

THE PASS-THROUGH OF SOVEREIGN RISK

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The views expressed herein are those of the author and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

INTRODUCTION

- Southern European banks are major holders of domestic government debt and main providers of external finance to local firms.
 - In 2009, holdings of government bonds equivalent to 93% of their equity.
 - In 2009, 2/3 of external financing of firms from domestic intermediaries.
- Concerns of policymakers: Sovereign debt crisis could result in a tightening of credit.
- Questions:
 - 1 How does sovereign credit risk propagate to real economic activity?
 - 2 Were credit market interventions successful in limiting its propagation?
- This paper
 - 1 Model with financial intermediation and sovereign credit risk.
 - 2 Empirical analysis based on Italian data.

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MODEL OVERVIEW

Model builds on Gertler and Karadi (2011) and Gertler and Kiyotaki (2010).

Main ingredients:

- 1 Banks issue debt to households and buy gov. bonds and claims on firms.
- 2 Funding ability of banks *occasionally* limited by their net worth.
- 3 Time varying risk of a sovereign default (reduced form).

How does the economy respond to news about a future sovereign default?

Liquidity channel: Funding ability of banks adversely affected.

Risk channel: Lending to firms riskier when government is close to default.

Risk channel overlooked in the literature because of local approximation

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PREVIEW OF MAIN RESULTS

Estimate nonlinear model on Italian data with Bayesian methods. Use it for measurement and policy evaluation.

Measurement:

- Sovereign credit risk highly recessionary ($\approx 1.75\%$ cumulative output loss).
- Risk channel played quantitatively first order role (50% of the effects).

Policy Evaluation:

- Evaluate the effects of a long term subsidized loan to banks (LTROs).
- Policy effects highly state-dependent:
 - 1 Stronger if intermediaries face funding constraints.
 - 2 Weaker if intermediaries' precautionary motives are sizable.

RELATIONSHIP TO THE LITERATURE

Macro models with financial intermediation: Gertler and Karadi (2011), Gertler and Kiyotaki (2010), Brunnermeier and Sannikov (2013), He and Kryshnamurthy (2013).

This paper: Nonlinear analysis of quantitative model.

- Risk channel.
- State and size dependence in credit market interventions.

Sovereign default crises and financial intermediation:

- Feed-back loops: Acharya et al. (2013), Cooper and Nikolov (2013), Farhi and Tirole (2014).
- Output losses: Gennaioli et al. (2013), Sosa-Padilla (2013), Boz et al. (2014).
- "Anticipation" effects: Corsetti et al. (2013), Broner et al. (2013).

This paper: Transfer of risk from government bonds to corporate assets.

PLAN FOR THE TALK

- 1 The Model
- 2 The Mechanisms
- 3 Estimation
- 4 Measurement
- 5 Policy Evaluation

THE ECONOMY



A diagram showing five sectors of the economy arranged in a circle around a central node. The sectors are: Households (top-left), Final Good Producers (top-right), Banks (center), Capital Good Producers (bottom-right), and Government (bottom-left). Each sector is represented by a blue-outlined circle.

