Sovereign Debt Crises and Financial Contagion

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Motivation

- European sovereign debt crisis has generated substantial fears of financial contagion
  - Default of one sovereign leads to default of others
  - Potential for default elevates credit risk and cost of borrowing throughout Europe

"It was the ECB's responsibility, Mr Draghi insisted, to point out the costs of a Greek default, which would result from any attempt to impose costs on private sector investors. '*We have to be pragmatic. . . We could have a chain of contagion*,' he said." – [Financial Times, 6/14/11]

"*The report ignores the interconnected nature of the euro area member states. Private debt restructuring would have certainly risked systemic contagion at that stage*." –[Spokesman for Olli Rehn, EU Commissioner, Economic Affairs]

"[Action] *has to be done now, has to be done very fast. It's not a question of the danger of contagion. Contagion has already happened.*" –[Angel Gurria, OECD Secretary General]

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- Risk of contagion can (potentially) justify bailouts
  - Donor countries benefit by reducing or eliminating contagion externality that would impact their own economies
  - Not simply a handout to a distressed sovereign

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- A rich theoretical literature has developed on contagion in financial networks

- Little empirical work formally related to these models

- We provide an assessment of the potential for contagion in the ongoing Eurozone sovereign debt crisis based on a simple network model

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  - Similar trends in debt loads

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- Primary contagion mechanism in theoretical literature is direct effect on the budget constraint ("balance sheet" effect)
  - Default of one entity reduces the assets of its creditors $\rightarrow$ increases their probability of default
  - Cascade of defaults may occur due to interconnected borrowing-lending relationships

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  - Cascade of defaults may occur due to interconnected borrowing-lending relationships
- Alternative contagion mechanisms (*not this paper*):
  - Fragile beliefs; learning about a hidden state variable
  - Potential role for contagion via updating of beliefs
  - Policy remedies less clear

Related work on financial networks and sovereign default

- Theoretical literature on financial networks: Allen and Gale (2000); Babus (2013); Acemoglu, Ozdaglar, and Tahbaz-Salehi (2013); Elliott, Golub, and Jackson (2013)
  - One-shot models (t=0,1,2), liquidity or productivity shocks, simple default rules
  - Particular interest in network structure and potential for contagion

- Models of linkages between sovereign and financial sector: Acharya, Drechsler, Schnabl (2012); Bolton and Jeanne (2012)

- Sovereign default literature: Eaton and Gersovitz (1981); Arellano (2008); Aguiar and Gopinath (2006)
  - Default is optimal choice in some states of the world
  - No network, no interdependencies among debtors (recent exception: Arellano and Bai 2013)

- Credit risk of sovereigns: Pan and Singleton (2008); Longstaff, Pan, Pedersen, and Singleton (2011); Ang and Longstaff (2013)

Overview

1. Simple model of default in a network of sovereign borrowing and lending (exogenous default rule)

2. Estimate model with data on financial linkages among countries, sovereign debt loads, GDP, and CDS rates

3. Measure direct contagion mechanism as distinct from country-specific factors and common macroeconomic shocks

4. Use simulations from model to assess interdependencies among sovereign borrowers and risk of contagion
   - How default of one sovereign affects credit risk of others
   - Construct "contagion centrality" measure, examine differences across sovereigns and changes over time

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   - How default of one sovereign affects credit risk of others
   - Construct "contagion centrality" measure, examine differences across sovereigns and changes over time

Find small effects overall, but substantial increase in potential for contagion and informative differences based on network position

Model: A Network of Sovereigns

- N large economies (not massless)
  - Borrowing and lending network: $L_t = [l_{ij,t}]$
  - Total debt: D_{it} = internal + in-network ($\sum_{j \neq i} l_{ji,t}$) + external
  - Aggregate output: Y_{it}
  - Financial shocks: X_{it}

- Broader framework, not explicitly modeled:

  Each period t, countries are endowed with bilateral claims ($l_{ij,t}$) and total debt (D_{it}), then:

  1. Output (Y_{it}) and financial shocks (X_{it}) are realized
  2. Solvency (s_{it}) is jointly determined among the countries in the network
  3. Solvent countries make borrowing and lending decisions for the next period ($D_{i,t+1}$, $l_{ij,t+1}$)

- Our model pertains to step 2 – default and contagion in short run

Solvency and Repayment Equilibrium

- General solvency condition:

$$s_{it} = \mathbb{1}\{\underbrace{g(R_{it}, Y_{it})}_{\text{revenues}} - \underbrace{h(D_{it}, X_{it})}_{\text{obligations}} > \pi\} \tag{1}$$

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- R_{it} : total repayments received from other sovereigns
  - if country j is solvent, i receives $l_{ij,t}$ (inclusive of interest rate)
  - if country j defaults, i receives $\delta l_{ij,t}$ (exogenous recovery rate)

  ...result:

$$R_{it} \equiv \sum_{j \neq i} l_{ij,t}[\delta + (1-\delta)s_{jt}]$$

- Equilibrium is a vector $(s_{it})_{i=1}^{N}$ that solves the system of equations (1)

Equilibrium Selection

Multiple equilibria are possible:

- Suppose for all $k \neq i, j$, solvency does not depend on s_{it}, s_{jt} (e.g., $g(R_{kt}, Y_{kt}) - h(D_{kt}, X_{kt}) \gg \pi$)
- But for i and j, solvency depends on whether they pay each other back (i.e., $(1-\delta)l_{ijt}$ makes the difference for country i)

We select the "best-case" equilibrium where the largest number of countries remain solvent:

- To find it, first compute R_{it} with $s_{jt} = 1, \ \forall j$
- Determine which countries would still default
- Update R_{it} for all countries, repeat until convergence

Focus on best case is similar to Elliott et al. (2013); seems likely outcome if there were some coordination mechanism

Empirical Approach

Empirical Approach

CDS rates reflect market expectations of default probabilities and losses given default

- Beliefs about solvency in period t, based on information available at end of period $t-1$:

$$p_{it} \equiv \mathrm{E}[s_{it} | \underbrace{L_t, D_t, Y_{t-1}, X_{t-1}}_{\text{network-wide}}]$$

- Need distributions of $Y_t|Y_{t-1}$ and $X_t|X_{t-1}$
- Then apply solvency condition and selection rule to compute p_t

Specification

- Changes in output are predicted by both common and country-specific shocks to GDP

$$\mathrm{E}[Y_{it}|Y_{t-1}] = \beta_0 + \beta_1 Y_{t-1}^{com} + \beta_2 Y_{i,t-1}^{own}$$

$Y_{it}|Y_{t-1}$ has a normal distribution around this mean

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- Financial shocks X_{it} are assumed to be IID normal...
- Could include other variables: $g(R_{it}, Y_{it}, Z_{1it}) - h(D_{it}, X_{it}, Z_{2it})$
- Current empirical specification:

$$(p_{it})_{i=1}^{N} = \int 1\left\{R_{it} + \beta_0 + \beta_1 Y_{t-1}^{com} + \beta_2 Y_{i,t-1}^{own} + \gamma I_{i,t-1} - \alpha_1 D_{it} - \alpha_2 D_{it}^2 - u_{it} > 0\right\}_{i=1}^{N} \cdot \mathrm{d}F(u_{1t} \ldots u_{Nt})$$

$I_{i,t-1}$ is aggregate investment
$u_{it} \sim \mathcal{N}(0, \sigma^2)$ combines X_{it} and the deviation of Y_{it} from its mean

Data

Data

- Bilateral borrowing-lending relationships taken from Bank for International Settlements (BIS)
  - Claims held by banks in a set of reporting countries with established banking industries
  - Larger set of counterparty countries, but we restrict to reporting countries (can be both borrowers and lenders)
- Rates charged for 5-year CDS contracts, collected from CMA
- Macroeconomic and financial data from IMF and OECD:
  - Government debt (total and external)
  - Yields on 10-year sovereign bonds
  - GDP growth rates
  - Investment – fixed capital formation

