EUROPEAN CENTRAL BANK

EUROSYSTEM

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Assessing capital-based macroprudential policy using an integrated Early Warning (EW-) GVAR Model*

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* The views expressed are those of the authors and do not necessarily reflect those of the ECB or the ESRB.

Motivation

- We develop a model that can help assess when capital-based macroprudential measures should be implemented + help calibrate them
- Distinguish between costs and benefits of potential measures
  - Benefit: reduction in the probability of systemic banking sector crises
  - Cost: potential output loss due to implementation of measures
- Shock to capital ratios likely to come along with endogenous response of macro-financial variables included in logistic early warning models
- Integrate an Early Warning (EW) Model with a Global Vector Autoregressive (GVAR) model
- Why: to endogenise predictor variables contained in early warning model

The integrated Early Warning (EW-) GVAR Model

MCS-GVAR
Nominal GDP
Inflation
Equity prices
House prices
Loan volumes
Loan interest rates
Capital ratios

→

Shock simulation output
Responses of endogenous variables to exogenous shocks to capital ratios are fed through EW model

Logistic EW model

… to compute forward looking conditional probabilities of systemic banking crises

- Model accounts for direct effects of higher bank capitalization and for feedback effects from responses of macro-financial variables
- It helps shape our understanding of transmission channels of capital-based measures
- Can be used to analyze cross-country spillover effects
- Has some elements of reciprocity built-in

Contribution

1) Develop an integrated framework with consistent multi-country macro / multi-banking system model at its basis
   - many existing models based on area aggregates (euro area) → risk: aggregation (attenuation) bias
   - Explicit channels for cross-border transmission of capital ratio shocks, which existing models do not capture
2) Concerning identification: propose to derive bounds in terms of credit supply reaction
   - Distinguish between how banks get to higher capital ratios
   - Do not attempt to provide point estimates of reaction of lending and macro variables to capital ratio shock, but rather derive bounds
   - Do not make overly conservative assumptions about funding cost impact and pass-through to lending spreads

Overview

Data

- Sample of 18 EU countries, 1980Q2-2014Q4
- Dependent variable in EW model:
  - Indicator of systemic financial stress events from the database recently created by Duprey, Klaus and Peltonen (2015)
  - Evaluation horizon: 7-12 quarters prior to the crisis
- Independent variables in EW and basis for GVAR:
  - BIS long series on domestic bank credit and total credit to the private non-financial sector
  - Macro-financial indicators: GDP, inflation, stock prices, house prices (from various sources, sourced through Haver Analytics)
  - Banking sector capitalization (BSI/OECD)
- Output cost of a banking crisis:
  - Average cost of a banking crisis obtained from Laeven and Valencia (2012)
  - Cumulative sum of the differences between actual and trend real GDP over the period of one year, expressed as a percentage of trend real GDP → output loss due to the crisis

Crisis dates and costs of banking crises

	Crisis dates	Average output loss associated with a banking crisis (in % of GDP)
Austria	2008q1-2010q3	14
Belgium	1990q3-1993q3, 2007q4-2013q1	19
Germany	1980q2-1982q1, 1992q3-1994q3, 2001q4-2003q3, 2008q3-2010q2	11
Denmark	1992q3-1993q3, 2008q1-2010q2	36
Estonia	—	—
Spain	1992q3-1992q3, 2008q1-ongoing	49
Finland	1990q4-1996q2, 2001q1-2001q3, 2008q4-2010q3	70
France	1991q2-1993q1, 2008q1-2012q3	23
Greece	2008q1-ongoing	43
Ireland	2008q1-ongoing	106
Italy	1991q3-1996q3, 2008q1-ongoing	32
Luxembourg	2008q2-ongoing	36
Netherlands	1980q2-1983q3, 2002q2-2004q2, 2008q1-2010q3	23
Portugal	2008q1-ongoing	37
Sweden	1982q1-1983q2, 1991q1-1994q3, 2000q4-2001q3, 2008q3-2010q3	29
Slovenia	2008q2-ongoing	39
Slovakia	—	—
United Kingdom	2007q4-2010q2	25

Source: Duprey, Klaus, and Peltonen (2015), Laeven and Valencia (2012)

Overview

Logistic regressions

$$P(y_{it} = 1) = \frac{e^{\alpha_i + X'_{it}\beta}}{1 + e^{\alpha_i + X'_{it}\beta}}$$

Note: The dependent variable is equal to one seven to twelve quarters preceding a banking crisis in a respective country and zero otherwise. Observations for crisis periods are omitted. Robust standard errors adjusted for clustering at the quarterly level are reported in parentheses. * indicates statistical significance at the 10 %-level, ** at the 5 %-level, and *** at the 1 %-level.

Dependent variable	*Indicator for vulnerable state*	
	(1)	(2)
Credit growth	0.142***	
	(0.030)	
Bank credit growth		0.256***
		(0.035)
GDP growth	-0.109	-0.190*
	(0.086)	(0.101)
Inflation	-0.014	0.063
	(0.095)	(0.102)
House price growth	0.184***	0.183***
	(0.023)	(0.024)
Equity price growth	0.014**	0.013**
	(0.007)	(0.006)
Bank capitalization	-0.674***	-0.726***
	(0.142)	(0.144)
Country dummies	YES	YES
Observations	878	878
Pseudo R-Squared	0.216	0.279
AUROC	0.806	0.846
Preference parameter (μ)	0.85	0.85
Optimal threshold	64	71
Type 1 errors	0.255	0.276
Type 2 errors	0.293	0.214
Relative usefulness	0.421	0.477
Adj noise-to-signal	0.394	0.296
Perc predicted	0.745	0.724
Cond prob	0.334	0.401
Prob diff	0.169	0.236

Mixed cross-section GVAR model

- Adopted from Gross, Kok, and Zochowski (2015)
- Mixed cross-section GVAR with two equation blocks: countries and banking systems; see Annex for details
- Different weights to link different cross sections (help reflect possible transmission channels)
- Note: For a bank it doesn't matter how much the country in which it's located trades with other countries. Its own exposure matters instead.

From...	**To...**	**Banking system-based model**
Countries -	- Countries	Bilateral trade (sum of nominal inports and exports)
	- Banking system	Transpose of Banking system (banks) - Countries matrices
Banking system -	- Countries	BSI domestic and cross-border exposure data
	- Banking system	BSI cross-banking system exposure to financial institutions

Defining deleveraging

- Deleveraging means that the leverage ratio (TA/E) comes down, i.e. capital ratio up; can be achieved via one or combination of:

A↓ E→ D↓	: reduce assets via selling off business, disposal of liquid assets, non-renewal of maturing loans
A↑ E↑ D→	: raise equity capital and invest in new assets
A→ E↑ D↓	: raise equity and replace debt (i.e. constant BS)

- Retaining earnings to gradually build up E falls into 2nd (or 3rd) category
- First two reactions form starting point for shock simulations with the integrated EW-GVAR model

Shock identification – Simulation types

Scenario Type 1: Banks get to higher capital ratio (Δ) by letting business mature or selling assets → negative credit supply shock ("lower bound")

→ Sign constraints: loans down, loan interest rates up

Scenario Type 2: Banks get to higher capital ratio (Δ) by raising capital and investing → positive credit supply shock ("upper bound")

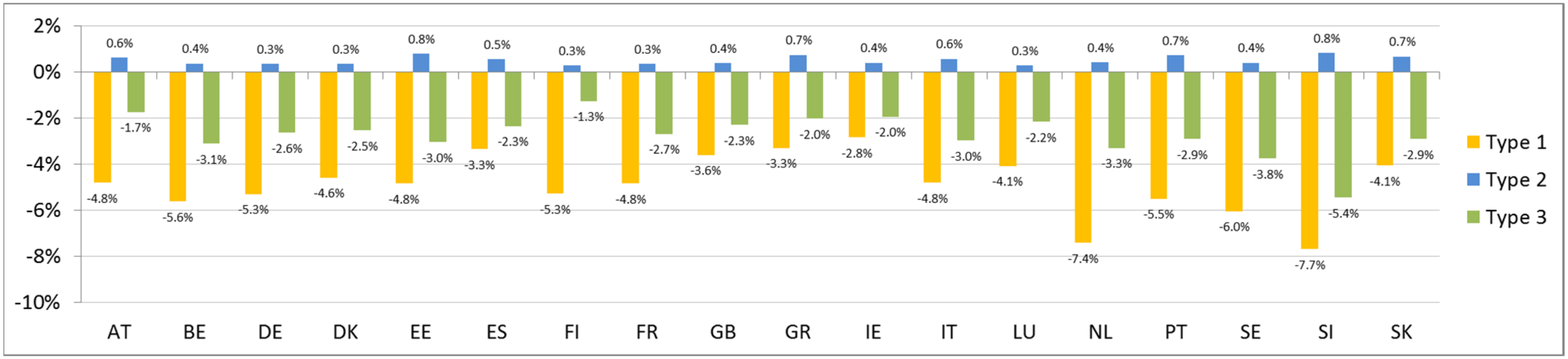
→ Sign constraints: loans up, loan interest rates down

Scenario Type 3: Unconstrained capital ratio shock (Δ) to see how banks went over deleveraging process historically

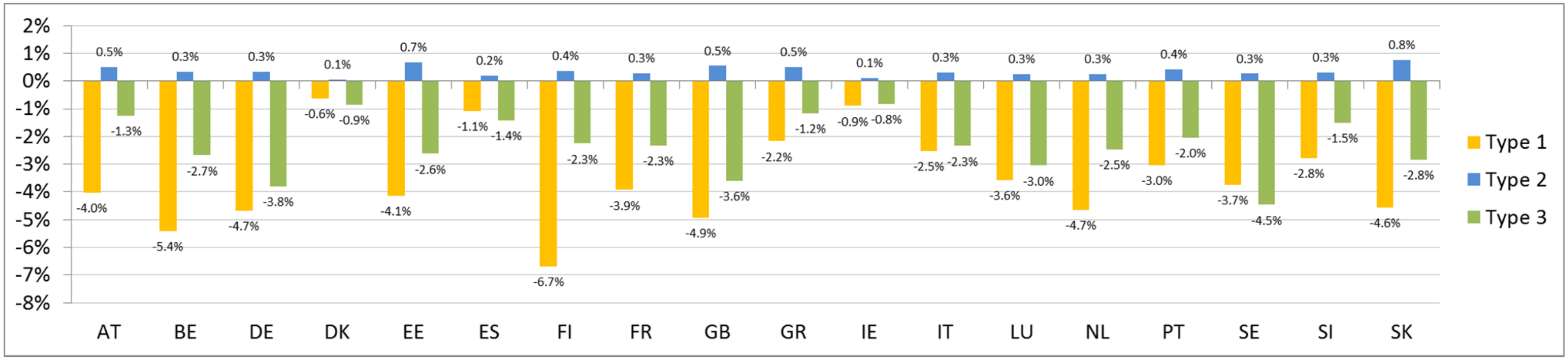
→ No sign constraints

Simulation results – Nominal credit and real GDP

Cumulative loan growth effects under Type 1/2/3 (100 bps capital ratio shock):



Cumulative real GDP growth responses under Type 1/2/3:



Feeding simulated shocks/responses through EWM

- Feed simulated shocks and responses for 2015Q1-2017Q4 through logistic model to obtain predicted probabilities of being in vulnerable state

- Change in the probability of being in a vulnerable state: difference between average predicted probability over simulation horizon and predicted probability in 2014Q4:

$$\Delta p = \overline{p_{sim}} - p_{2014Q4}$$

- Benefit of capital ratio shocks: product of reduction in crisis probabilities and average output loss associated with banking sector crises in respective country (output loss estimate from Laeven and Valencia 2012):

$$benefit = -\Delta p * crisis\ cost$$

The net benefit of capital-based measures

- $Net\ benefit$ of capital-based measures:

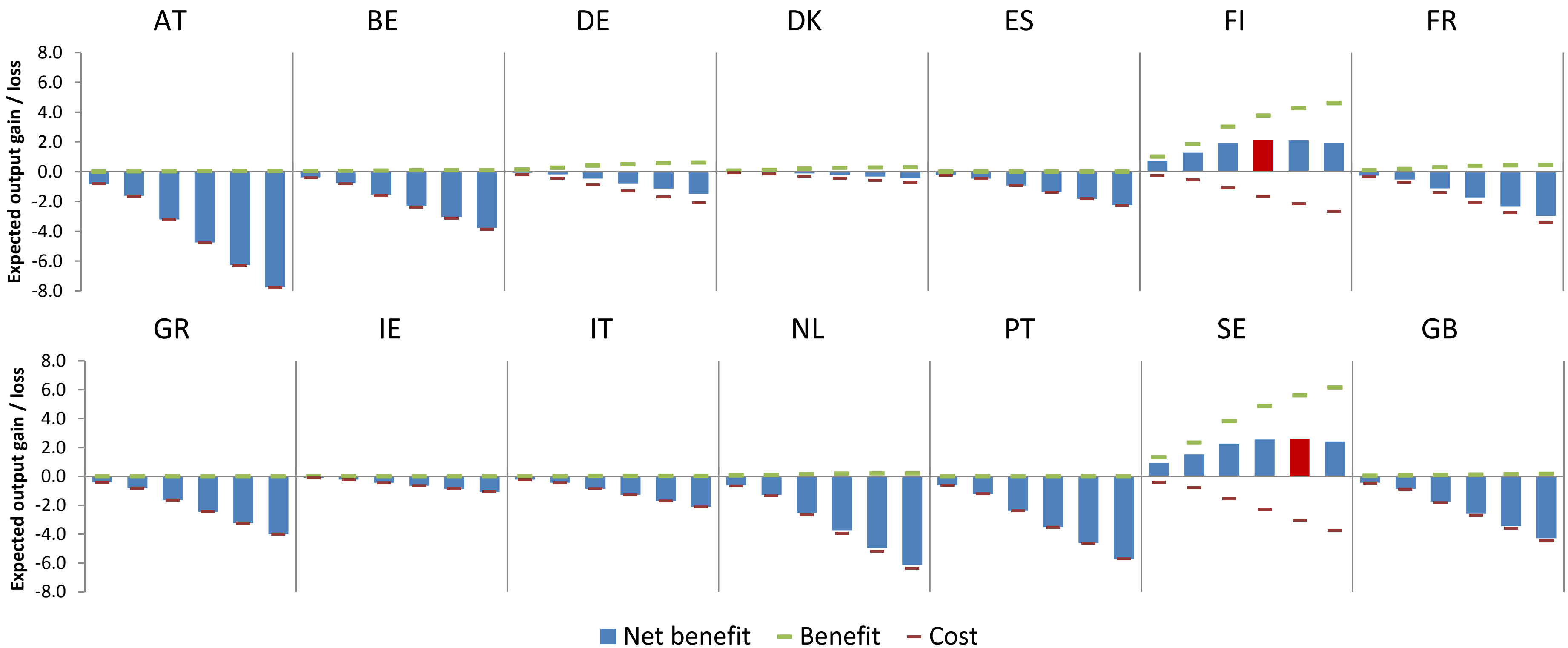
$$net\ benefit = benefit - cost$$

- $Cost$ estimate from GVAR: cumulative output loss relative to baseline
- $Net\ benefit$ can be interpreted as expected output gain or loss from imposing capital ratio shock on banking system

- Assess the $net\ benefit$ for the 3 types of shocks
  - Type 1: contractionary deleveraging
  - Type 2: expansionary deleveraging
  - Type 3: unconstrained deleveraging

Overview

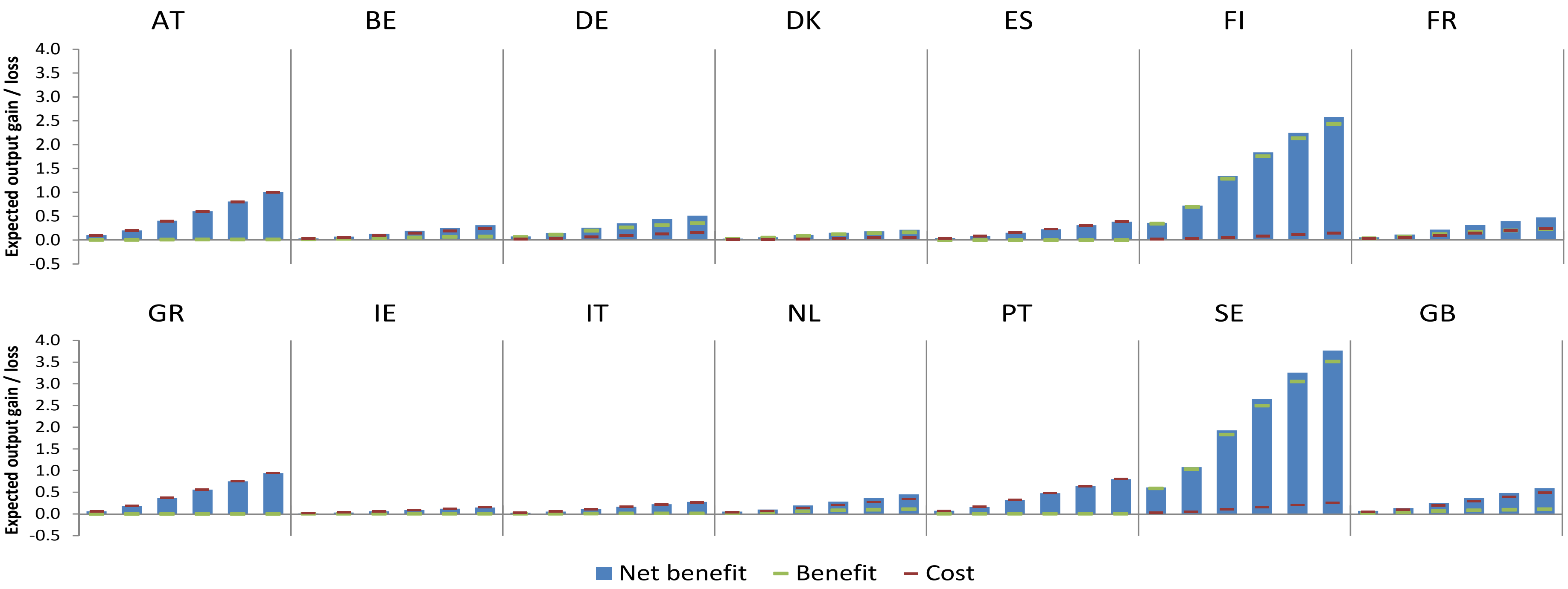
Net benefits – contractionary deleveraging (Type 1)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- Cross-country heterogeneity: countries with predicted probabilities close to 0 in 2014Q4 do not have much to gain from capital-based measures
- Only FI and SE would benefit at the current stage of the cycle

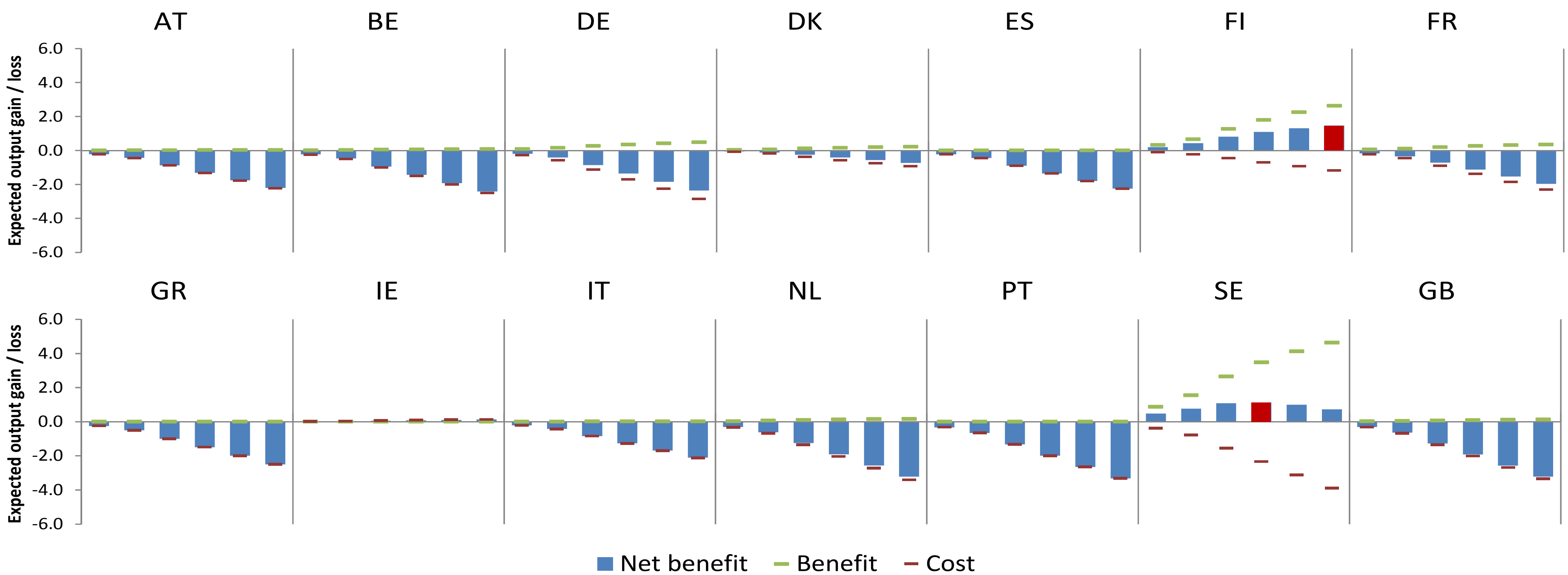
Net benefits – expansionary deleveraging (Type 2)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- Predicted probabilities decrease, since the effects of higher bank capitalization dominate the effects of (slightly) increased credit growth
- GDP reacts positively to the positive credit supply shock → no costs

Net benefits – unconstrained deleveraging (Type 3)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- Results for Type 3 scenario fall in between Type 1 and 2
- Closer to type 1, since credit/asset prices & GDP tend to react negatively

Interpretation and further results

- Benefits depend on relative importance of individual variable reactions:
  - higher credit / asset price growth ⇒ p↑, benefit ↓
  - higher GDP growth / bank capitalization ⇒ p↓, benefit ↑

  } different reactions across scenario types

- Model allows to analyse contribution of individual variables on Δp:
  - Type 1 & 3: p↓ mainly driven by higher bank capitalization and lower credit growth; to a lesser extent: lower house price growth; countervailing: lower GDP growth
  - Type 2: p↓ almost entirely driven by higher bank capitalization; countervailing effects due to higher credit growth are of minor importance

- Model allows to analyse spillover effects since GVAR model generates domestic and foreign responses
  - two channels: (1) cross-border lending; and (2) trade
  - significant (negative) spillover effects particularly for larger countries
  - aggregate foreign effects tend to go on in same direction as domestic effects

Overview

Conclusions

- Integrated tool for informing activation and calibration of capital-based measures
- Account for costs and benefits of capital-based measures
- Results (in particular short-run macro costs) depend on how banks move to higher capital ratios
- Effects of dampened credit/asset price growth can be sizable: under Type 1 shocks they can account for >50% of the reduction in predicted probabilities

  → macroprudential policy should be ambitious in smoothening the cycle
- Not much potential for countercyclical measures at the current stage of the cycle (exception: Finland and Sweden)
- Spillover effects mostly in larger countries, under Type 1 and 3 shocks

Conclusions (ctd)

- Additional steps:
  - Robustness checks with respect to prediction horizon (currently 7-12 quarters before crisis), crisis definition, and out-of-sample performance
  - For benefit calculations:
    - Estimate average output loss during crises based on our own data, instead of referring to Laeven / Valencia (2012)
    - Use cross-country average (or other moments of the distribution) of GDP losses during crises instead of country specific crisis costs
  - Use alternative evaluation method for the benefits that makes stronger use of the model’s binary signalling properties (signal vs. no signal)

Background slides

Related literature

- Early warning literature: Kaminsky et al. (1998), Alessi and Detken (2011), Behn et al. (2013), Lo Duca and Peltonen (2013), Betz et al. (2014)
- Effects of macroprudential instruments: Lim et al. (2011), Galati and Moessner (2014), Bruno et al. (2015), Cerutti et al. (2015)
- Relationship between capital ratios and loan growth: Bernanke and Lown (1991), Gambacorta and Mistrulli (2004), Francis and Osborne (2009), Berrospide and Edge (2010), Bochmann et al. (2015), Gross et al. (2015)
- Empirical literature on capital requirements and lending: Brun et al. (2013), Carlson et al. (2013), Aiyar et al. (2014), Jimenez et al. (2014), Behn et al. (2015), Marques-Ibanez et al. (2015)
- See Annex to the slides and draft paper for more references