Households

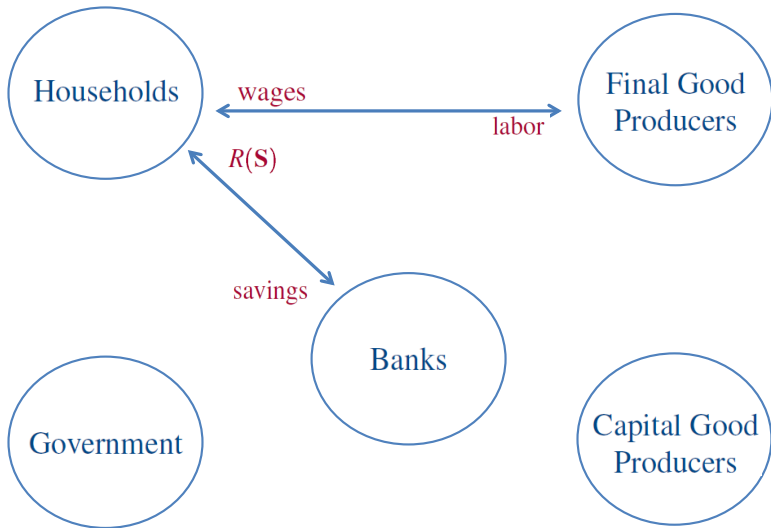
Final Good
Producers

Banks

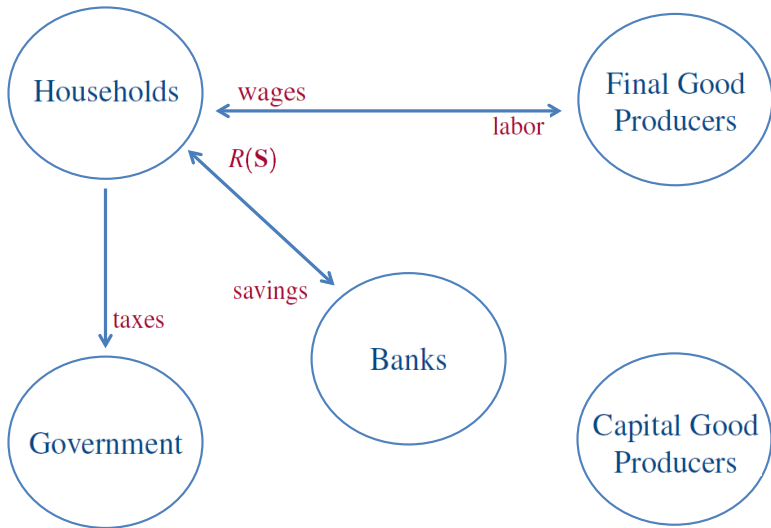
Government

Capital Good
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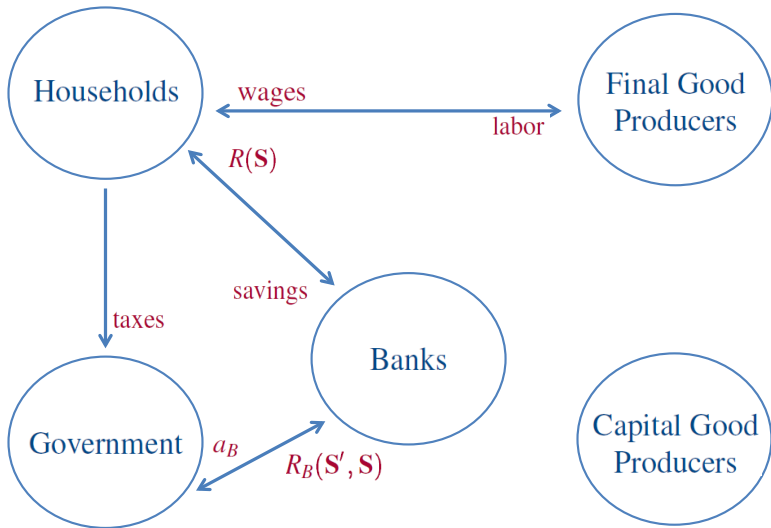
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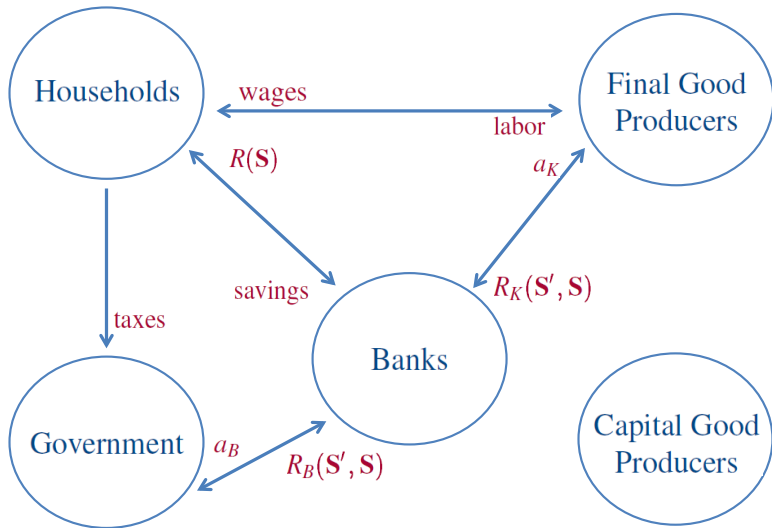
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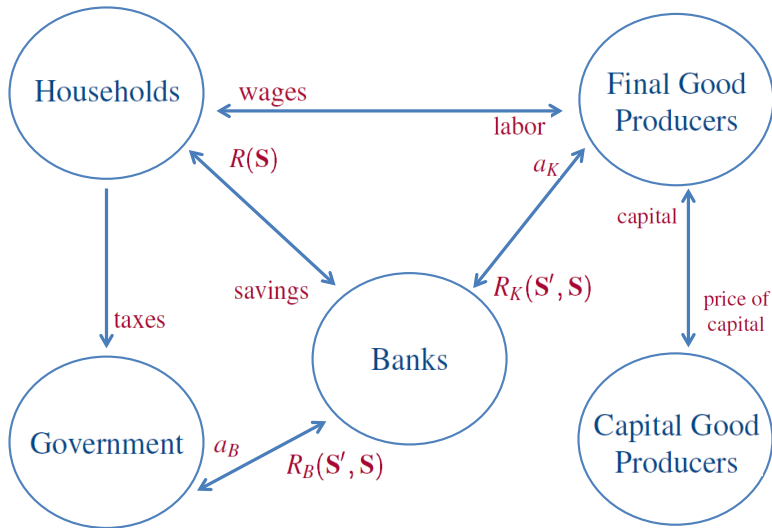
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HOUSEHOLDS

