with

$$f(k,p) = E_{s'|s}\left(M(s,s')\times\left(\frac{z'}{z}\right)^{\lambda}\left(d(k',p')+f(k',p')\right)\right), \tag{C.1}$$

which can be solved simply by iterating starting with an initial guess $f(k,p)=0$.

We solve using exactly the same method for the other country, then simulate the two countries given that disasters (and hence disaster risk) is perfectly correlated across countries, and given the assumed correlation of ε_t and $\varepsilon_t^{\star}$. The exchange rate satisfies

$$\frac{Q_{t+1}}{Q_t} = \frac{M_{t+1}^{\star}}{M_{t+1}},$$

where a higher Q corresponds to a depreciation of the home currency. The initial value of Q is set to 1, which is immaterial for our purposes.

To obtain the model statistics, we simulate 100 samples of length 50,000, starting at the nonstochastic steady-state levels of capital in each country, and cut off the first 1,000 periods. We use such long samples because some statistics suffer from small sample bias, see the discussion in the paper. We simulate samples with or without disasters, see the discussion in the paper.

The Matlab(c) programs are available on the author's web pages.

Appendix D. Robustness

In this section, we discuss briefly several variations and extensions of our model. Our discussion highlights the main changes only.

Constant disaster risk. The model with positive, but constant probability of disaster, has very similar implications to the model with only TFP shocks. The key differences regard the mean returns on equity, on the risk-free asset, and on the carry trade: the equity premium is higher, the mean risk-free rate is lower, and the mean carry trade excess return is larger. They remain substantially smaller than in our benchmark model, however, because the time-varying risk of disaster creates an additional risk factor. Moreover, all volatilities and correlations are extremely similar to the RBC model, since TFP shocks are the only source of fluctuations (at least in samples without disasters).

Consumption Comovement and correlation of TFP and disaster risk shock. Our model implies that consumption initially rises when the probability of disaster goes up. This may sound counterintuitive, because most recessions show a fall in consumption (even if it is much smaller than that of investment or durable goods purchases). There are various theoretical reasons why consumption may actually fall when the disaster probability rises, but we think that the most important is that increases in the disaster probability are not purely exogenous events but actually occur when bad (and uncertain) news lead people to become pessimistic. A simple way to capture this in the model is to assume that TFP shock and shocks to the disaster probability are correlated. Figure D.4 plots the impulse response to the two combined shocks. Evidently, the comovement puzzle is much attenuated in this case.

Samples including disasters. We also report in the appendix the statistics discussed in the section above, but calculated in long samples which include disaster realizations. Computing the statistics in that way does not affect our main results. Disaster realizations create additional volatility in macroeconomic quantities (except for employment which is unaffected by disasters in our calibration), and because disasters are worldwide they significantly increase the comovement of quantities. The mean excess return on equity is reduced by about 26bp per quarter, or 1% per year, in the more risky country, but the equity premium remains about 6% per year: sample selection does not drive our results. Similarly, the mean excess carry trade return is reduced slightly from 110bp to 98bp per quarter. The equity return and the exchange rates are slightly more volatile, since they move sharply when a disaster occurs. Finally, the correlation of the carry trade return with consumption in the home country turn from negative (-.12) to positive (.18), reflecting better the underlying risk of the carry trade.

Small sample bias. Our statistics are computed by averaging across 100 very long samples (50,000 periods each). The motivation for running simulations with very long samples is that one important statistic that we report, the slope of the standard UIP regression, appears to be affected by an important small sample bias. If one simulates samples of length 200 or 300 periods, all of our statistics are the same, except for this regression slope, which is -4.02 in the RBC model and -5.06 in our benchmark. In contrast, in long samples the slope is 0.99 the RBC model and -2.57 in our benchmark.[1]

Default of government bonds. Our benchmark model assumes that government bonds are risk-free assets. In reality government bonds are likely to default partially during disasters. Here, we introduce default and assume that government bonds default half of the time during disasters. Note that because government bonds do not play any allocative role in this economy, changing their characteristics does not affect quantities or the exchange rate at all. The only effect is to change the properties of the "risk-free" analog. Because government bonds are now more risky, the equity premium is now smaller (158bp vs. 182bp in the benchmark), but it remains quite significant. The volatility of the short rate becomes even lower (0.65% vs. 1.25% in the benchmark). For this calibration, the sort on interest rate is not affected, i.e. the low interest rate country remains the more risky country. However, if the recovery rate on the government bond in disaster is very low for one country, that country may have higher interest rates, which would affect the determination of which countries are more risky.