Literature on impact of higher capital requirements

- Assumed trade-off between financial stability and cost of financial intermediation
- Concave function between capital and welfare implies an optimal level of capital exists
- Operating below optimal capital level means lower financial intermediation cost in short run but higher probability of bank or banking system default (costly)
- Operating above optimal capital level means too high financial intermediation cost, more than outweighing the gain from lower crisis probability
- BIS 2010: net benefit from increasing cap ratios positive for broad range
- Miles/Yang/Marcheggiano 2012: optimal bank capital should be around 20%
- Kashyap et al. 2010: focus on cost side; though conclude with respect to net benefit: likely positive because lending rates will not react much

Literature on impact of higher capital requirements

- Higher capital induces banks to better screen borrowers (Coval and Thakor 2005) and to more efficiently monitor them (Holmstrom and Tirole 1997 and Mehran and Thakor 2011)

- Based on Miller 1995 and the Modigliani-Miller capital structure irrelevance theorem: Admati et al. (2011) and Admati and Hellwig (2013) call for much higher capital ratios than currently imposed; social costs of significantly higher requirements will be negligible and the benefit of reduced probabilities of failure far outweigh these costs

- Further references: Beguenau (2014), Nguyen (2014), van den Heuvel (2008), Calomiris and Herring (2013)

Micro-econometric studies to measure impact of changes in capital requirements

- Micro (bank-level) data helps for shock identification

- Effects on an increase in capital requirements on bank lending

In the transition…

	pp-variation in cap. Req.	Effect on bank lending volume	Horizon
Maurin and Toivanen (2012)	+1pp	-2.15%	medium term
Aiyar et al. (2014)	+1pp	-8.40%	1 year
Noss and toffano (2014)	+1pp	-4.50%	3 years
Mesonnier and Monks (2014)	+1pp	-1.40%	1 year
Brun et al. (2015)	-1pp	5.00%	short term

… and in the long run

	pp-variation in cap. Req.	Effect on bank lending rate
Kashyap et al. (2010)	+1pp	+0.03pp
King (2010)	+1pp	+0.15pp
Kisin and Manela (2015)	+1pp	+0.003pp

Source: From the response to the EC Consultation on the impact of CRR/CRD4 on bank lending, prepared jointly with I. Jaccard, F. Boissay

Recognition provisions in EU law

Macro-prudential measure	Legal basis	Recognition in EU law
Countercyclical capital buffer	130, 135-140 CRDIV	Mandatory (up to 2.5 %)
Higher RWs for SA banks	124 CRR	Mandatory
Higher LGDs for IRB banks	164 CRR	Mandatory
National flexibility measures	458 CRR	Voluntary
Systemic risk buffer	133-134 CRDIV	Voluntary
Pillar II measures	103 CRDIV	Not mentioned
G-SII buffer	131 CRDIV	Not mentioned
O-SII buffer	131 CRDIV	Not mentioned

Source: IWG Expert Group on cross-border effects of macro-prudential policy and reciprocity, Report to the ATC.

Transmission channels for capital-based policy

- Broad capital-based instrument applied to bank in Country A which does significant x-border business in Country B likely causes x-border loan supply change in Country B

- Even if banks are active only in home country, change in their capital and hence domestic loan supply may feed first through domestic macro but then to Country B through the trade channel

- Both channels well captured in the MCS-GVAR

- Distinguish between x-border business through subsidiaries vs branches vs direct cross-border lending

- BSI data: carving out only direct x-border lending which we add to banking system credit; meaningful because direct x-border lending likely among the most reactive to capital change for parent bank

Shock identification

- Observed capital ratios very much endogenous
- Capital ratio change as such should not have any macro impact as long as prices or volumes (loan supply) are not affected
- We circumvent identification based on capital by first translating capital ratio shocks into credit supply shocks, considering two polar cases of reaction (seen as upper and lower bound reaction)
- Identification based on sign restrictions for credit supply shocks

Shock identification – Simulation types

Scenario Type 1: Banks get to higher capital ratio (Δ) by letting business mature or selling assets → negative credit supply shock ("lower bound")

$$shock^{Type1} = \ln\left(\frac{E_0}{E_0/A_0 + \Delta}\right) - \ln(A_0)$$

[A_0: assets at T_0 , E_0: equity at T0 , Δ: capital ratio shock in p.p.]

Scenario Type 2: Banks get to higher capital ratio (Δ) by raising capital and investing → positive credit supply shock ("upper bound")

$$shock^{Type2} = ln\left(A_0 - E_0\left(\frac{\left(\Delta + E_0/A_0\right)(A_0 - E_0)}{E_0\left(\Delta + E_0/A_0 - 1\right)} + 1\right)\right) - ln(A_0)$$

Scenario Type 3: Unconstrained capital ratio shock (Δ) to see how banks went over deleveraging process historically

#	Scenario	Shock	Sign constraints
1	Contractionary deleveraging shock	LEV down	L down, I up
2	Expansionary deleveraging shock	LEV down	L up, I down
3	Deleveraging shock -- No sign constraints	LEV down	-

The semi-structural MCS-GVAR model

The equation system

$$x_{it} = a_i + \sum_{p_1=1}^{P_1} \Phi_{ip_1} x_{i,t-p_1} + \sum_{p_2=0}^{P_2} \Lambda_{i,0,p_2} x_{i,t-p_2}^{*,C-C} + \sum_{p_3=0}^{P_3} \Lambda_{i,1,p_3} y_{i,t-p_3}^{*,C-B} + \sum_{p_4=0}^{P_4} \Lambda_{i,2,p_4} z_{i,t-p_4}^{*,C-CB} + \sum_{p_5=0}^{P_5} \mathrm{K}_{i,p_5} v_{t-p_5} + \varepsilon_{it}$$

$$y_{jt} = b_i + \sum_{q_1=1}^{Q_1} \Pi_{jq_1} y_{j,t-q_1} + \sum_{q_2=0}^{Q_2} \Xi_{j,0,q_2} x_{j,t-q_2}^{*,B-C} + \sum_{q_3=0}^{Q_3} \Xi_{j,1,q_3} y_{j,t-q_3}^{*,B-B} + \sum_{q_4=0}^{Q_4} \Xi_{j,2,q_4} z_{j,t-q_4}^{*,B-CB} + \sum_{q_5=0}^{Q_5} \mathrm{E}_{j,q_5} v_{t-q_5} + \omega_{jt}$$

$$z_{lt} = c_i + \sum_{r_1=1}^{R_1} \Gamma_{lr_1} z_{l,t-r_1} + \sum_{r_2=0}^{R_2} \Psi_{l,0,r_2} x_{l,t-r_2}^{*,CB-C} + \sum_{r_3=0}^{R_3} \Psi_{l,1,r_3} y_{l,t-r_3}^{*,CB-B} + \sum_{r_4=0}^{R_4} \Psi_{l,2,r_4} z_{l,t-r_4}^{*,CB-CB} + \sum_{r_5=0}^{R_5} \mathrm{T}_{l,r_5} v_{t-r_5} + \tau_{lt}$$

Three sets of equations for countries, banks, and central banks.

Global exogenous (***v**$_t$*) or local exogenous variables can be included. Global exogenous for instance oil price. Local exogenous can be anything, depending on needs and type of application/simulation.

The semi-structural MCS-GVAR model

The equation system

$$x_{it} = a_i + \sum_{p_1=1}^{P_1} \Phi_{ip_1} x_{i,t-p_1} + \sum_{p_2=0}^{P_2} \Lambda_{i,0,p_2} x_{i,t-p_2}^{*,C-C} + \sum_{p_3=0}^{P_3} \Lambda_{i,1,p_3} y_{i,t-p_3}^{*,C-B} + \sum_{p_4=0}^{P_4} \Lambda_{i,2,p_4} z_{i,t-p_4}^{*,C-CB} + \sum_{p_5=0}^{P_5} \mathrm{K}_{i,p_5} v_{t-p_5} + \varepsilon_{it}$$

$$y_{jt} = b_i + \sum_{q_1=1}^{Q_1} \Pi_{jq_1} y_{j,t-q_1} + \sum_{q_2=0}^{Q_2} \Xi_{j,0,q_2} x_{j,t-q_2}^{*,B-C} + \sum_{q_3=0}^{Q_3} \Xi_{j,1,q_3} y_{j,t-q_3}^{*,B-B} + \sum_{q_4=0}^{Q_4} \Xi_{j,2,q_4} z_{j,t-q_4}^{*,B-CB} + \sum_{q_5=0}^{Q_5} \mathrm{P}_{j,q_5} v_{t-q_5} + \omega_{jt}$$

$$z_{lt} = c_i + \sum_{r_1=1}^{R_1} \Gamma_{lr_1} z_{l,t-r_1} + \sum_{r_2=0}^{R_2} \Psi_{l,0,r_2} x_{l,t-r_2}^{*,CB-C} + \sum_{r_3=0}^{R_3} \Psi_{l,1,r_3} y_{l,t-r_3}^{*,CB-B} + \sum_{r_4=0}^{R_4} \Psi_{l,2,r_4} z_{l,t-r_4}^{*,CB-CB} + \sum_{r_5=0}^{R_5} \mathrm{T}_{l,r_5} v_{t-r_5} + \tau_{lt}$$

Fully endogenous (though constrained) cross-cross-section dependence via weighted variable vectors ("star-variables").

To establish link b/w 3 cross-sections, up to 9 weight matrices needed. Some weight sets not needed due to exclusion restrictions.

The semi-structural MCS-GVAR model

The equation system

- See the difference between MCS structure and standard GVAR with variable-specific weights!
- Example: loan growth equation

  → Standard GVAR w/ v-specific weights: e.g. BIS weights on credit but trade weights on GDP (!)

  → MCS-GVAR: exposure of bank or banking system vis-à-vis countries, i.e. reflecting its activity there and hence susceptibility to macro

- For a bank it doesn't matter how much the country in which it's located trades with other countries; its x-border exposure matters
- Predictive performance tests confirm MCS makes more sense

The semi-structural MCS-GVAR model

Solving the global model – STEP 1/4

Step 1: Generate A-matrices. One starts by stacking the within-cross-section vectors along with the cross-cross-section weighted variable vectors in (here) three vectors $\boldsymbol{m}_{it}^{x}$, $\boldsymbol{m}_{jt}^{y}$, and $\boldsymbol{m}_{lt}^{z}$.

$$
\begin{aligned}
\boldsymbol{m}_{it}^{x} &= \begin{pmatrix} \boldsymbol{x}_{it'} & \boldsymbol{x}_{it}^{*,C-C\prime} & \boldsymbol{y}_{it}^{*,C-B\prime} & \boldsymbol{z}_{it}^{*,C-CB\prime} \end{pmatrix}' \\
\boldsymbol{m}_{jt}^{y} &= \begin{pmatrix} \boldsymbol{y}_{jt'} & \boldsymbol{x}_{jt}^{*,B-C\prime} & \boldsymbol{y}_{jt}^{*,B-B\prime} & \boldsymbol{z}_{jt}^{*,B-CB\prime} \end{pmatrix}' \\
\boldsymbol{m}_{lt}^{z} &= \begin{pmatrix} \boldsymbol{z}_{lt'} & \boldsymbol{x}_{lt}^{*,CB-C\prime} & \boldsymbol{y}_{lt}^{*,CB-B\prime} & \boldsymbol{z}_{lt}^{*,CB-CB\prime} \end{pmatrix}'
\end{aligned}
$$

The equation system can be re-written with these $\boldsymbol{m}$ vectors as follows.

$$
\begin{aligned}
\underbrace{\begin{pmatrix} I_{k_i^x} & -\Lambda_{i,0,0} & -\Lambda_{i,1,0} & -\Lambda_{i,2,0} \end{pmatrix}}_{\equiv \boldsymbol{A}_{i0}^{x}} \boldsymbol{m}_{it}^{x} &= \boldsymbol{a}_i + \underbrace{\begin{pmatrix} \Phi_{i1} & \Lambda_{i,1,1} & \Lambda_{i,2,1} \end{pmatrix}}_{\equiv \boldsymbol{A}_{i1}^{x}} \boldsymbol{m}_{i,t-1}^{x} + \ldots + \boldsymbol{\epsilon}_{it} \\
\underbrace{\begin{pmatrix} I_{g_j^y} & -\Xi_{j,0,0} & -\Xi_{j,1,0} & -\Xi_{j,2,0} \end{pmatrix}}_{\equiv \boldsymbol{A}_{j0}^{y}} \boldsymbol{m}_{jt}^{y} &= \boldsymbol{b}_j + \underbrace{\begin{pmatrix} \Pi_{j1} & \Xi_{j,1,1} & \Xi_{j,2,1} \end{pmatrix}}_{\equiv \boldsymbol{A}_{j1}^{y}} \boldsymbol{m}_{j,t-1}^{y} + \ldots + \boldsymbol{\omega}_{jt} \\
\underbrace{\begin{pmatrix} I_{k_l^z} & -\Psi_{l,0,0} & -\Psi_{l,1,0} & -\Psi_{l,2,0} \end{pmatrix}}_{\equiv \boldsymbol{A}_{l0}^{z}} \boldsymbol{m}_{lt}^{z} &= \boldsymbol{c}_l + \underbrace{\begin{pmatrix} \Gamma_{l1} & \Psi_{l,1,1} & \Psi_{l,2,1} \end{pmatrix}}_{\equiv \boldsymbol{A}_{l1}^{z}} \boldsymbol{m}_{l,t-1}^{z} + \ldots + \boldsymbol{\tau}_{lt}
\end{aligned}
$$