Countries in the sample

Sample partly determined by availability of data on foreign claims (BIS) and CDS prices (CMA)

Austria	AT	Ireland	IE
Australia	AU	Italy	IT
Belgium	BE	Japan	JP
Spain	ES	Netherlands	NL
Finland	FI	Portugal	PT
France	FR	Sweden	SE
Germany	DE	United Kingdom	GB
Greece	GR	United States	US

Sample period is 2005-Q1 to 2011-Q3

Construction of debt cross-holdings matrix (L_t)

- BIS reports asset holdings of financial institutions according to country of counterparty at a quarterly frequency
- This gives cross-exposure of asset holdings between countries
  - All assets, not just sovereign debt
  - Held by financial sector

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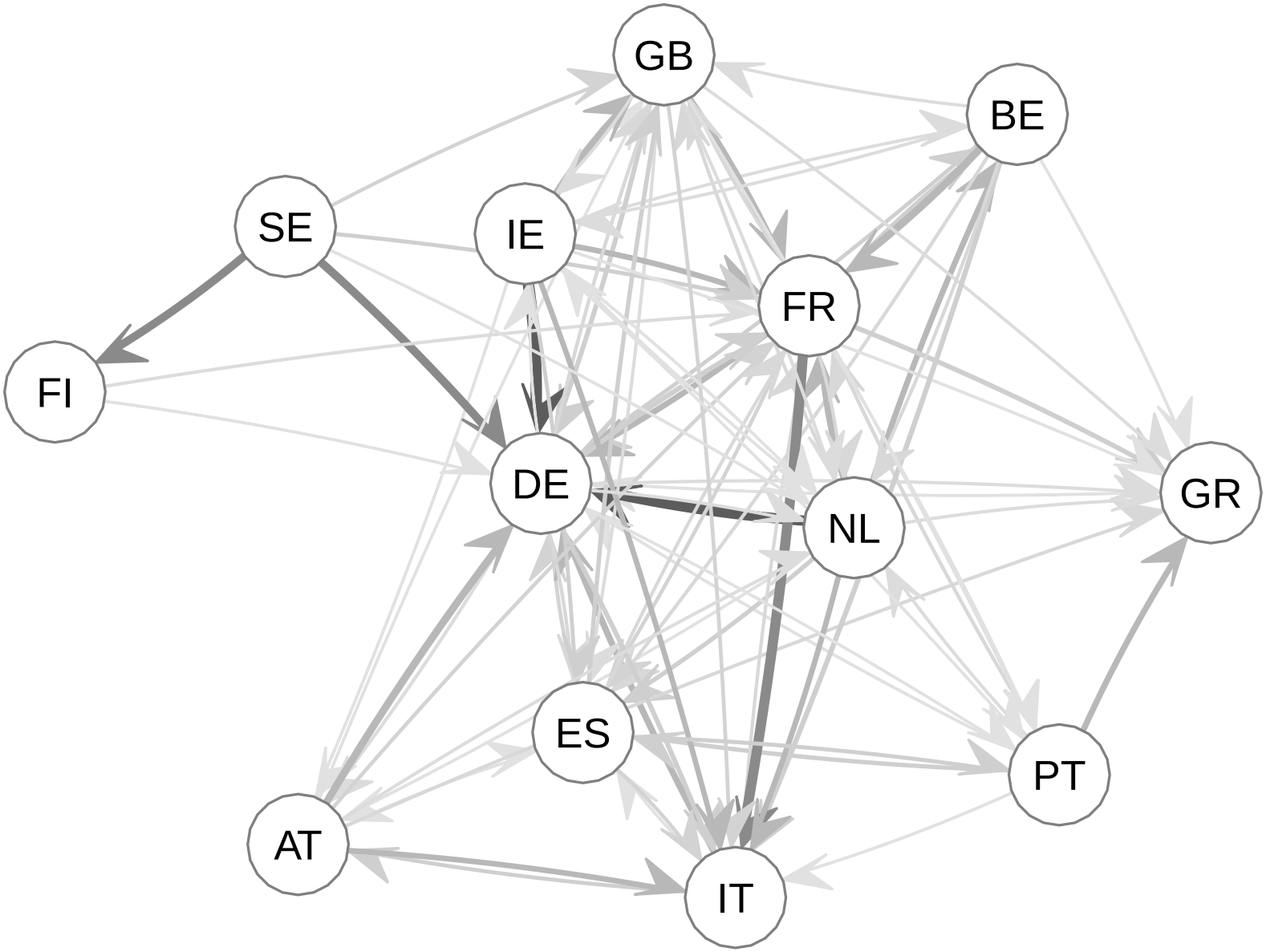
  - Held by financial sector
- IMF reports the fraction of a sovereign's debt held by foreign entities at a quarterly frequency (recent data release)
- Use weights derived from the BIS data to allocate each sovereign's foreign debt across the other countries in the network $\rightarrow$ approximates the exposure of one sovereign to another

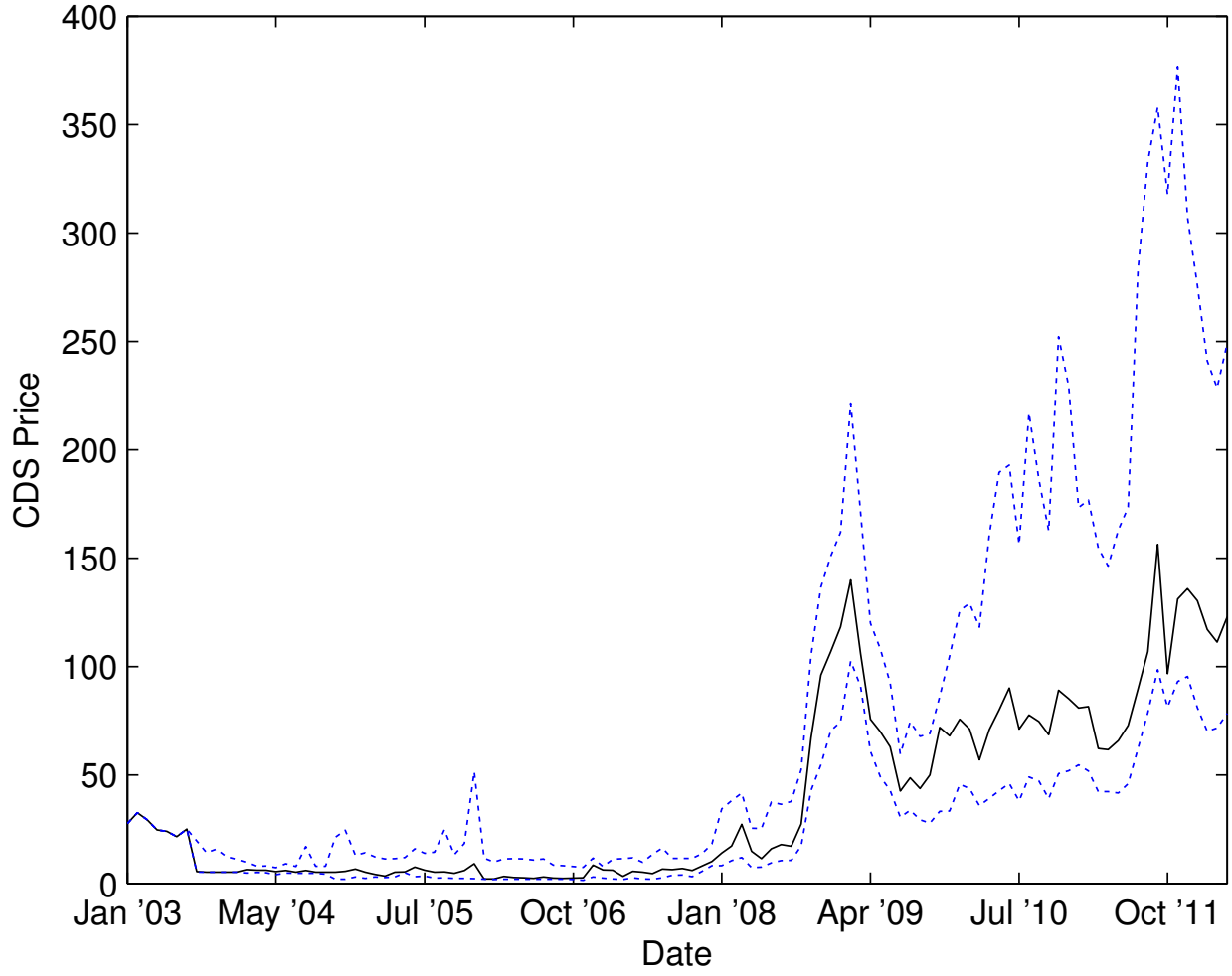
Borrowing-Lending Network, 2011-Q1



CDS contracts

- Credit default swap insures a buyer against a credit event
- Buyer pays a semi-annual premium – basis points on the contracted amount
- In exchange receives a contingent payoff in a credit event
  - Settlement is a swap where the buyer delivers an admissible bond in exchange for the original face value of the bond
- Given an assumed recovery rate on defaulted bonds, we can use the CDS spread to impute a (risk-neutral) default probability for the referenced entity (i.e., sovereign borrower)