Recursive utility vs. expected utility. Recursive utility allows for a clear separation between the coefficient of relative risk aversion (θ) and the elasticity of intertemporal substitution (IES $1/\sigma$). This section discusses how our results are affected if we change either the risk aversion coefficient, or the IES.

In our model, risk aversion determines both the magnitude of risk premia and the size of the response of quantities to a disaster risk shock (since the importance of disaster risk depends on risk aversion). Hence, solving the model with expected utility, with same IES but a lower risk aversion ($\theta = .5$ so that $\theta = \sigma$, and we are in the familiar case of expected utility) yields the same qualitative effects, but they are much reduced in size. For instance, the equity premium is 34bp per quarter (182bp in the benchmark), and the cross-correlation of investment is 0.38 (0.59 in the benchmark).

In contrast, changing the IES leads to a qualitative change in behavior of the model. If the IES is less than unity, the model implies that an increase in disaster risk leads to a boom of investment, employment and output. We conclude that an IES above unity is critical for our results. It should be noted though that not all our results depend on this assumption. In particular the failure of the UIP condition is independent of the IES larger than one.

Higher TFP volatility. As discussed the previous section, our model counterfactually implies that low interest rate countries should be more volatile. Panel I of Table **??** reveals, however, that low interest rate

[1] Alvarez et al. (2009) also report an important small sample bias.

countries also have lower TFP volatility, which may explain part of the result. In an experiment, we set the volatility of TFP shocks to .007 in the low interest rate country and .015 in the high interest rate country, roughly in line with our data. Of course, as a result the high interest rate country quantities become significantly more volatile, reconciling our model and data. Because TFP has much less effect on asset prices than disaster risk, however, our model remains at odds with the return volatility. Adding long-run productivity shocks in the manner of Bansal and Yaron (2004) may help in this respect.

Correlation of TFP shocks. Our results rely on an assumption for the correlation of TFP shocks. However this correlation is difficult to measure, due to time-aggregation, lags and other issues. For robustness, we discuss here how our results are affected if we pick a higher correlation. First, the cross-country correlation of quantities becomes larger: for instance, the correlation of consumption growth rates goes from 0.32 to 0.49. Exchange rates become slightly less volatile, consistent with intuition, but overall this change makes little difference to asset prices and exchange rates.

Idiosyncratic disaster risk. We focus in the paper on worldwide disasters, which affect all countries simultaneously; as we discussed in section 2, this is required to account for the documented properties of the carry trade. Of course, there are also "idiosyncratic disaster", i.e. large negative shocks which occur in only one country. In our model, if a country has a large disaster, its output, consumption, investment, and stock prices drop sharply, while the interest rate and employment are unaffected, and the exchange rate appreciates (assuming complete markets). An increase in disaster risk, on the other hand, would lead to a decline in investment, employment, output, stock prices, and the interest rate, and an increase in consumption and the exchange rate on impact. If capital was mobile across countries, capital would flow out of the now-more risky country.

Different dynamics of disasters. In our calibration, we use a very simple modeling of disasters: they are instantaneous, permanent, and the capital destruction equals the TFP destruction. However, one may want to model disasters as graduals, or transitory, and one may want to assume that capital destruction or TFP destruction plays a more prominent role. The reader is refereed to Gourio (2009) for a discussion of how these different assumptions affect the results.