The semi-structural MCS-GVAR model

Solving the global model – STEP 2/4

Step 2: Generate L-matrices ("link" matrices). With a global, stacked variable vector $\boldsymbol{s}_t = (\boldsymbol{x}'_{1t}, ..., \boldsymbol{x}'_{Nt}, \boldsymbol{y}'_{1t}, ..., \boldsymbol{y}'_{Mt}, \boldsymbol{z}'_{1t}, ..., \boldsymbol{z}'_{Bt})$ at hand, the cross-section-specific variable vectors $\boldsymbol{m}^x_{it}$, $\boldsymbol{m}^y_{jt}$, and $\boldsymbol{m}^z_{lt}$ to $\boldsymbol{s}_t$ can be linked. The link matrices $\boldsymbol{L}^x_i$, $\boldsymbol{L}^y_j$, and $\boldsymbol{L}^z_l$ are used to map the local cross-section variables into the global vector, which involve the weights from the weight matrices $\boldsymbol{W}$.

$$\boldsymbol{m}^x_{it} = \boldsymbol{L}^x_i \boldsymbol{s}_t \quad \rightarrow \quad \boldsymbol{A}^x_{i0} \boldsymbol{L}^x_i \boldsymbol{s}_t = \boldsymbol{a}_i + \boldsymbol{A}^x_{i1} \boldsymbol{L}^x_i \boldsymbol{s}_{t-1} + ... + \boldsymbol{\epsilon}_{it}$$

$$\boldsymbol{m}^y_{jt} = \boldsymbol{L}^y_j \boldsymbol{s}_t \quad \rightarrow \quad \boldsymbol{A}^y_{j0} \boldsymbol{L}^y_j \boldsymbol{s}_t = \boldsymbol{b}_j + \boldsymbol{A}^y_{j1} \boldsymbol{L}^y_j \boldsymbol{s}_{t-1} + ... + \boldsymbol{\omega}_{jt}$$

$$\boldsymbol{m}^z_{lt} = \boldsymbol{L}^z_l \boldsymbol{s}_t \quad \rightarrow \quad \boldsymbol{A}^z_{l0} \boldsymbol{L}^z_l \boldsymbol{s}_t = \boldsymbol{c}_l + \boldsymbol{A}^z_{l1} \boldsymbol{L}^z_l \boldsymbol{s}_{t-1} + ... + \boldsymbol{\tau}_{lt}$$

The semi-structural MCS-GVAR model

Solving the global model – STEP 3/4

Step 3: Generate G-matrices. The equation-by-equation system can now be stacked into a global system.

$$G_0^x = \begin{pmatrix} A_{10}^x L_1^x \\ \dots \\ A_{N0}^x L_N^x \end{pmatrix}, G_1^x = \begin{pmatrix} A_{11}^x L_1^x \\ \dots \\ A_{N1}^x L_N^x \end{pmatrix}, \dots, a = \begin{pmatrix} a_1 \\ \dots \\ a_N \end{pmatrix}$$

$$G_0^y = \begin{pmatrix} A_{10}^y L_1^y \\ \dots \\ A_{M0}^y L_M^y \end{pmatrix}, G_1^y = \begin{pmatrix} A_{11}^y L_1^y \\ \dots \\ A_{M1}^y L_M^y \end{pmatrix}, \dots, b = \begin{pmatrix} b_1 \\ \dots \\ b_M \end{pmatrix}$$

$$G_0^z = \begin{pmatrix} A_{10}^z L_1^z \\ \dots \\ A_{B0}^z L_B^z \end{pmatrix}, G_1^z = \begin{pmatrix} A_{11}^z L_1^z \\ \dots \\ A_{B1}^z L_B^z \end{pmatrix}, \dots, c = \begin{pmatrix} c_1 \\ \dots \\ c_B \end{pmatrix}$$

These cross-section-specific G matrices can be further combined to a set of global G matrices. The intercept vectors $\boldsymbol{a}$, $\boldsymbol{b}$, and $\boldsymbol{c}$ will be combined in a vector $\boldsymbol{d}$. That is,

The semi-structural MCS-GVAR model

Solving the global model – STEP 4/4

Step 4: Generate H-matrices. The global system can now be pre-multiplied by the inverse of G_0. The system is now ready to be used for shock simulation and forecast purposes.

$$s_t = \underbrace{G_0^{-1} d}_{\equiv H_0} + \underbrace{G_0^{-1} G_1}_{\equiv H_1} s_{t-1} + ... + G_0^{-1} \varphi_t$$

Signalling approach

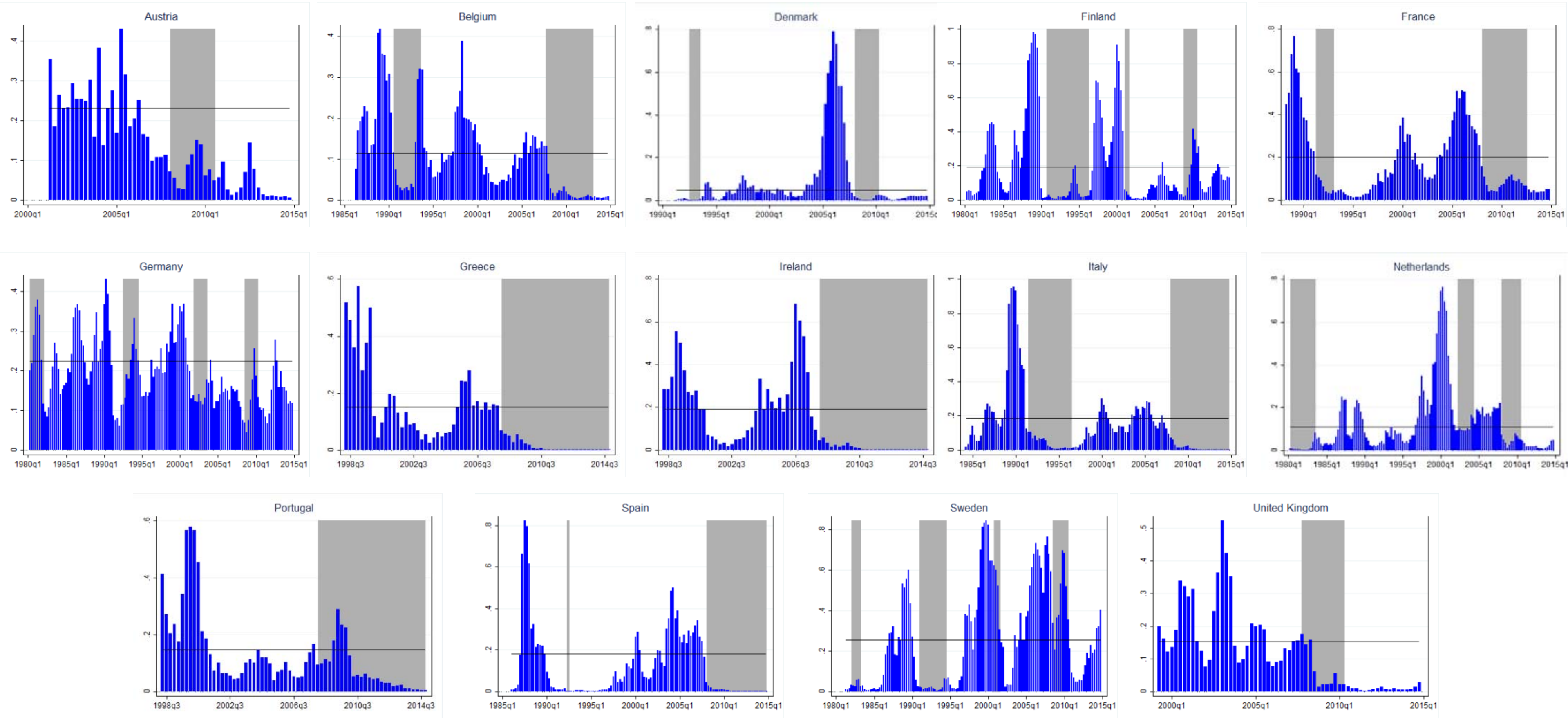
- Assume that a model issues a warning whenever the predicted probability surpasses a threshold τ, defined as a percentile of the country-specific distribution of predicted probabilities
- Compare signals issued by model to actual outcomes for each observation
- Optimal warning threshold depends on policy makers' relative aversion with respect to type I ($T_1(\tau)$, missing crisis) and type II ($T_2(\tau)$, false alarm) errors, and the unconditional probability of crisis (P_1) vs. non-crisis periods (P_2)
- Optimal warning threshold minimizes the following loss function:

$$L(\tau) = \mu * P_1 * T_1(\tau) + (1 - \mu) * P_2 * T_2(\tau)$$

- Benchmark: μ = 0.85, policy maker is more averse against missing a crisis
- Absolute usefulness: $U_a = \min(\mu P_1, (1-\mu)P_2) - L(\mu)$
- Relative usefulness: $U_r = U_a / \min(\mu P_1, (1-\mu)P_2)$

Predicted probabilities of being in a vulnerable state

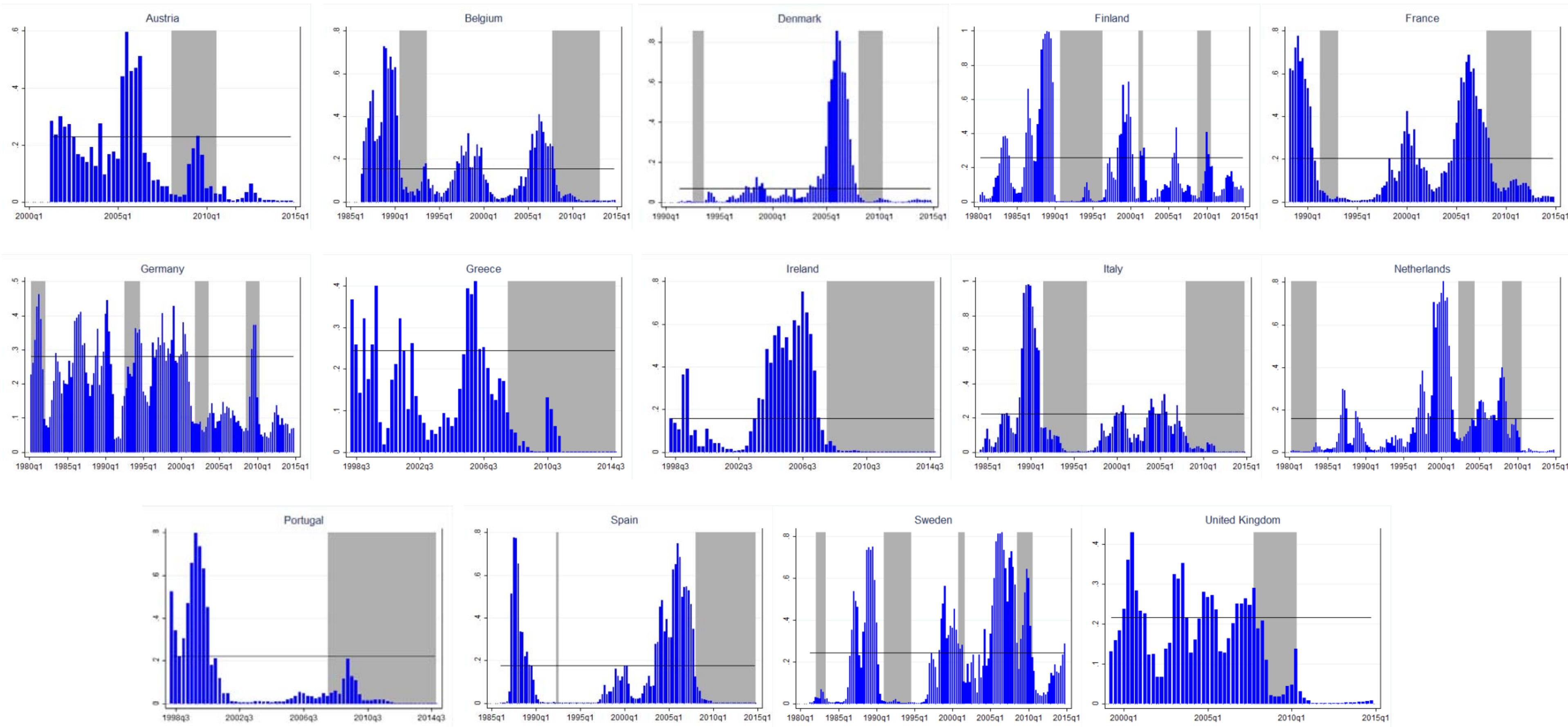
Model 4



Note: Predicted probabilities are depicted in blue. Horizontal black lines indicate the optimal warning threshold (μ=0.85). Shaded grey areas correspond to systemic events.