Time Series of CDS Spreads



(Quartiles, 5-year sovereign CDS)

Principal components analysis of CDS and GDP

CDS Spreads

	Proportion of Variation	Cumulative Variation
PC 1	0.640	0.640
PC 2	0.248	0.888

GDP Growth Rates

	Proportion	Cumulative
PC 1	0.630	0.630
PC 2	0.079	0.709

- Significant commonality in sovereign CDS spreads
- As much commonality as GDP growth (or more)
- Due to common shocks or contagion?

Estimation

Predicted solvency probabilities:

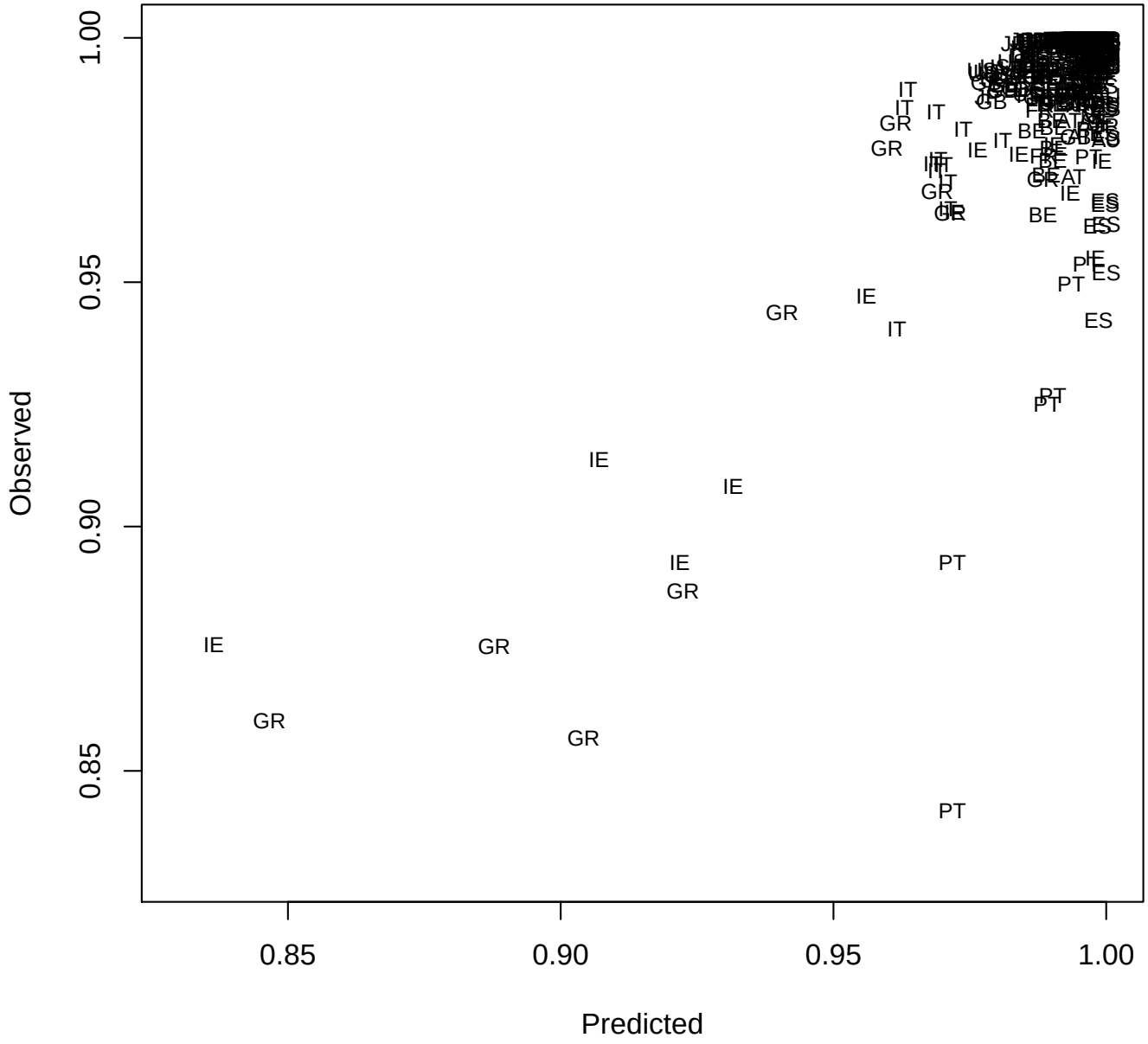
$$
\begin{aligned}
(\hat{p}_{it})_{i=1}^{N} &= \mathrm{E}[s_{it}|L_t, D_t, Y_{t-1}, X_{t-1}] \\
&= \int 1\left\{R_{it} + \beta_0 + \beta_1 Y_{t-1}^{com} + \beta_2 Y_{i,t-1}^{own} + \gamma I_{i,t-1} - \alpha_1 D_{it} - \alpha_2 D_{it}^2 - u_{it} > 0\right\}_{i=1}^{N}
\end{aligned}
$$

- Variables normalized relative to each country's GDP in 2004 ($l_{ij,t}$, I_{it}, D_{it}) or historical growth (Y_{it})
- Given parameters, compute solvency probabilities jointly for all sovereigns in the network via Monte Carlo integration
- Minimize distance between model-implied and empirical default probabilities (nonlinear least squares)
  - set $\delta = 0.4$ based on prior literature

Parameters

Parameter	Value
α_1	13.78
α_2	-3.60
β_0	10.70
β_1	17.50
β_2	53.34
σ	6.29
γ	71.15

Observed and Predicted Solvency Probabilities



Correlation = 0.76

Default Simulations

How does the default of one country affect the solvency of other European sovereigns in our network?