Table D.6: Business Cycle Statistics - Robustness

	Standard Deviations								Cross-country Correlations			
	$\sigma(\Delta c)$	$\sigma(\Delta i)$	$\sigma(\Delta n)$	$\sigma(\Delta y)$	$\sigma(\Delta c^\star)$	$\sigma(\Delta i^\star)$	$\sigma(\Delta n^\star)$	$\sigma(\Delta y^\star)$	$(\Delta c, \Delta c^\star)$	$(\Delta i, \Delta i^\star)$	$(\Delta n, \Delta n^\star)$	$(\Delta y, \Delta y^\star)$
Benchmark	1.18	3.97	0.66	1.62	1.14	3.45	0.53	1.60	0.36	0.51	0.67	0.32
RBC	1.10	2.91	0.37	1.58	1.10	2.91	0.37	1.58	0.30	0.30	0.30	0.30
high TFP 2	1.18	3.95	0.66	1.62	1.89	5.30	0.74	2.69	0.33	0.42	0.55	0.31
w disaster	4.20	5.73	0.66	4.40	3.35	4.74	0.53	3.58	0.75	0.68	0.67	0.71
constant p	1.10	2.93	0.37	1.58	1.10	2.92	0.37	1.58	0.30	0.30	0.30	0.30
low risk aversion	1.13	3.36	0.51	1.59	1.12	3.18	0.46	1.59	0.33	0.42	0.55	0.31
low IES	1.23	2.91	0.46	1.50	1.21	2.70	0.38	1.49	0.33	0.50	0.75	0.32
high corr TFP	1.18	3.97	0.66	1.62	1.14	3.44	0.53	1.60	0.63	0.71	0.80	0.61
default on debt	1.18	3.95	0.66	1.62	1.14	3.44	0.53	1.60	0.36	0.51	0.67	0.32

Notes: This table reports the standard deviations of log differences in consumption, investment, labor and output, along with the cross-country correlation of these variables. Panel I reports moments from the actual data. We use series from the OECD database, available on Datastream. Data are quarterly. The maximum sample period is 197.I–2009.IV, but sample windows vary across countries.

Table D.7: Financial Statistics - Robustness

	Averages				Autocorr.		Standard Deviations				Cross-country Corr.	
	$E(r^e)$	$E(r^f)$	$E(r^{e\star})$	$E(r^{f\star})$	$Ac(r^f)$	$Ac(r^{f*})$	$\sigma(r^e)$	$\sigma(r^f)$	$\sigma(r^{e\star})$	$\sigma(r^{f\star})$	$(r^e, r^{e\star})$	$(r^f, r^{f\star})$
Benchmark	5.64	1.85	2.74	2.40	0.95	0.95	15.12	3.06	8.31	1.99	0.89	0.98
RBC	0.17	3.26	0.17	3.26	0.99	0.99	3.32	0.18	3.32	0.18	0.30	0.28
high TFP 2	5.61	1.87	3.04	2.32	0.95	0.95	14.96	3.01	9.54	1.98	0.77	0.96
w disaster	4.67	1.85	1.99	2.40	0.95	0.95	15.03	3.01	9.00	1.95	0.89	0.98
constant p	3.02	3.23	1.52	3.26	0.99	0.99	3.39	0.18	3.36	0.18	0.30	0.28
low risk aversion	1.50	2.59	1.14	2.79	0.95	0.95	5.50	1.72	4.76	1.28	0.64	0.96
low IES	1.18	2.91	0.92	3.12	0.95	0.95	4.29	1.70	3.88	1.32	0.57	0.94
high corr TFP	5.65	1.85	2.74	2.40	0.95	0.95	15.08	3.05	8.29	1.98	0.92	0.99
default on debt	5.09	2.41	2.38	2.77	0.95	0.95	14.50	1.91	7.93	1.21	0.88	0.96

Notes: This table reports the averages and standard deviations of log equity excess returns and log short-term interest rates, along with the cross-country correlation of these variables and the first order autocorrelation of risk-free rates. Data are from the IMF and MSCI databases, available on Datastream. See Table 1 in the paper for more details.