Predicted probabilities of being in a vulnerable state

Model 8



Note: Predicted probabilities are depicted in blue. Horizontal black lines indicate the optimal warning threshold (μ=0.85). Shaded grey areas correspond to systemic events.

Recalling the transmission channels

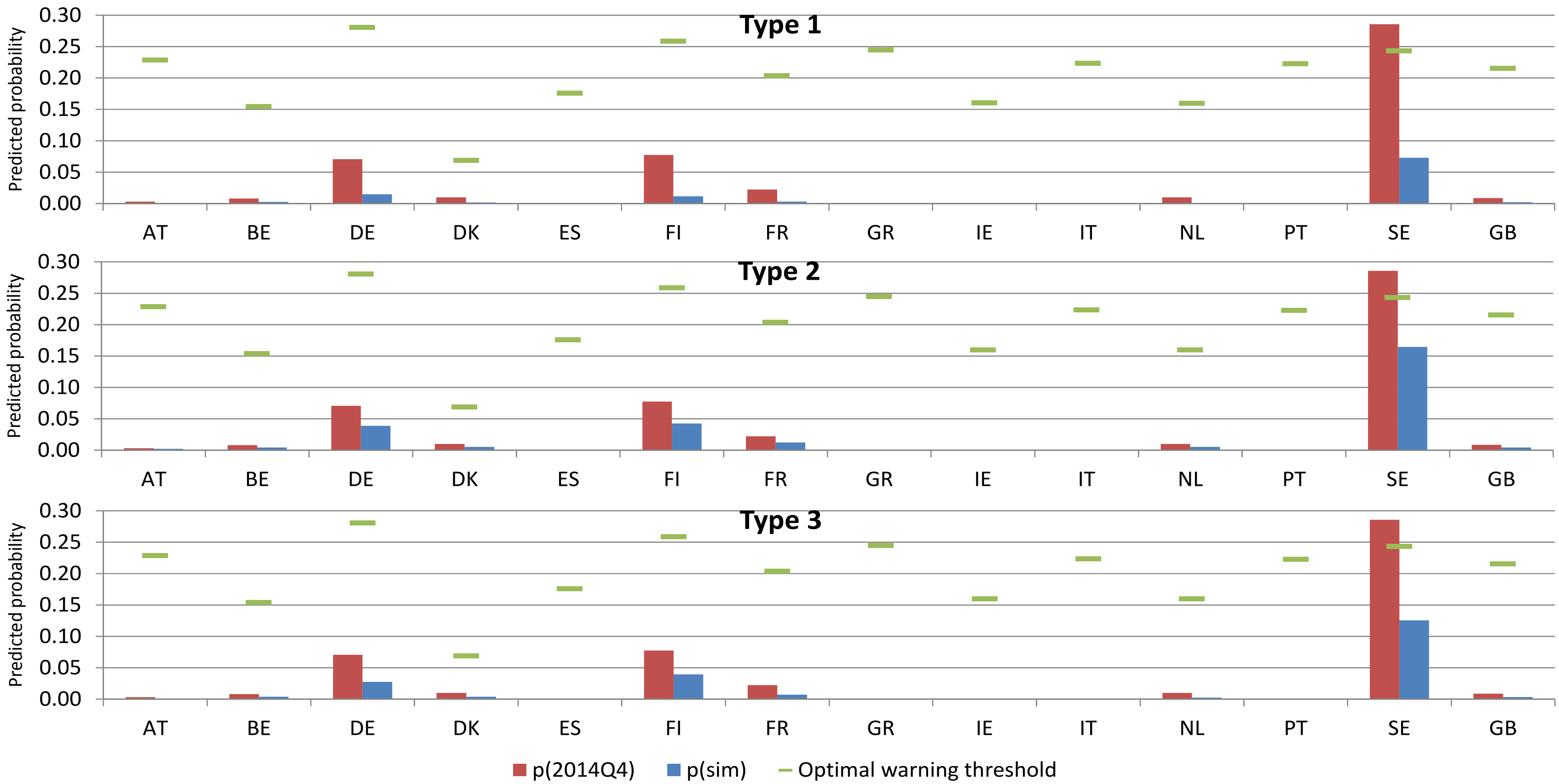
Bank credit growth	0.256***
	(0.035)
GDP growth	-0.190*
	(0.101)
Inflation	0.063
	(0.102)
House price growth	0.183***
	(0.024)
Equity price growth	0.013**
	(0.006)
Bank capitalization	-0.726***
	(0.144)

- Recall coefficients from logit model:
  - higher credit / asset price growth ⇒ p↑
  - higher GDP growth / bank capitalization ⇒ p↓

Type 1	Type 2
• Credit growth ↓ ⇒ p↓	• Credit growth ↑ ⇒ p↑
• Asset prices ↓ ⇒ p↓	• Asset prices ↑ ⇒ p↑
• GDP growth ↓ ⇒ p↑	• GDP growth ↑ ⇒ p↓
• Bank capital ↑ ⇒ p↓	• Bank capital ↑ ⇒ p↓

- Whether crisis probabilities go up or down depends on the relative importance of the effects ⇒ 'benefit' can be positive or negative
- Costs are estimated as the cumulative output loss or gain relative to the baseline from the GVAR ⇒ 'cost' positive under Type 2, negative under Type 1, and tends to be negative under Type 3

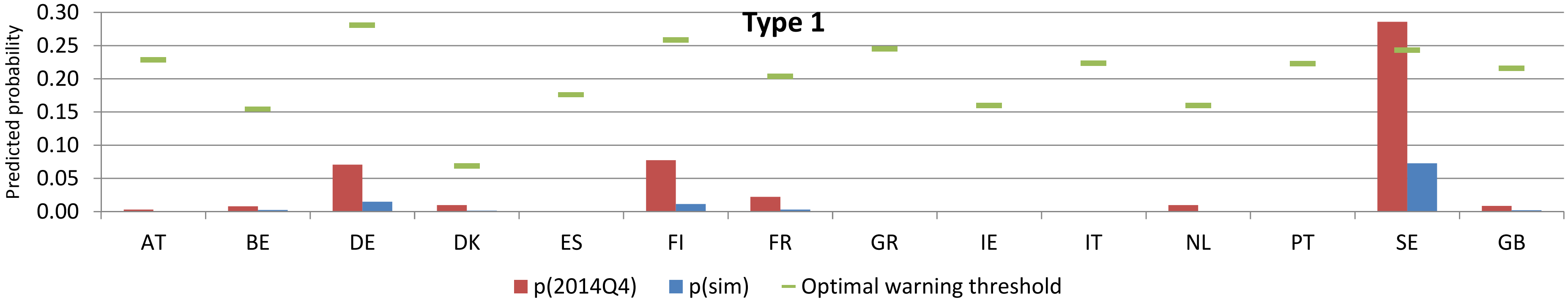
Impact on predicted probabilities I



Note: p(sim) corresponds to the average predicted probability over simulation horizon, assuming a capital ratio shock of 250 bps, where the optimal warning threshold corresponds to μ=0.85.

- Cross-country heterogeneity: countries with predicted probabilities close to 0 in 2014Q4 do not have much to gain from capital-based measures

Impact on predicted probabilities II



Note: p(sim) corresponds to the average predicted probability over simulation horizon, assuming a capital ratio shock of 250 bps, where the optimal warning threshold corresponds to μ=0.85.

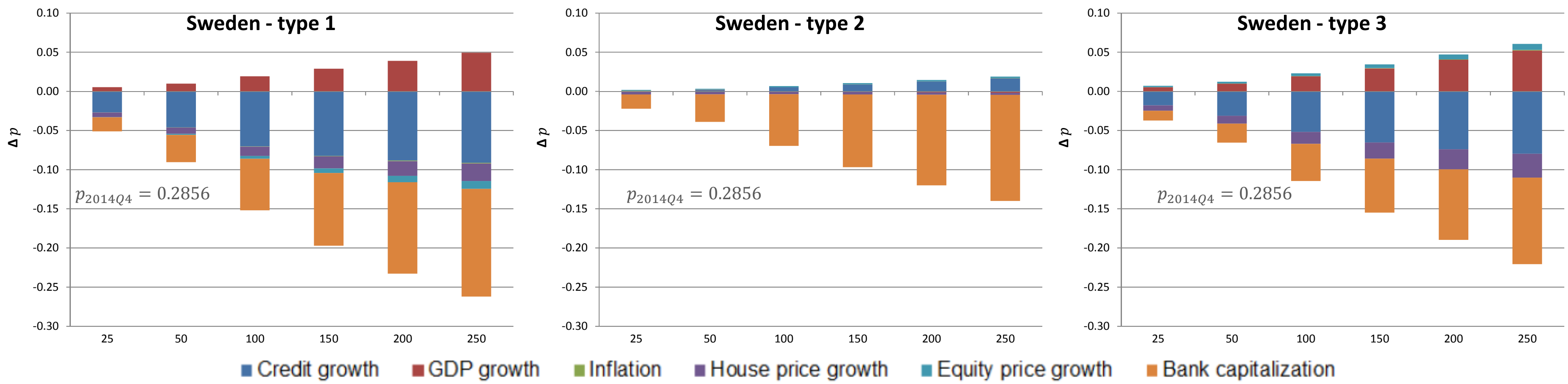
- Benchmark: bank credit model (Model 8, μ = 0.85)
- Model is currently issuing a warning for Sweden
- Probability of being in a vulnerable state is reduced in all countries
- Cross-country heterogeneity: countries with predicted probabilities close to 0 in 2014Q4 do not have much to gain from capital-based measures

Impact on predicted probabilities III

Type 1 shock						
Buffer size (in bps)	25	50	100	150	200	250
$-\Delta p$ in average country	0.006	0.010	0.018	0.022	0.025	0.028
... relative to average p	0.031	0.051	0.090	0.112	0.128	0.139
... relative to p in 2014Q4	0.176	0.295	0.517	0.649	0.739	0.802
Type 2 shock						
Buffer size (in bps)	25	50	100	150	200	250
$-\Delta p$ in average country	0.003	0.004	0.008	0.011	0.014	0.016
... relative to average p	0.013	0.022	0.042	0.056	0.068	0.078
... relative to p in 2014Q4	0.070	0.124	0.239	0.321	0.385	0.435
Type 3 shock						
Buffer size (in bps)	25	50	100	150	200	250
$-\Delta p$ in average country	0.004	0.006	0.011	0.015	0.018	0.020
... relative to average p	0.018	0.030	0.057	0.075	0.090	0.101
... relative to p in 2014Q4	0.109	0.191	0.360	0.478	0.569	0.640

- Reduction in crisis probabilities is greatest under type 1
- About half the size under type 2, somewhere in between under type 3

Transmission channels – contribution of variables



Note: The figures shows the contribution of individual variables to the change in the probability of being in a vulnerable state relative to 2014Q4 for different capital ratio shocks.