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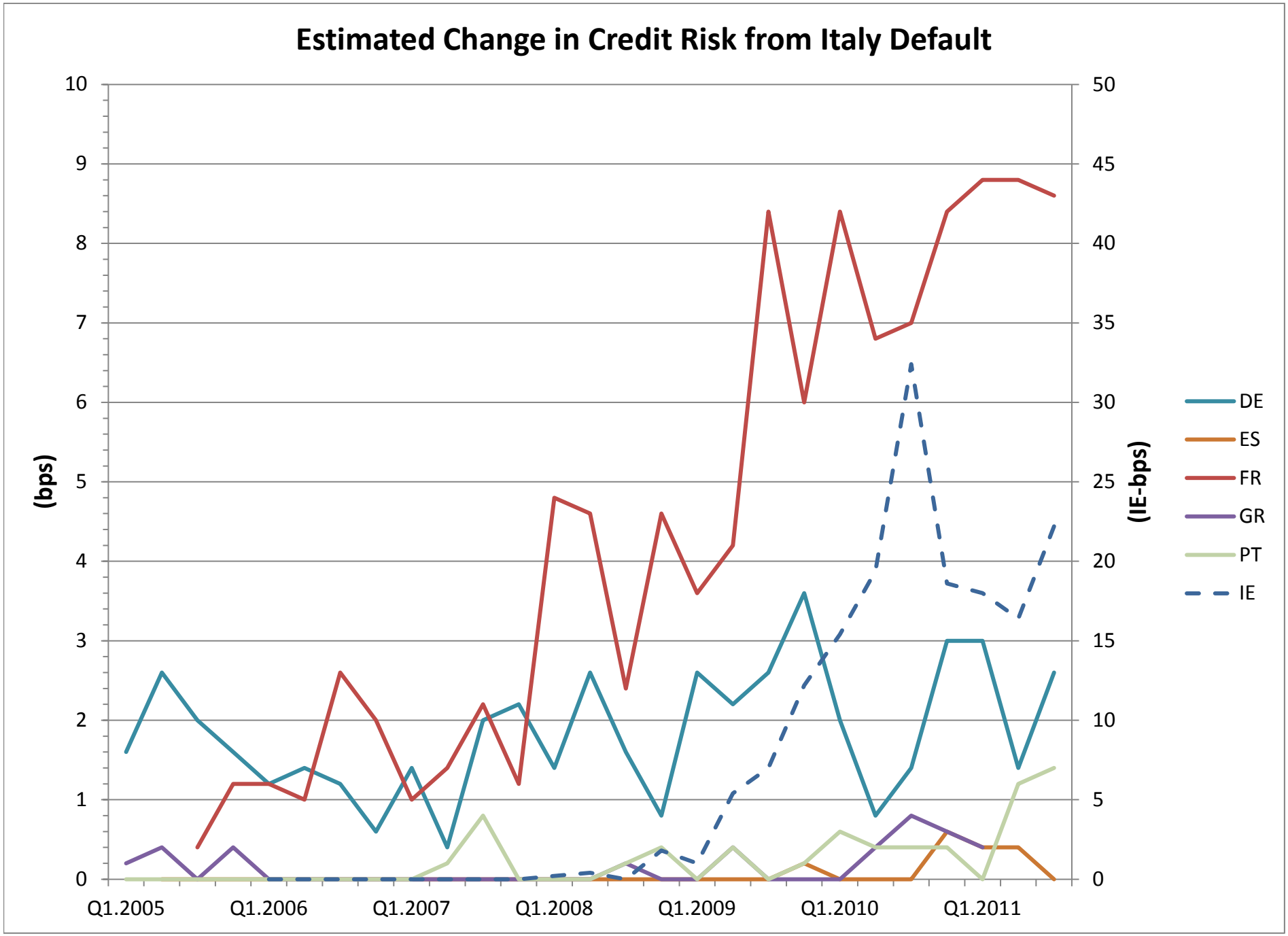
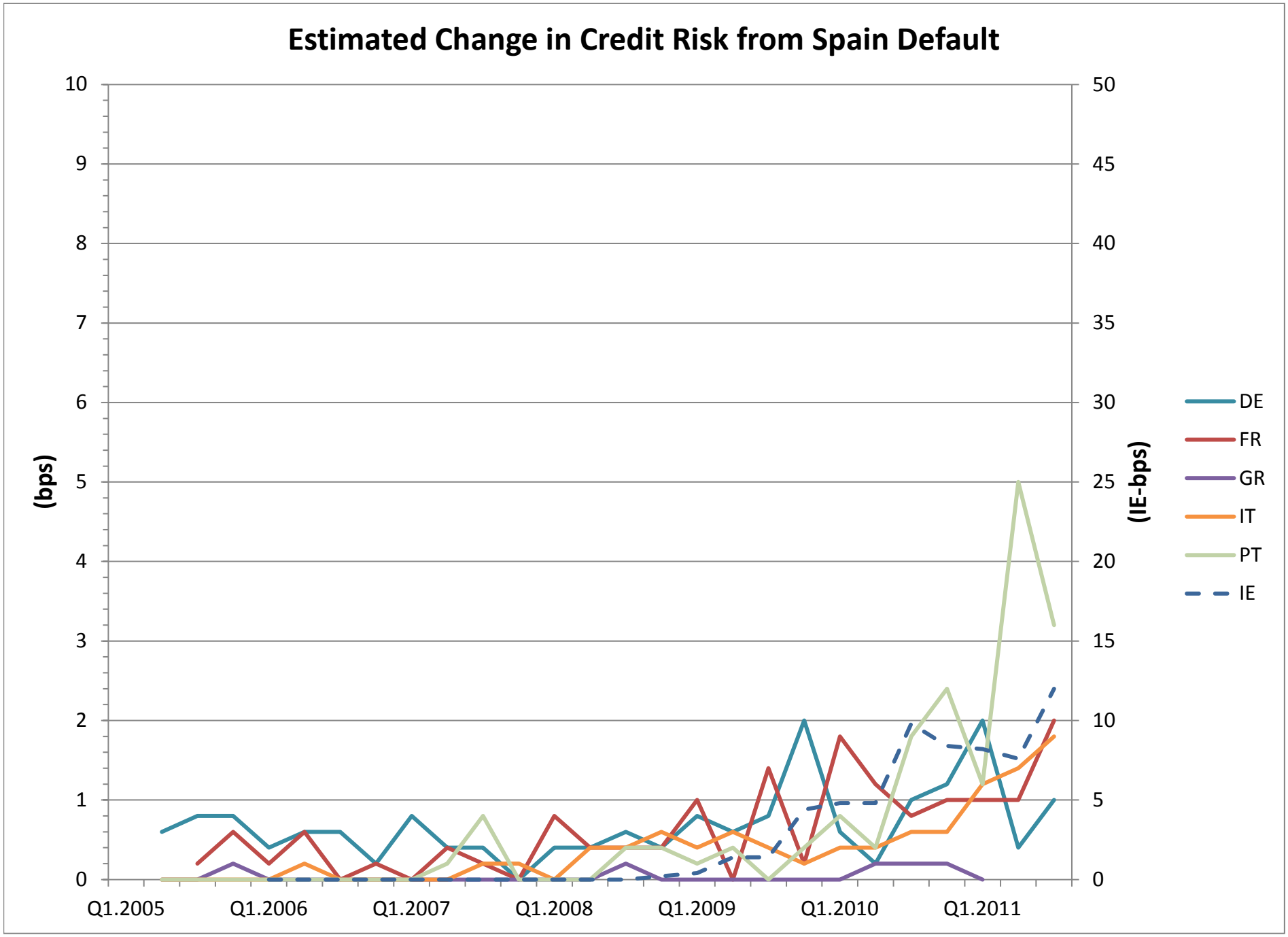
- Use estimated model to compute solvency probability for country j if country i defaults:

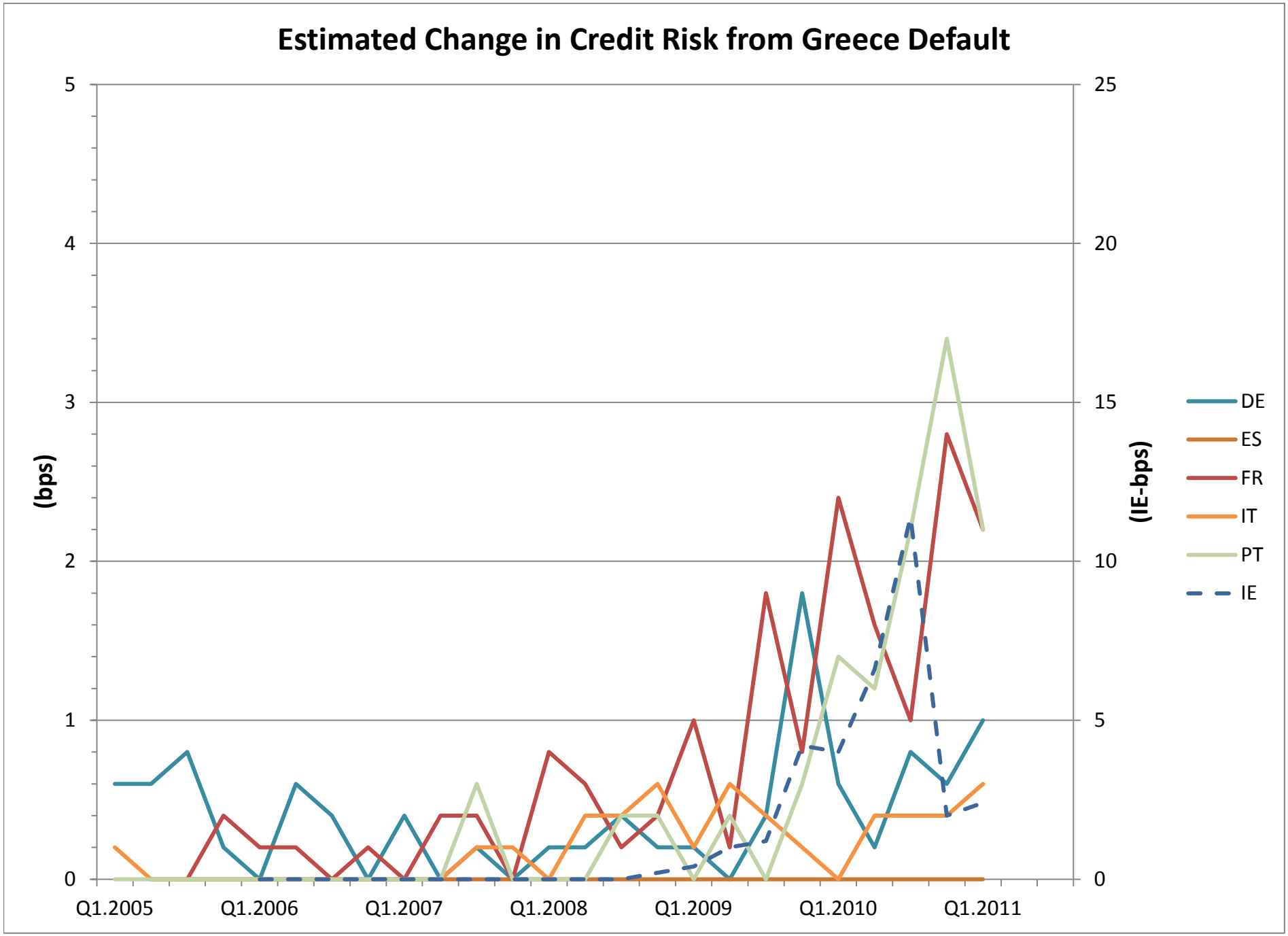
$$\tilde{p}_{jt}(i) = \mathrm{E}[s_{jt} | s_{it} = 0, \dots]$$

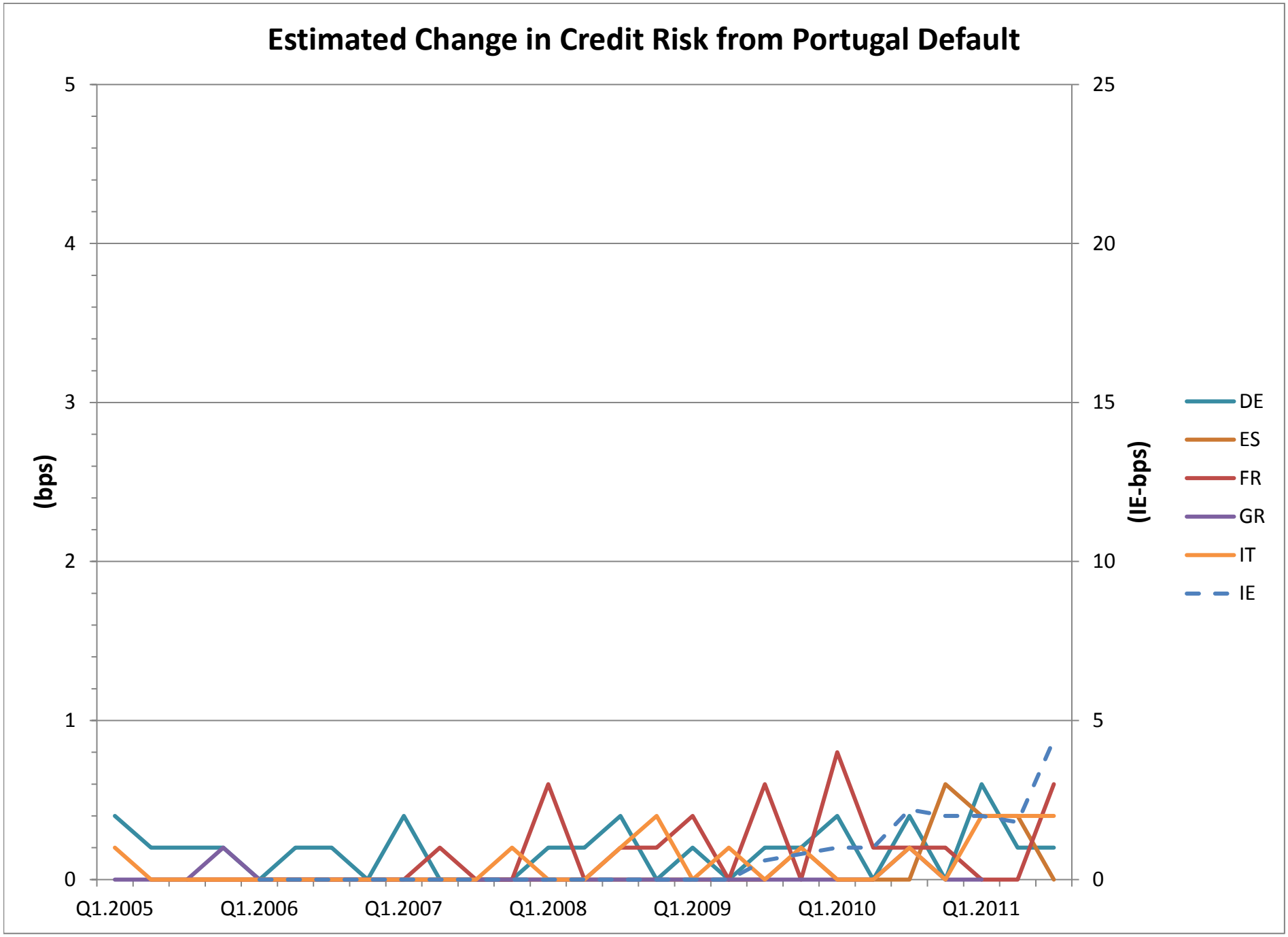
  - Compare with baseline predicted solvency probability to get change in probability of default at country j: $\hat{p}_{jt} - \tilde{p}_{jt}(i)$
  - Can interpret as change in credit risk

- Evaluate the effects of a default by:
  - Italy, Spain
  - Greece, Portugal


Estimated Change in Credit Risk from Italy Default
(bps)
(IE-bps)
10
9
8
7
6
5
4
3
2
1
0
50
45
40
35
30
25
20
15
10
5
0
Q1.2005
Q1.2006
Q1.2007
Q1.2008
Q1.2009
Q1.2010
Q1.2011
DE
ES
FR
GR
PT
IE


Estimated Change in Credit Risk from Spain Default
(bps)
(IE-bps)
10
9
8
7
6
5
4
3
2
1
0
50
45
40
35
30
25
20
15
10
5
0
Q1.2005
Q1.2006
Q1.2007
Q1.2008
Q1.2009
Q1.2010
Q1.2011
DE
FR
GR
IT
PT
IE


Estimated Change in Credit Risk from Greece Default
(bps)
(IE-bps)
5
4
3
2
1
0
25
20
15
10
5
0
Q1.2005
Q1.2006
Q1.2007
Q1.2008
Q1.2009
Q1.2010
Q1.2011
DE
ES
FR
IT
PT
IE