Table D.8: Real Exchange Rates - Robustness

	Moments of Δq				Corr. Δq and		
	$\sigma(\Delta q)$	$Ac(\Delta q)$	$S(\Delta q)$	$K(\Delta q)$	$r^m - r^{m,\star}$	$r^f - r^{f,\star}$	$\Delta c - \Delta c^\star$
Benchmark	10.71	0.71	0.07	2.73	0.98	-0.13	0.66
RBC	6.27	0.75	0.00	-0.06	1.00	0.19	1.00
high TFP 2	12.57	0.72	0.03	1.45	0.98	-0.08	0.77
w disaster	10.80	0.71	-0.33	3.20	0.98	-0.04	0.68
constant p	6.35	0.75	0.00	-0.04	1.00	0.19	1.00
low risk aversion	2.14	0.76	0.00	-0.03	1.00	0.11	0.99
low IES	0.86	0.79	0.00	-0.02	0.91	0.28	0.95
high corr TFP	9.79	0.70	0.08	3.73	0.98	-0.16	0.58
default on debt	10.66	0.71	0.06	2.59	0.99	-0.11	0.66

Notes: This table reports the averages, standard deviations, annual autocorrelation, skewness and kurtosis of changes in log real exchange rates, along with the cross-country correlation of changes in log real exchange rates with cross-country differences in real equity returns, real risk-free rates, real consumption growth, real output growth, real investment growth, and employment growth rates. For actual data, we use series from the IMF, OECD and MSCI databases, available on Datastream. See Table 1 in the paper for more details.

Table D.9: Carry Trade Excess Returns - Robustness

	Moments of rx		Corr. rx and						UIP	
	$E(rx_{t+1})$	$\sigma(rx_{t+1})$	$\overline{\Delta c}$	$\overline{\Delta i}$	$\overline{\Delta n}$	$\overline{\Delta y}$	$\overline{r^m_{t+1}}$	$\overline{\sigma_{r^m_{t+1}}}$	β_{UIP}	R^2_{UIP}
Benchmark	2.36	10.87	-0.24	0.42	0.52	0.15	0.62	-0.61	-2.90	0.04
RBC	0.00	6.26	0.00	0.00	0.00	0.00	0.00	0.02	1.00	0.00
high TFP 2	2.27	12.78	-0.21	0.21	0.30	0.01	0.42	-0.47	-2.82	0.03
w disaster	1.95	10.94	0.07	0.41	0.48	0.22	0.61	-0.57	-1.91	0.02
constant p	0.17	6.43	0.00	0.01	0.00	0.00	0.00	0.05	1.00	0.00
low risk aversion	-0.07	2.13	-0.04	0.07	0.09	0.02	0.09	-0.12	-0.18	0.00
low IES	-0.24	0.83	-0.05	0.11	0.14	0.04	-0.10	0.16	0.36	0.02
high corr TFP	2.35	9.93	-0.24	0.43	0.56	0.15	0.68	-0.68	-2.92	0.05
default on debt	2.36	10.83	-0.23	0.41	0.52	0.15	0.61	-0.61	-2.92	0.04

Notes: This table reports the averages and standard deviations of carry trade excess returns, along with the cross-country correlation of these excess returns with the average (across countries) of macroeconomic and financial variables: real consumption growth, real investment growth, real employment growth, real GDP growth, real stock market returns, and the changes in stock market return volatilities. The last two columns report the UIP slope coefficient and the associated R^2. See Table 1 in the paper for more details.