- Type 1 & 3:
  - Reduction in predicted probabilities mainly driven by increase in bank capitalization and reduction in credit growth; to a lesser extent: reduction in house price growth
  - Reduction in GDP growth increases probability of being vulnerable
- Type 2:
  - Reduction almost entirely driven by increase in banking sector capitalization
  - Countervailing effects due to higher credit growth are of minor importance

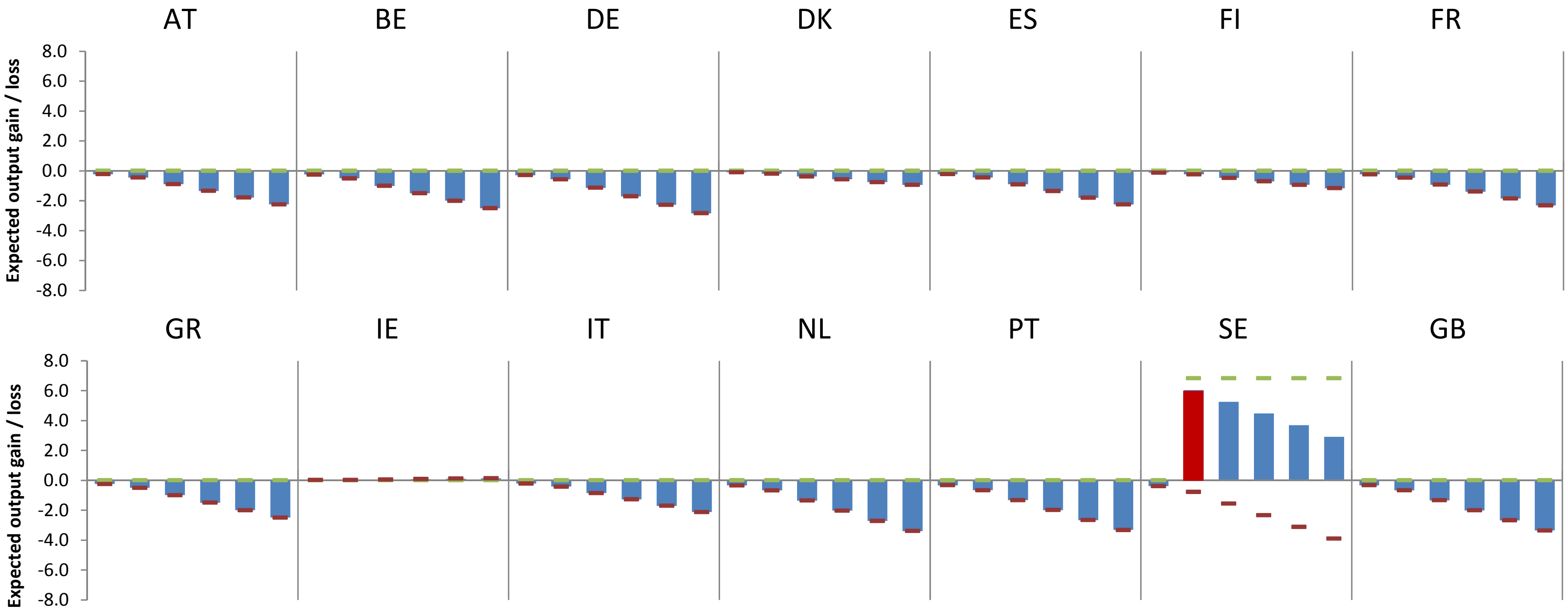
An alternative way to assess the net benefit

- Make stronger use of binary signals issued by the EWS
    1. Check whether the model is currently issuing a warning signal
    2. If yes, check whether capital ratio shock succeeds in pushing predicted probabilities below optimal early warning threshold
    3. If yes, calculate reduction in probability of being in vulnerable state, $-\Delta p$, as difference between probability of being in vulnerable state conditional on signal being issued and unconditional probability of being in vulnerable state
    4. Obtain estimate for benefit and net benefit as before (crisis cost unchanged):

$$benefit = -\Delta p * crisis\ cost \quad \text{and} \quad net\ benefit = benefit - cost$$

- Benefit equal 0 if model currently not issuing warning signal or if the measure does not succeed in pushing probabilities below threshold
- Optimal buffer rate likely to be the lowest one that succeeds in pushing predicted probability below optimal threshold

Net benefits – alternative assessment (Type 3)



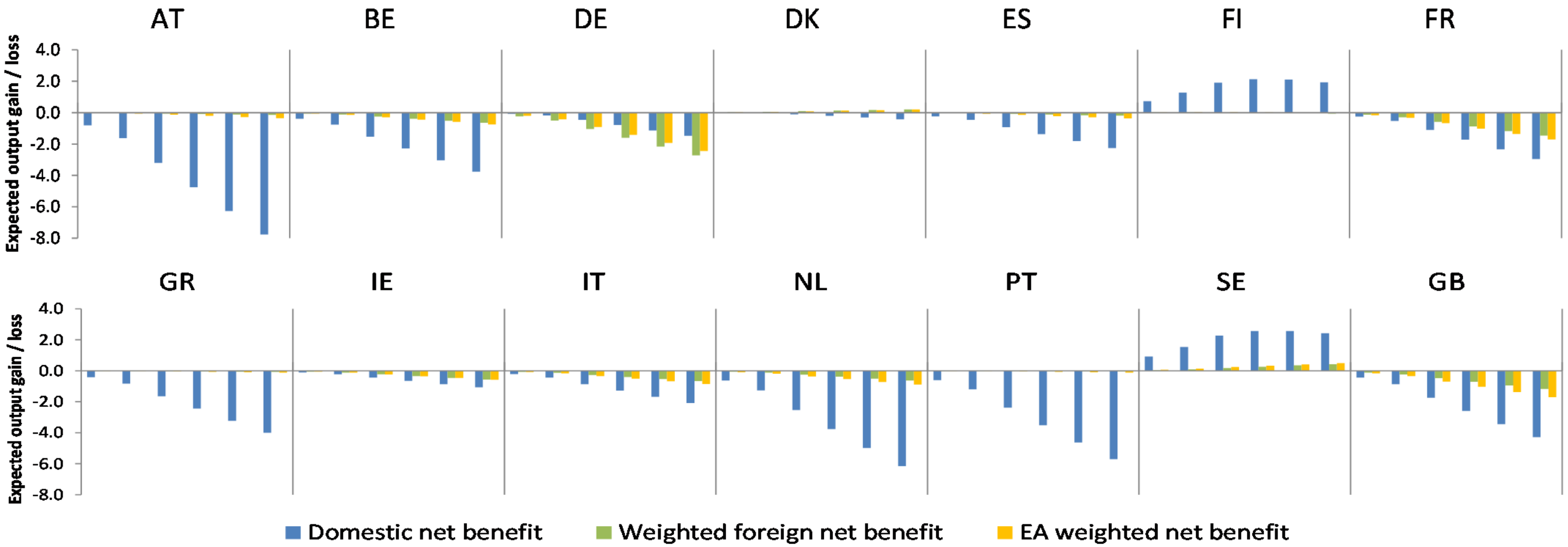
Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- Sweden is the only country for which models are issuing a warning
- Capital ratio shock of 50 bps would be sufficient to push predicted probabilities below optimal warning threshold

Spillover effects

- GVAR model structure allows looking at spillover effects as it generates domestic and foreign responses
- Our model captures two important channels through which capital-based measures may exert spillover effects:
  - through banks that do significant cross-border lending
  - through the trade channel
- Calculate net benefits in both domestic and foreign countries
- Three variables:
  - Domestic net benefit: as before
  - Weighted foreign net benefit: net benefits in countries abroad, weighted by GDP as of 2014Q4 (alternatively: unweighted average)
  - EA weighted net benefit: net benefits in all sample countries, weighted by GDP in 2014Q4, no distinction between domestic and foreign effects

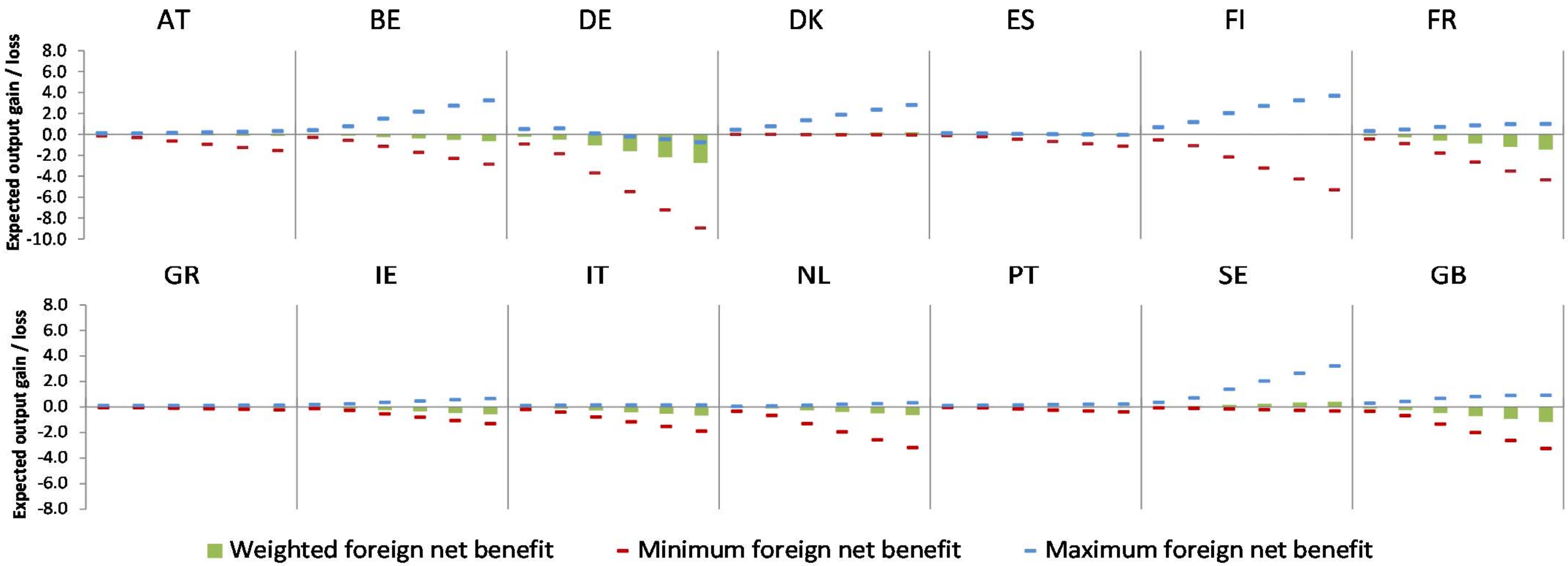
Spillovers – contractionary deleveraging (Type 1)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- Significant spillover effects particularly for larger countries
- Aggregate foreign effects tend to go on in same direction as domestic effects

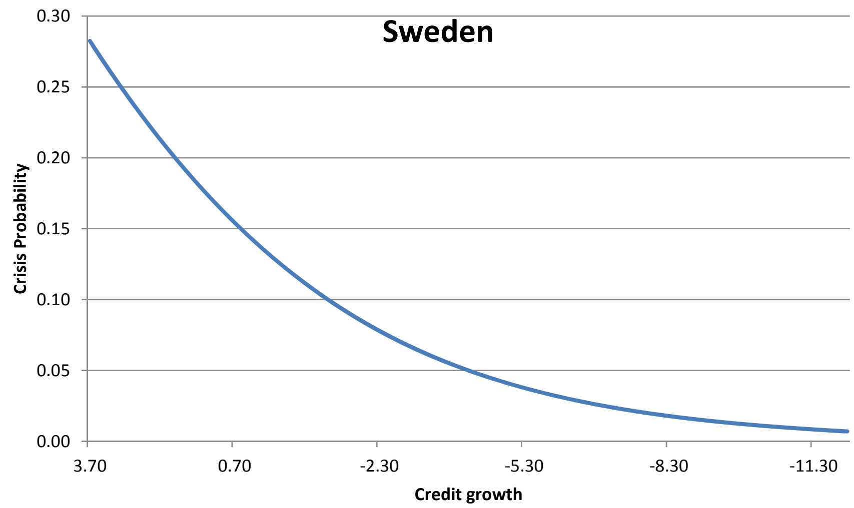
Heterogeneity in spillover effects (Type 1)

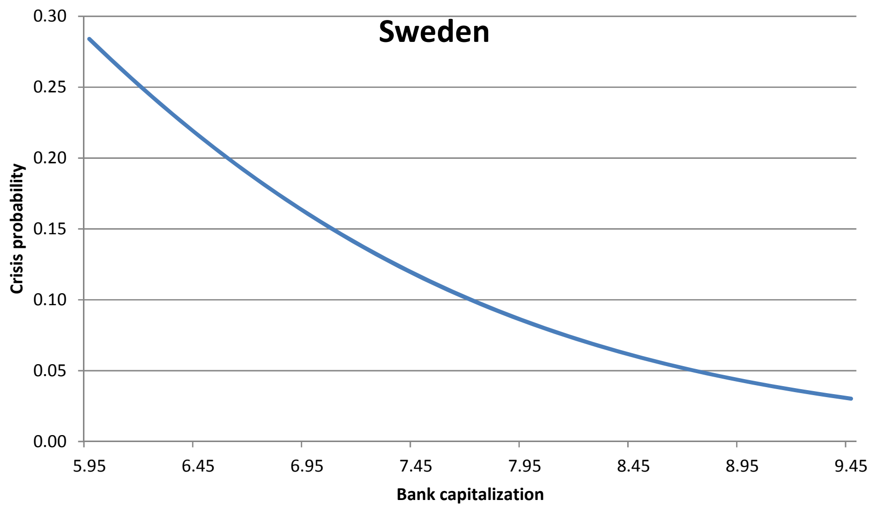


Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- Spillover effects can go in different directions, considerable heterogeneity
- For larger countries (DE, ES, FR, IT, GB) they tend to be negative at the current stage of cycle