Estimated Change in Credit Risk from Portugal Default
(bps)
(IE-bps)
5
4
3
2
1
0
25
20
15
10
5
0
Q1.2005
Q1.2006
Q1.2007
Q1.2008
Q1.2009
Q1.2010
Q1.2011
DE
ES
FR
GR
IT
IE

Magnitude of the effects

- These effects aren't large – compare with average default probability of 100 bps
- Simulations only capture direct financial losses (main mechanism in the theoretical literature)
  - Controlled for common shocks to output
  - Assumed that the shock generating the initial default does not affect other sovereigns directly
  - No abrupt change in investor beliefs about credit risk (no hidden state to learn about)
- Other amplification mechanisms would involve problems with issuing further debt
  - Rolling over debt, debt spirals
  - Investment and economic output
  - Marginal utility of consumption in bad states of the world – affects interest rates required by investors

Differences across countries and over time

- Sovereigns with more debt outstanding obviously have bigger effects overall
- Strength of network ties is important factor

  Example – normalized claims on Italy in Q1 of each year:

	2005	2006	2007	2008	2009	2010	2011
France	0.087	0.086	0.146	0.227	0.229	0.276	0.297
Germany	0.092	0.075	0.071	0.086	0.074	0.074	0.087

- More vulnerable countries are more sensitive to losses (e.g., Ireland)

Network Centrality – a model-based measure

Is the debt of some borrowers potentially more contagious than others (per unit)?

Network Centrality – a model-based measure

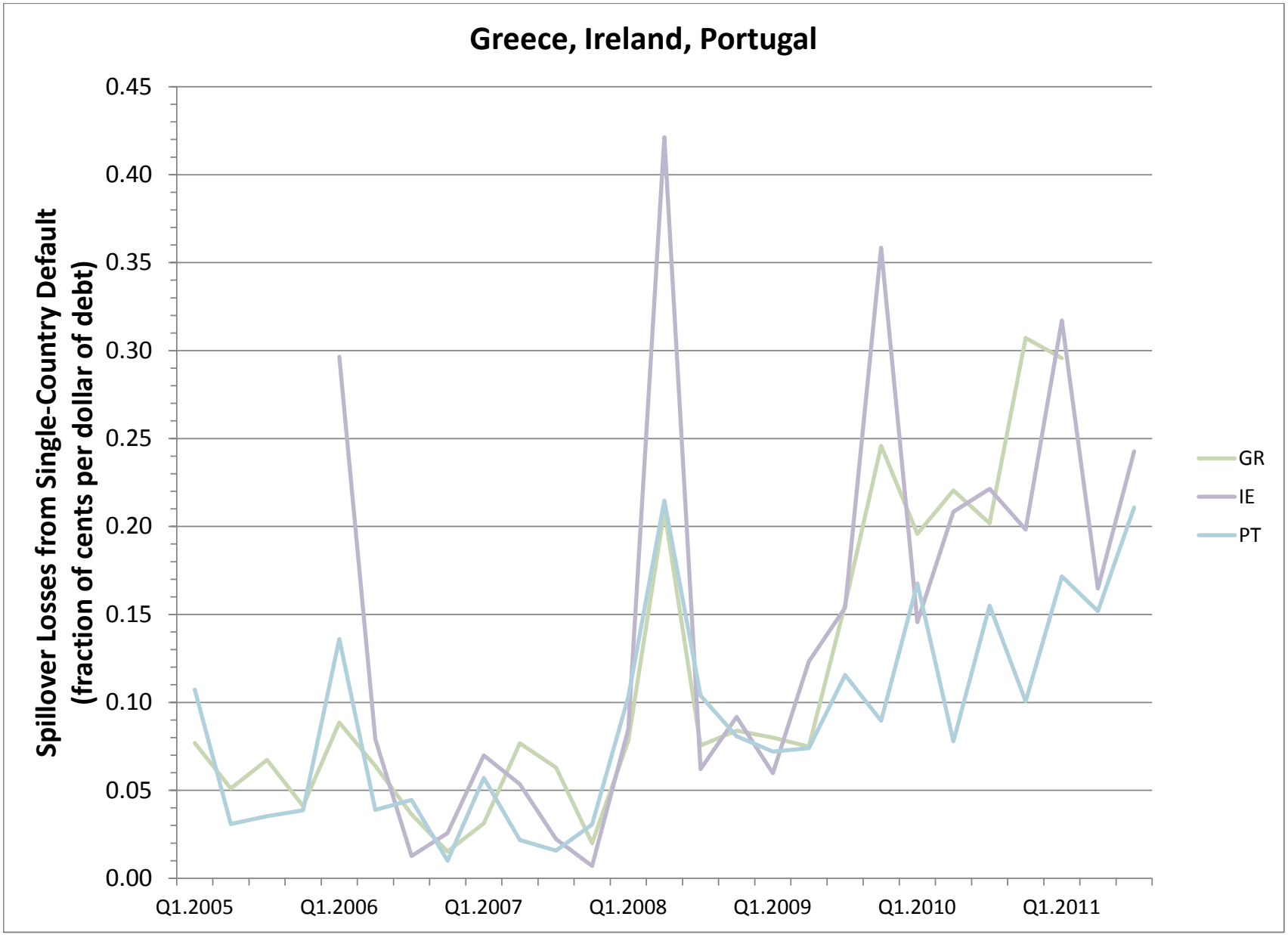
Is the debt of some borrowers potentially more contagious than others (per unit)?

- Construct a measure based on the expected spillovers from a single-country default
- Have changes in solvency probabilities from default simulations
  - Multiply by j's debt to get expected losses: $(\hat{p}_{jt} - \tilde{p}_{jt}(i))D_{jt}$
  - Add across j's (the creditors to i): $\sum_{j \neq i}(\hat{p}_{jt} - \tilde{p}_{jt}(i))D_{jt}$
- Normalize by the sovereign's total debt outstanding:

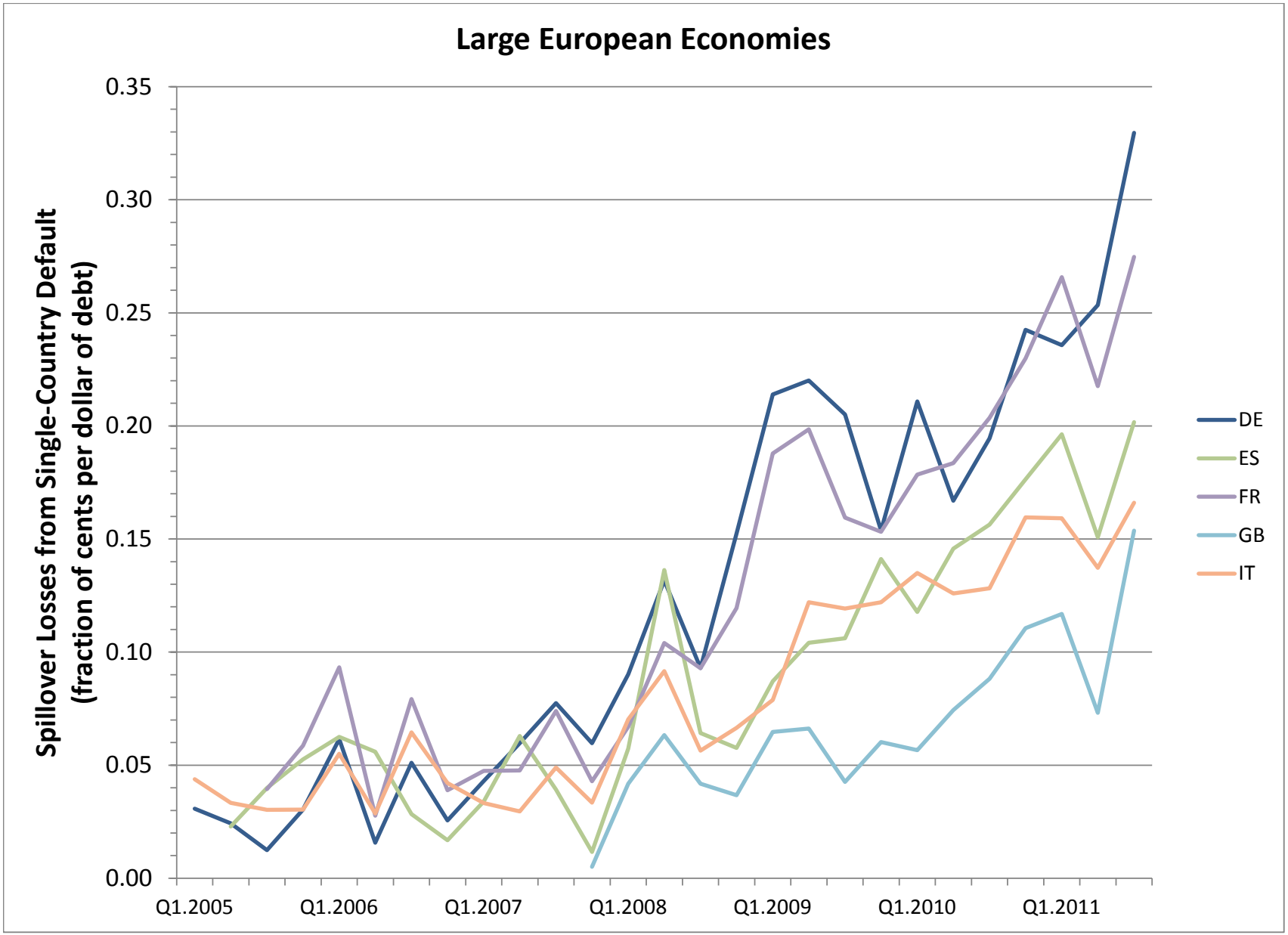
$$\lambda_{it} \equiv \frac{1}{D_{it}} \sum_{j \neq i} (\hat{p}_{jt} - \tilde{p}_{jt}(i))D_{jt}$$