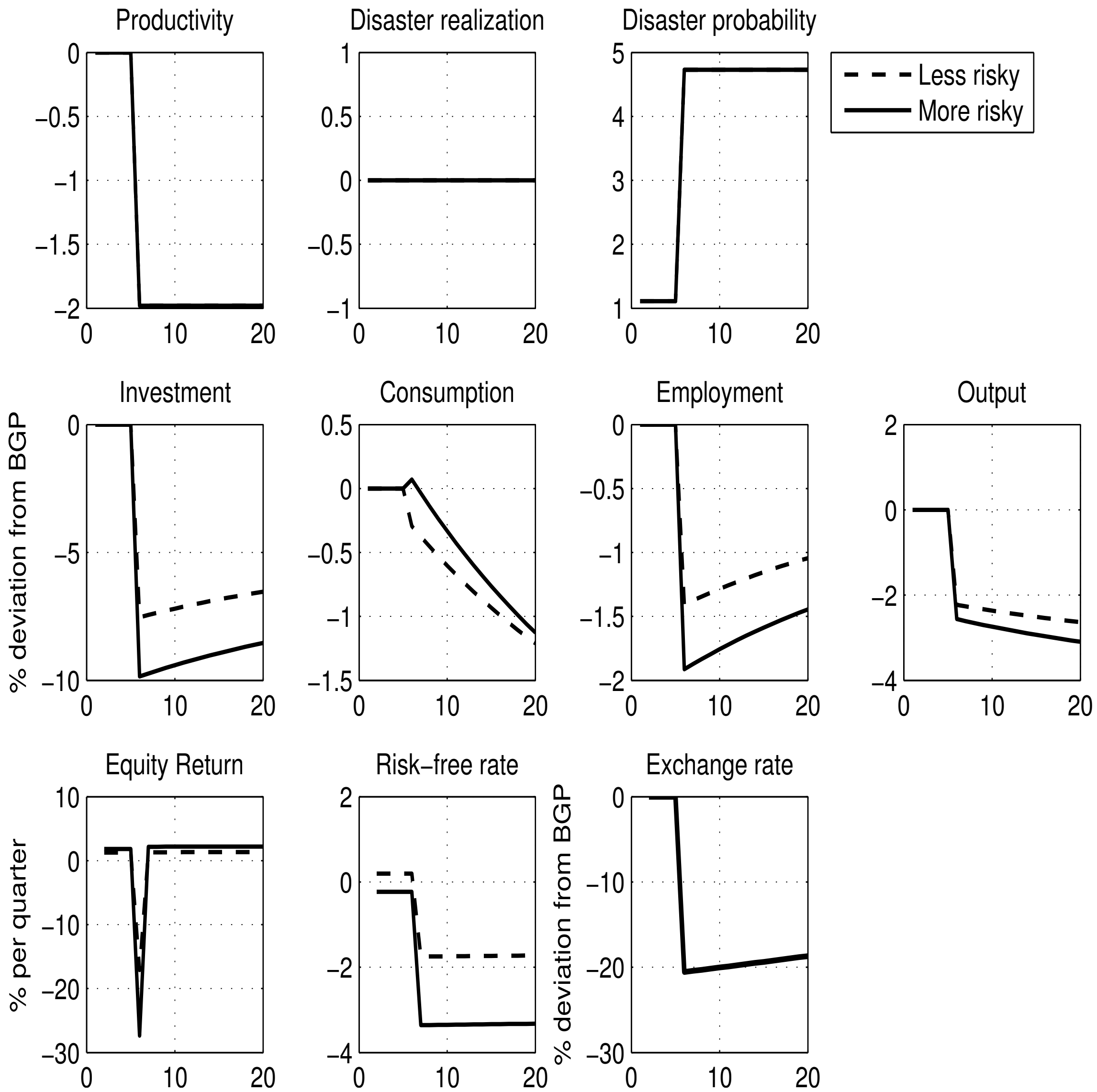

Figure D.4: **Impulse Response Functions to a Disaster probability shock combined with a TFP shock**: This figure presents the impulse response functions of macroeconomic and financial variables to a disaster probability shocks that occurs simultaneously with a negative TFP shock. Quantities are in percentage deviation from the balanced growth path. Asset returns are in percentage change per quarter. The disaster probability is in percentage point, and the disaster realization is an indicator function.

Appendix E. Interest Rate Regression

We examine in our model two international finance facts that Engel (2010) describes. First, higher than average real interest rates predict short term currency excess returns. Second, when a country's relative real interest rate rises above its average, its currency tends to be stronger than average.