Nonlinearities in impact on predicted probabilities



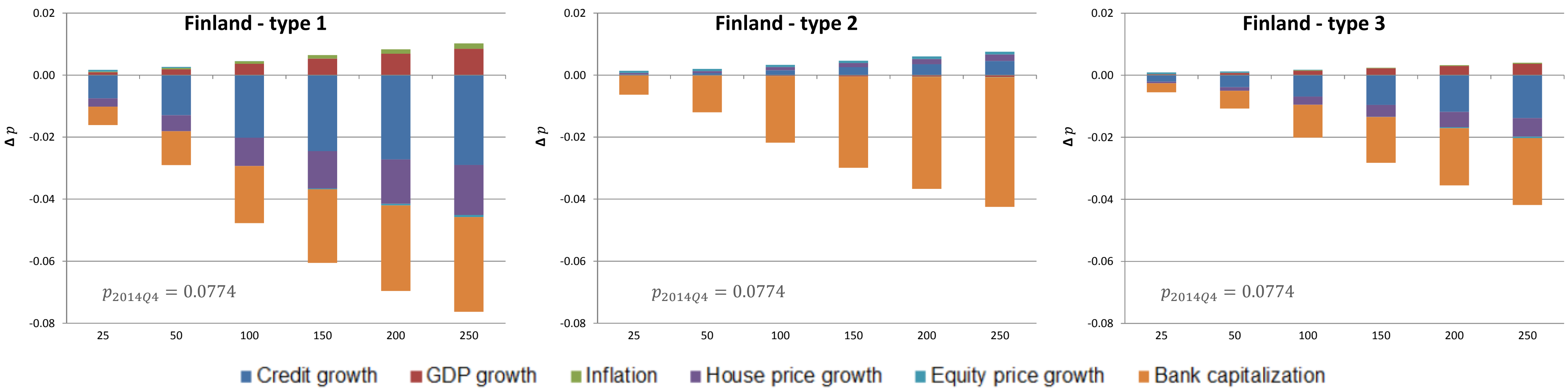


- Graphs show the influence of reductions in credit growth / increases in bank capitalization on predicted crisis probabilities, keeping all other variables fixed at their values in 2014Q4
- Convexity in the response functions: impact of further reductions / increases decreases in already achieved reductions / increases

Transmission channels – Calculation of contributions

- Aim: assess the relative contribution of variables in a nonlinear model
- We make use of the following 4-step procedure:
  1. Feed responses of individual variables (obtained from GVAR) into the logit model, one by one, assuming that the other variables remain at their 2014Q4 values, and obtain predicted probabilities
  2. For each variable, calculate the change in the probability of being in a vulnerable state as the difference between average predicted probability over the simulation horizon and the predicted probability in 2014Q4
  3. Sum the changes in the probability of being in a vulnerable state obtained from step 2, and calculate the relative contribution of each variable as the change in probability for that variable divided by the sum of all changes in probability
  4. Multiply the relative contribution of each variable from step 3 with the aggregate reduction in crisis probabilities for the respective country from the model
- Alternative: make use of marginal effects in 2014Q4 to obtain linear approximations for the effects of individual variables on crisis probabilities

Transmission channels – The case of Finland



Note: The figures shows the contribution of individual variables to the change in the probability of being in a vulnerable state relative to 2014Q4 for different capital ratio shocks.

- Type 1 & 3:
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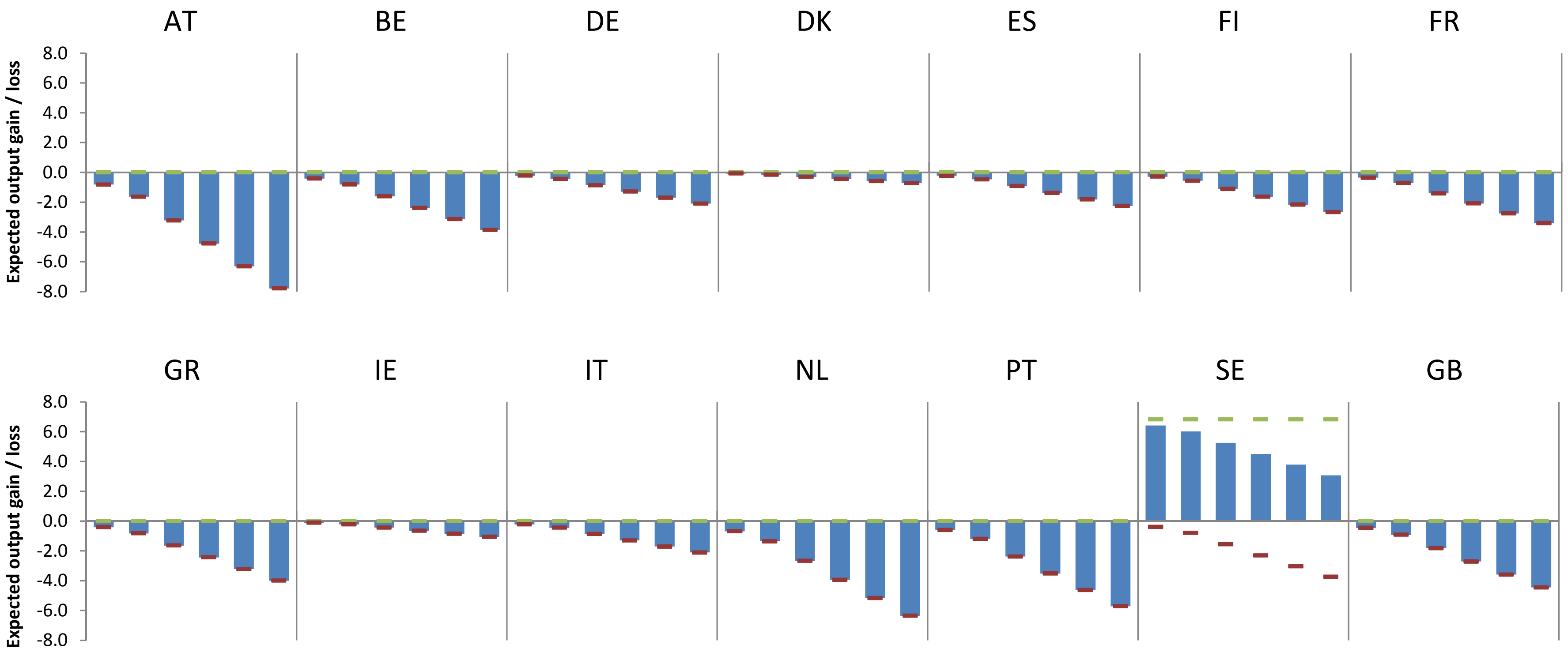
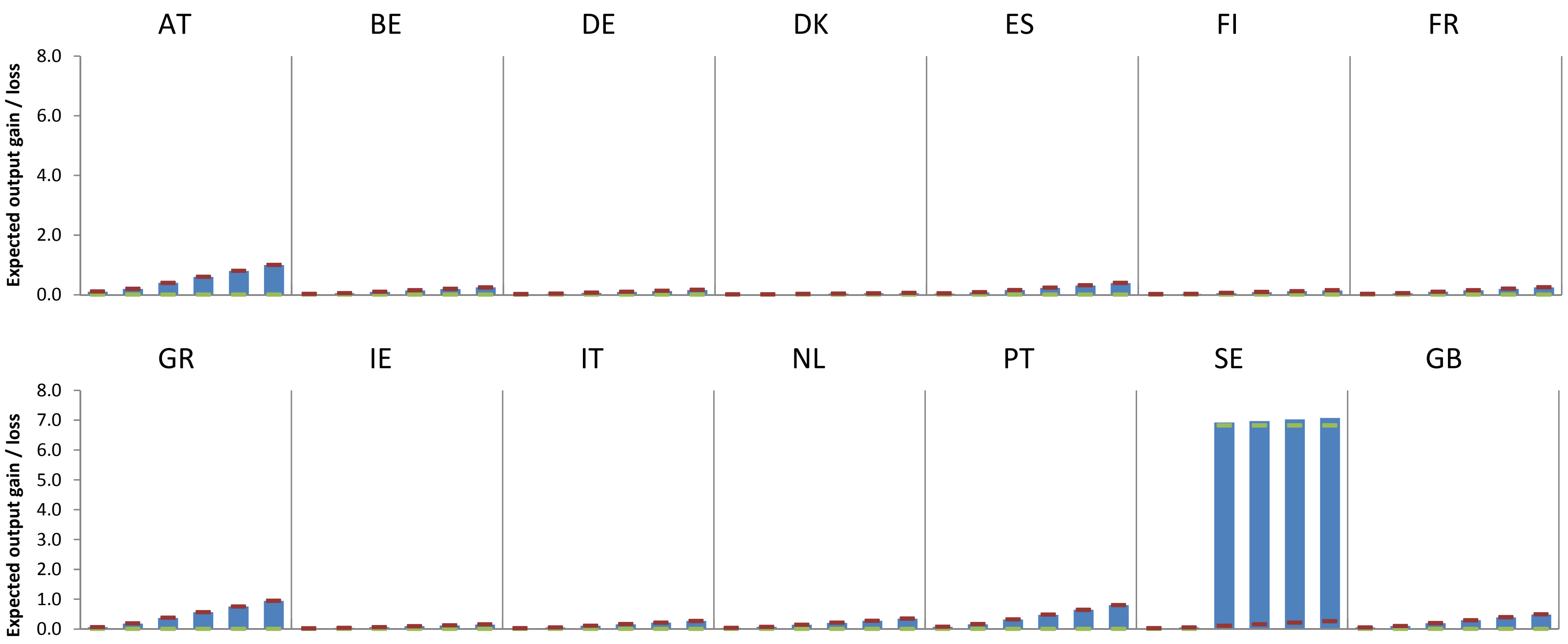
  - Reduction in GDP growth increases probability of being vulnerable
- Type 2:
  - Reduction almost entirely driven by increase in banking sector capitalization
  - Countervailing effects due to higher credit growth are of minor importance

Net benefits – alternative assessment (Type 1)



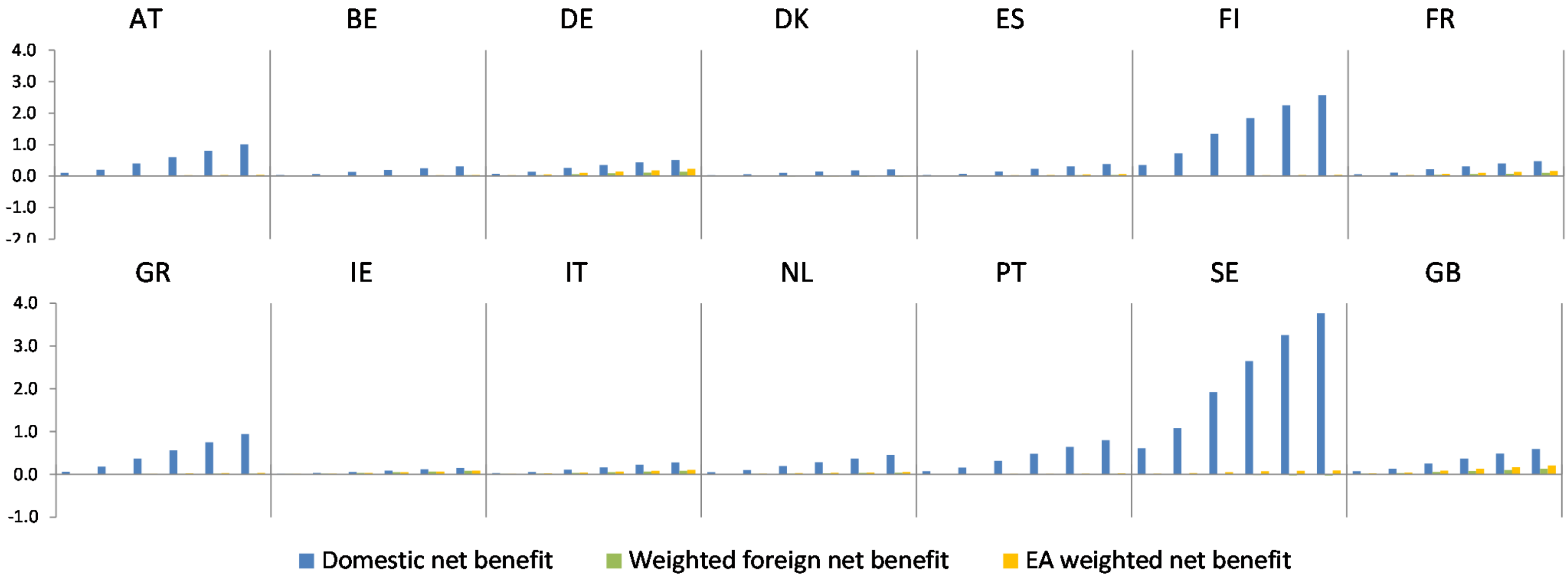
Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