Interpretation: *expected spillover losses per dollar of debt*

Expected spillover losses per dollar



Expected spillover losses per dollar



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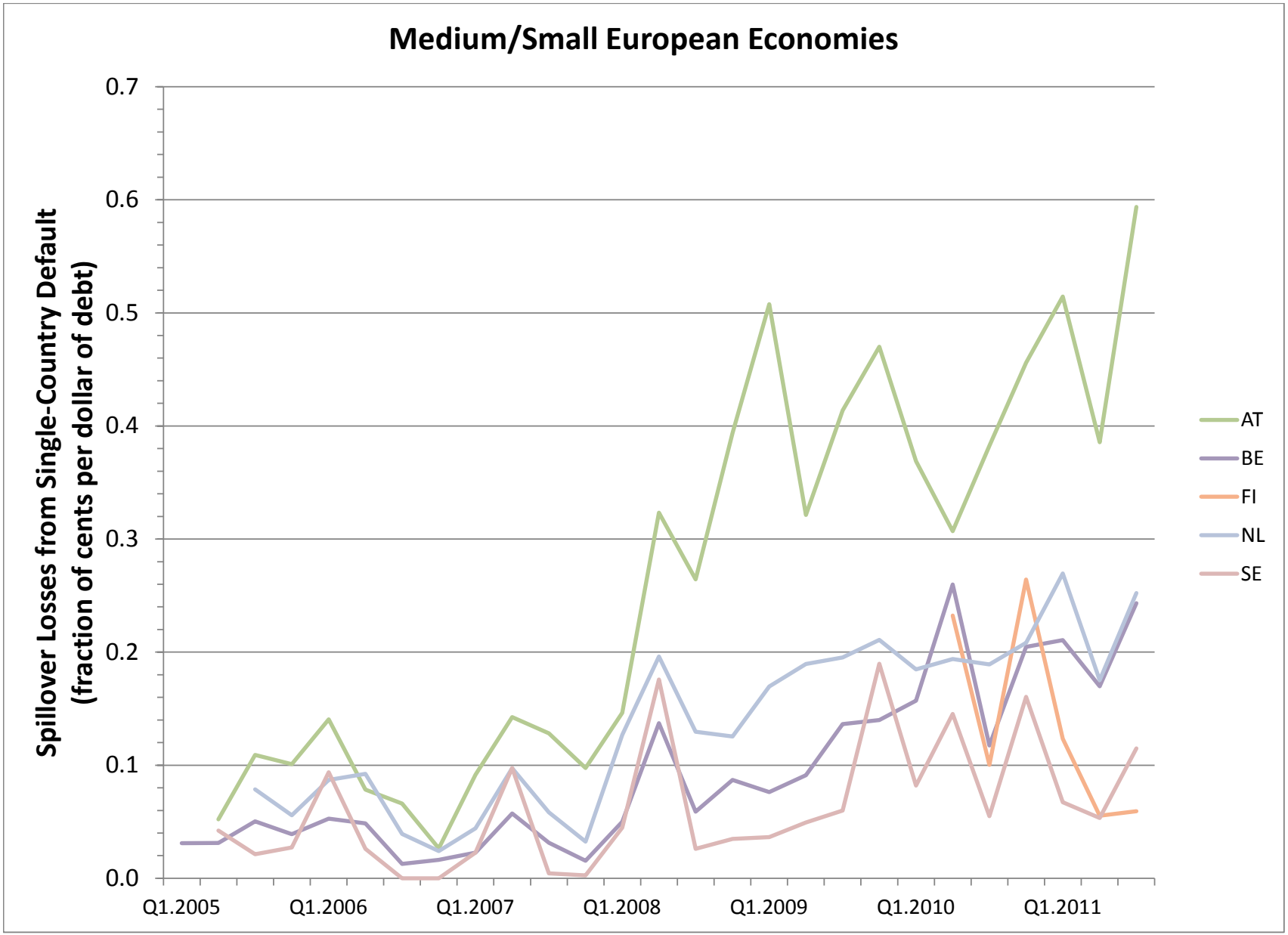


What makes a country more central?

To understand differences across countries in the potential for contagion, consider the case of Austria

Total debt load is roughly similar to Belgium:

	Austria	Belgium
2009 Q1	260	444
2010 Q1	272	481
2011 Q1	306	521

($ Billions)