We follow Engel (2010) and run the following two regressions for $j = 1, ..., 40$:

$$r_{t+j-1} - r^*_{t+j-1} = \alpha_{rj} + \beta_{rj}\left(r_t - r^*_t\right) + \varepsilon_j, \tag{E.1}$$

$$q_{t+j} - q_{t+j-1} = \alpha_{qj} + \beta_{qj}\left(r_t - r^*_t\right) + \epsilon_j. \tag{E.2}$$

Note that these regressions are slightly different from those of Engel (2010) in two ways. Engel (2010) considers expected values ($\hat{E}_t\left(r_{t+j-1} - r^*_{t+j-1}\right)$ and $\hat{E}_t\left(q_{t+j} - q_{t+j-1}\right)$) as dependent variables, where $\hat{E}_t$ denotes the forecast of a variable based on a VAR containing the real exchange rate, the nominal interest rate and inflation. In our model all variables are in real rather than nominal terms and we are thus unable to run the exact same VAR as in Engel (2010). Nonetheless this difference should not qualitatively alter the results. In contrast to Engel (2010) we do not consider the regression of the real exchange rate on the interest rate in levels since the exchange rate in our model is non-stationary.

Engel (2010) finds that β_{rj} tends to be positive at all horizons and is asymptotically going to zero over time. For $j = 1$, Equation (E.2) is the standard UIP regression with the well known fact that $\beta_{q1} < 0$. With increasing j, β_{qj} tends to eventually become positive.

All model specifications imply positive β_{rj}, as in the data. The benchmark case is converging faster to zero than the standard RBC and equal risk cases. Yet, Engel (2010) reports even faster convergence to zero in the data.

Our benchmark model delivers a negative slope coefficient β_{qj} at short horizons. While the standard RBC and equal risk models do not reproduce the UIP puzzle. The benchmark model, however, is not able to generate the sign reversal of the β_q coefficient.

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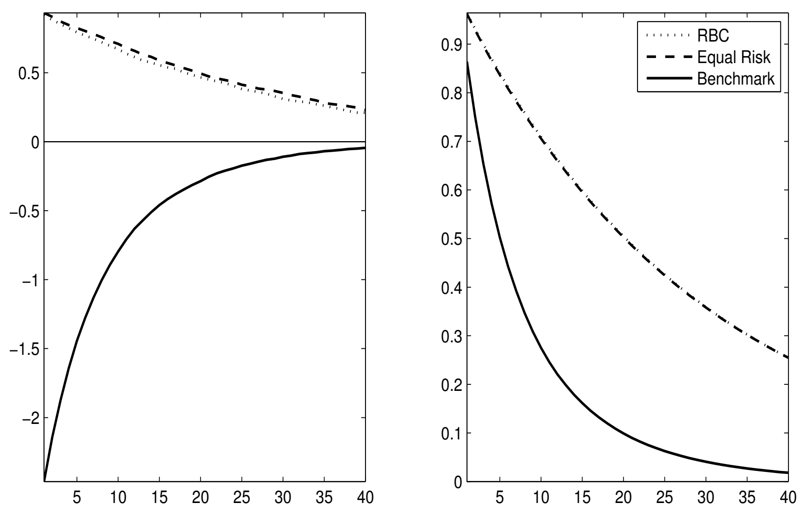

Figure E.5: **IUIP Tests at Long Horizons**: This figure reports the slope coefficients (β_{rj}, in the right panel, and β_{qj}, in the left panel) of the following regressions at different horizons $j = 1, ..., 40$: $r_{t+j-1} - r^*_{t+j-1} = \alpha_{rj} + \beta_{rj}\,(r_t - r^*_t) + \varepsilon_j$, and $q_{t+j} - q_{t+j-1} = \alpha_{qj} + \beta_{qj}\,(r_t - r^*_t) + \epsilon_j$. Data are simulated using three different models: standard RBC, disaster risk with equal risk, and our benchmark disaster risk model.