Net benefits – alternative assessment (Type 2)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

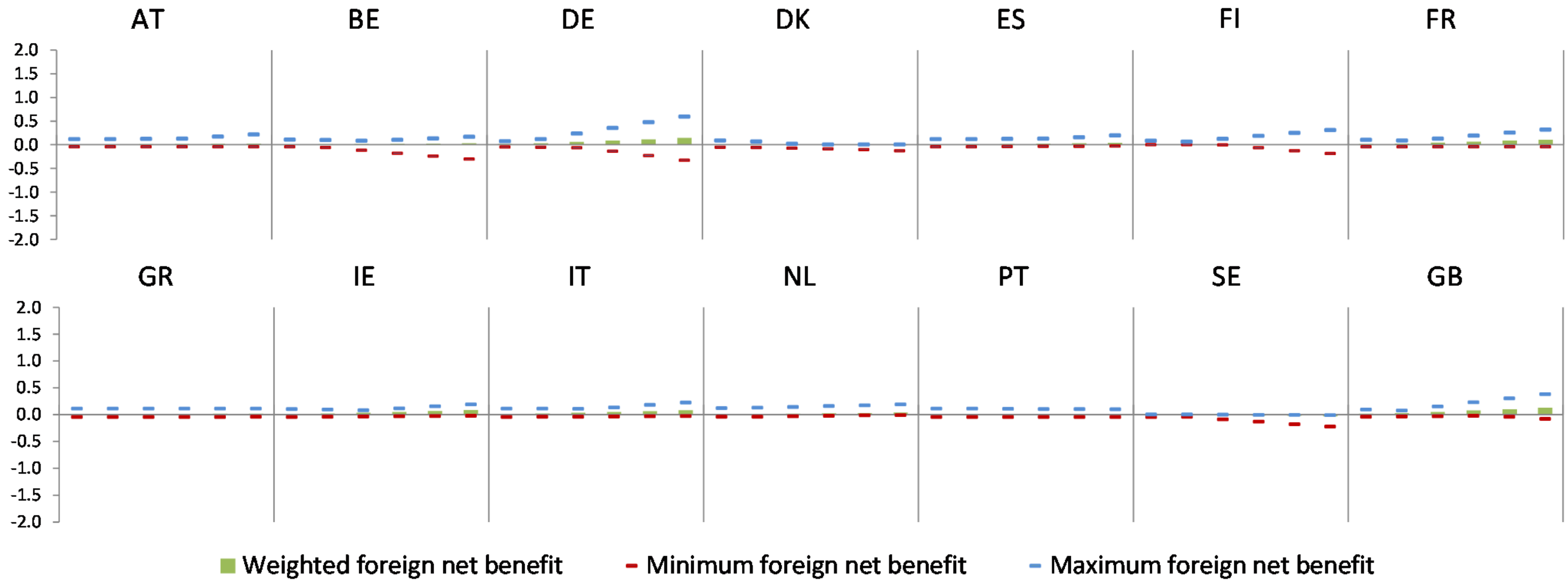
Spillovers – expansionary deleveraging (Type 2)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- Spillover effects much smaller for type 2 shocks, since credit, GDP and asset price responses are much less pronounced

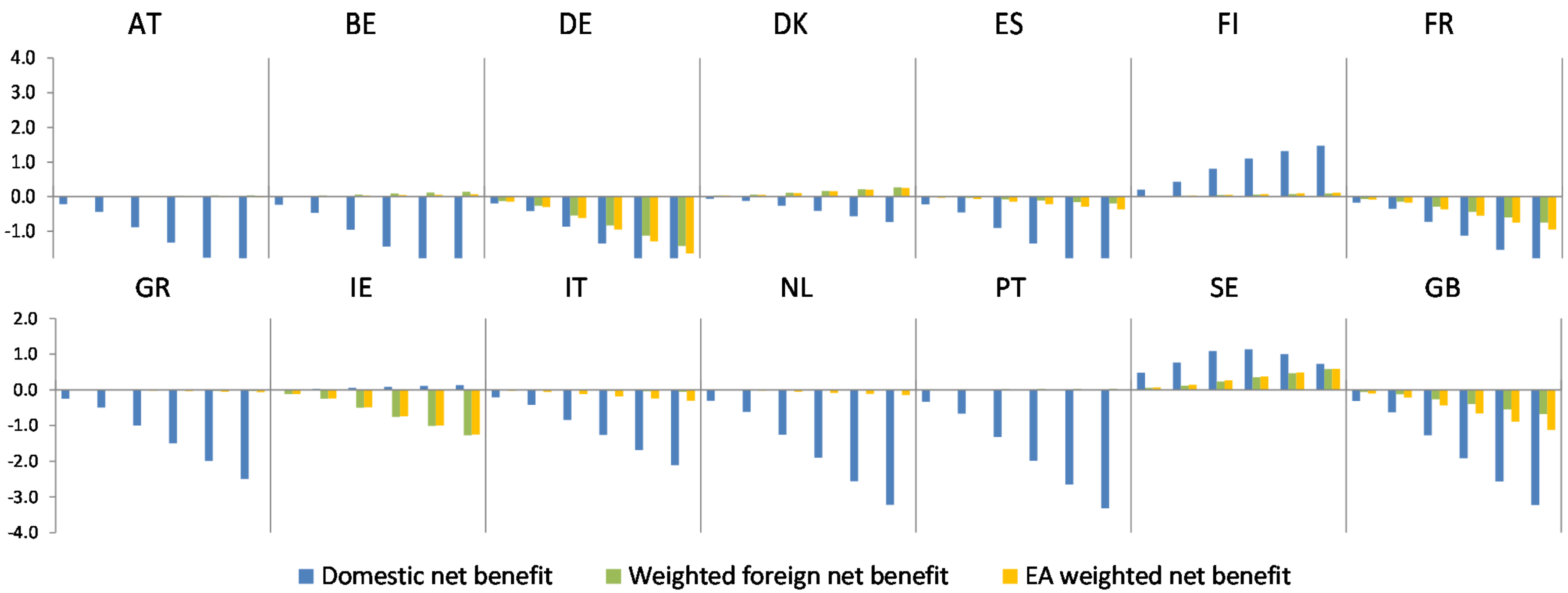
Heterogeneity in spillover effects (Type 2)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- No significant spillover effects for type 2 shocks

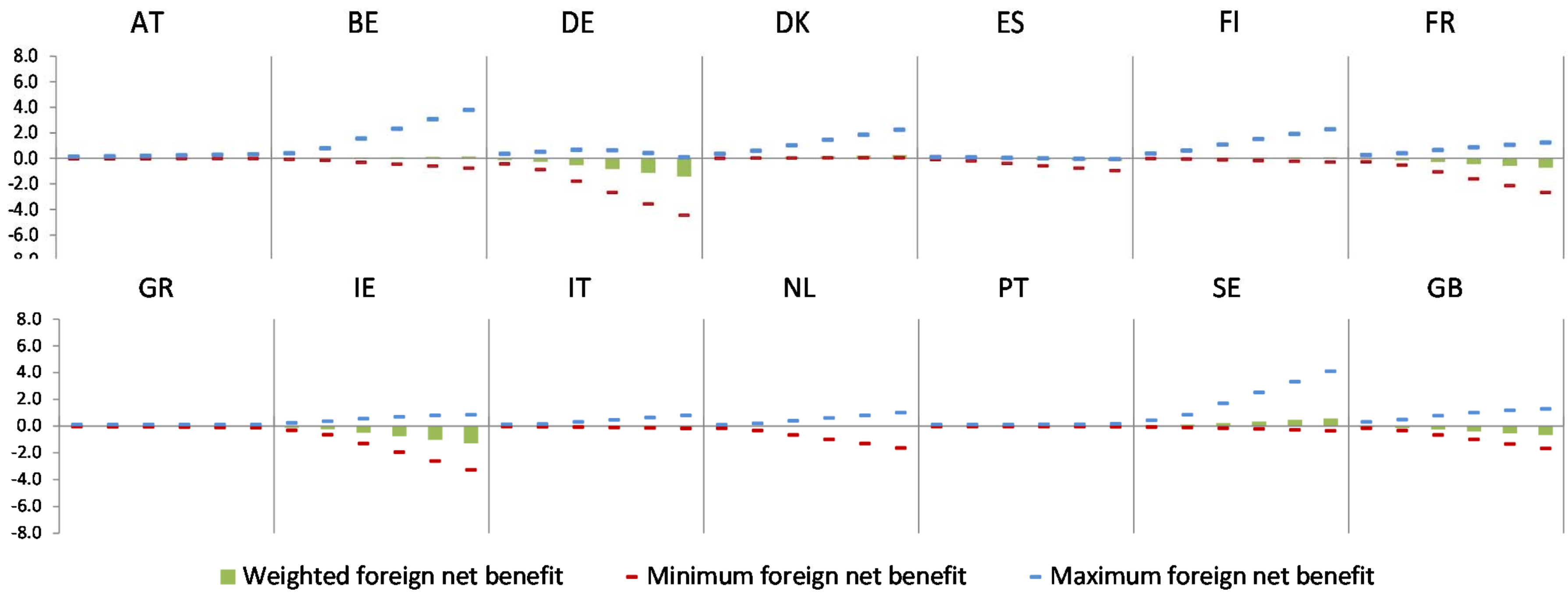
Spillovers – unconstrained deleveraging (Type 3)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- As before, type 3 effects are somewhere in between, closer to type 1

Heterogeneity in spillover effects (Type 3)



Note: Bars and markers for each country refer to capital ratio shocks of 25, 50, 100, 150, 200, and 250 bps, respectively.

- Spillover effects under type 3 simulation somewhat smaller but resemble those under type 1

Models used to estimate long-term cost of new regulatory framework

Table A4.1

Key features of the models used in the analysis

Model	Model type	Reference country/ area	Estimated/ calibrated	Features bank capital	Features bank liquidity	Key lending spread[1]
(1) Gerali et al (2010)	DSGE	euro area	largely estimated	yes	no	$i_l - i_d$
(2) Roger and Vlcek (2010)	DSGE	euro area	calibrated	yes	yes	$i_l - i_d$
(3) Roeger[2] (2010)	DSGE	euro area	calibrated	yes	yes	$i_l - i_d$
(4) Christiano et al (2010)	DSGE	euro area	estimated	yes	yes	$i_l - i_d$
(5) Antipa et al (2010)	DSGE	euro area	estimated	no	no	$i_l - i_d$
(6) Roger and Vlcek (2010)	DSGE	US	calibrated	yes	yes	$i_l - i_d$
(7) Van den Heuvel (2008)	DGE	US	calibrated	yes	no	$i_l - i_d$ $i_e - i_d$
(8) Curdia and Woodford (2009)	DSGE	US	estimated	no	no	$i_l - i_d$
(9) Dellas et al (2010)	DSGE	US	calibrated	no	yes	$i_l - i_d$
(10) Meh and Moran (2008)	DSGE	US	calibrated	yes	no	$i_l - i_d$
(11) Locarno (2004)	Semi-structural	Italy	estimated	no	no	$i_l - i_d$ $i_b - i_d$
(12) Bank of England	Semi-structural	UK	estimated	no	no	*n.a.*
(13) Gambacorta (2010)	VECM	US	estimated	yes	yes	$i_l - i_m$

[1] i_l: interest rate on loans to firms; i_b: interest rate on long-term bonds; i_d: interest rate on bank deposits; i_e: return on bank equity; i_m: monetary policy rate. [2] Model calibrated based on eight euro area countries.

Source: BIS 2010, An assessment of the long-term economic impact of stronger capital and liquidity requirements

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