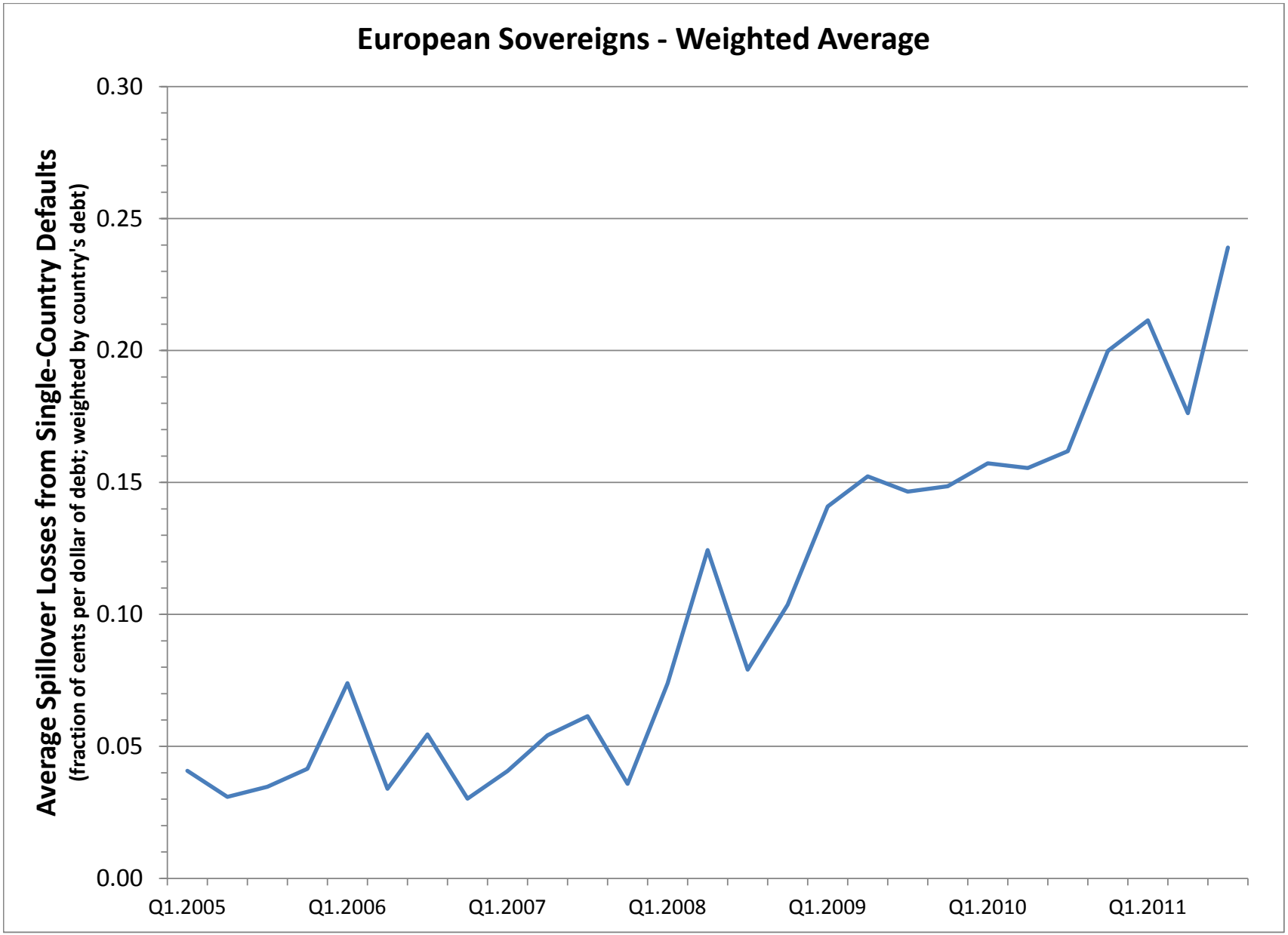
But allocation of debts is very different:

Creditor	Austria	Belgium
AT	0.000	0.006
BE	0.006	0.000
DE	0.027	0.008
ES	0.003	0.002
FI	0.002	0.001
FR	0.008	0.070
GB	0.003	0.009
GR	0.000	0.000
IE	0.016	0.020
IT	0.051	0.002
NL	0.012	0.120
PT	0.001	0.001
SE	0.003	0.006

(Normalized Claims, 2011 Q1)

- Owing proportionally more to relatively vulnerable creditors makes a sovereign more central under this measure

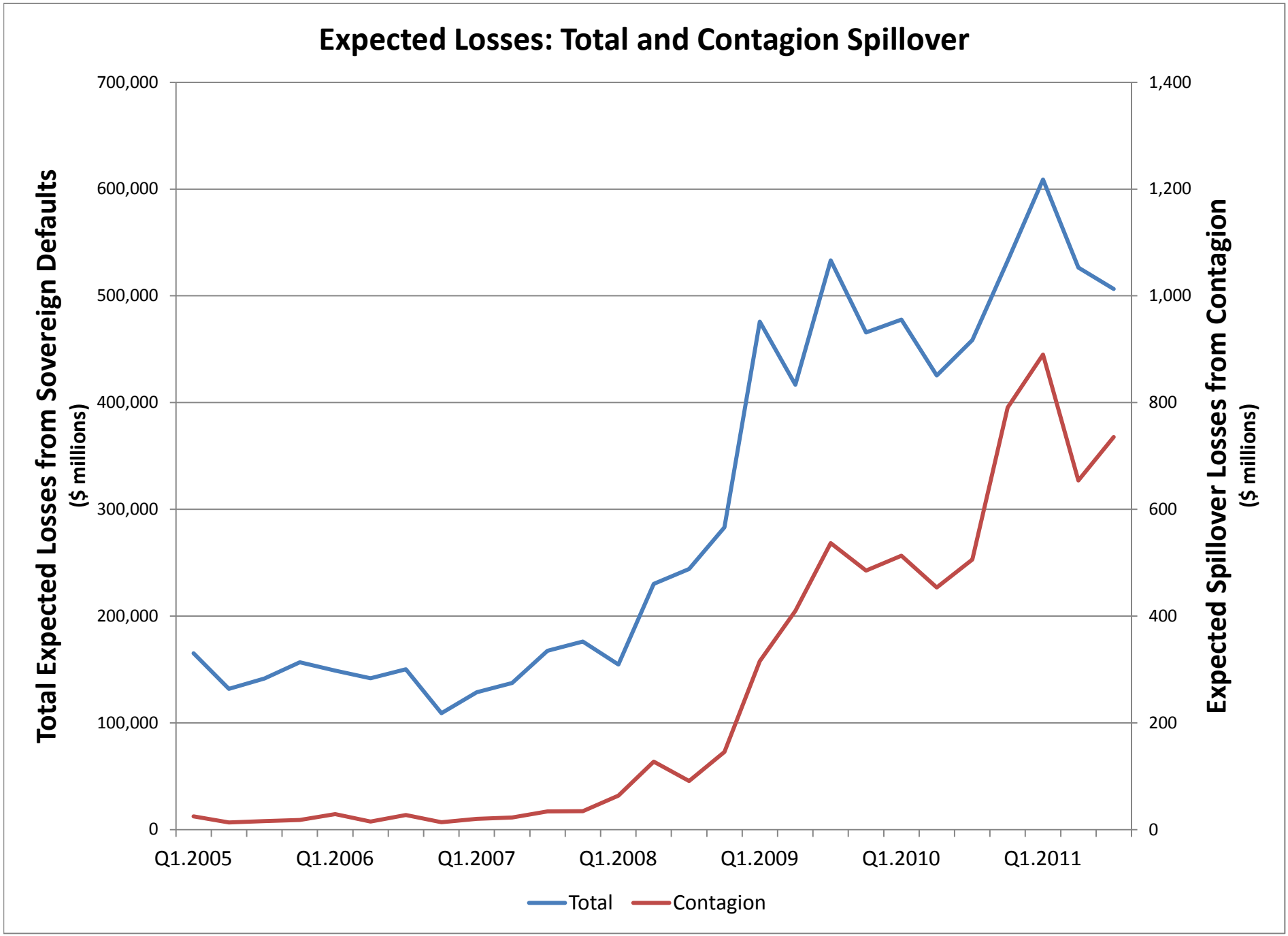
Average contagion centrality rises over time



Economic Impacts

The default simulations and centrality measure may be hard to put in context, especially given small probability of default

- Compare total expected losses implied by the CDS rates with the expected losses due to these spillovers
  - Total expected losses: $\sum_i (1 - \hat{p}_{it}) D_{it}$
  - Expected losses from to contagion of defaults: $\sum_i (1 - \hat{p}_{it}) D_{it} \lambda_{it}$
- Compute an impact on the cost of borrowing
  - Rough calculation shows this to be slightly less than impact on solvency probability (due to nonzero recovery rate)
  - For effects on solvency probabilities on the order of 10 bps, this would put the effect on cost of borrowing in single-digits of bps


Expected Losses: Total and Contagion Spillover
Total Expected Losses from Sovereign Defaults
($ millions)
Expected Spillover Losses from Contagion
($ millions)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1,400
1,200
1,000
800
600
400
200
0
Q1.2005
Q1.2006
Q1.2007
Q1.2008
Q1.2009
Q1.2010
Q1.2011
Total
Contagion

Conclusion, Future Work

- The interconnectedness of borrowing and lending relationships presents risk of contagion
- Important to understand the magnitude of this risk
- How it varies over time and across sovereigns
- Factors that increase or decrease contagiousness of debt

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Extensions, Future Work

- Additional data to discipline the estimation – e.g. other asset price data, term structures of debt
- Counterfactuals with alternative network structures
- Observable characteristics that correlate with contagion measures – cross-section and time series