- A household is a unit measure of members. Consumption insurance.
- $1 - f$ are *workers* and f are *bankers*.
- Every period a fraction $(1 - \psi)$ of bankers become workers.
- Workers send back wages $W(\mathbf{S})$. Bankers send back dividends.
- Households choose consumption (c) , labor (l) and savings (b') .
- Let $\Lambda(\mathbf{S}', \mathbf{S}) = \beta \frac{u_c(c', 1-l')}{u_c(c, 1-l)}$. Optimality:

$$\mathbb{E}_{\mathbf{S}}[\Lambda(\mathbf{S}', \mathbf{S})R(\mathbf{S})] = 1 \quad u_l(c, 1 - l) = W(\mathbf{S})u_c(c, 1 - l).$$

BANKERS

- Use net worth (n) and savings (b') to invest in assets

$$n + b' = Q_B(\mathbf{S})a_B + Q_K(\mathbf{S})a_K.$$

- Net worth evolves through retained earnings

$$n' = \underbrace{\sum R_j(\mathbf{S}', \mathbf{S})Q_j(\mathbf{S})a_j}_{\text{Returns on Assets}} - \underbrace{R(\mathbf{S})b'}_{\text{Promises to Households}}$$

- Limited enforcement of debt contracts:
 - Bankers can divert assets to their own family.
 - Households recover fraction $(1 - \lambda)$.

BANKERS: DECISION PROBLEM

- Choose assets $(\{a_j\})$ to maximize present discounted value of dividends

$$v_b(n; \mathbf{S}) = \max_{\{a_j\}} \mathbb{E}_{\mathbf{S}} \left\{ \Lambda(\mathbf{S}', \mathbf{S}) [(1 - \psi)n' + \psi v_b(n'; \mathbf{S}')] \right\},$$

$$n' = \sum_{j=\{B,K\}} [R_j(\mathbf{S}', \mathbf{S}) - R(\mathbf{S})] Q_j(\mathbf{S}) a_j + R(\mathbf{S})n,$$

$$v_b(n; \mathbf{S}) \geq \lambda \left[\sum_{j=\{B,K\}} Q_j(\mathbf{S}) a_j \right],$$

$$\mathbf{S}' = \Gamma(\mathbf{S}).$$

- Guess and verify that

$$v_b(n, \mathbf{S}) = \alpha(\mathbf{S})n.$$

is a solution to bankers' dynamic program.

BANKERS: EULER EQUATIONS

- IC constraint \rightarrow limits to bankers' leverage

$$\frac{\sum_j Q_j(\mathbf{S}) a_j}{n} \leq \frac{\alpha(\mathbf{S})}{\lambda} \quad \text{with Lagrange multiplier } \mu(\mathbf{S}) \geq 0.$$

- Let $\hat{\Lambda}(\mathbf{S}', \mathbf{S}) = \Lambda(\mathbf{S}', \mathbf{S}) [(1 - \psi) + \psi \alpha(\mathbf{S}')] \cdot$ Euler equations

$$\mathbb{E}_{\mathbf{S}} \left\{ \hat{\Lambda}(\mathbf{S}', \mathbf{S}) R_j(\mathbf{S}', \mathbf{S}) \right\} = \mathbb{E}_{\mathbf{S}} \{ \hat{\Lambda}(\mathbf{S}', \mathbf{S}) R(\mathbf{S}) \} + \lambda \mu(\mathbf{S}). \quad \text{for } j \in \{B, K\}$$

- Two distinctions with neoclassical model

1 $\mu(\mathbf{S}) \rightarrow$ Limits to arbitrage.

2 $\hat{\Lambda}(\mathbf{S}', \mathbf{S}) \rightarrow$ Leverage-based pricing kernel.

ASSETS

GOVERNMENT'S BONDS:

► Details

- The government issues long term bonds (π, ι) .
- In default ($d' = 1$), government writes off $D \in [0, 1]$ on bondholders.

Realized returns on government bonds is:

$$R_B(\mathbf{S}', \mathbf{S}) = [1 - d'D] \left\{ \frac{\pi + (1 - \pi)[\iota + Q_B(\mathbf{S}')] }{Q_B(\mathbf{S})} \right\}.$$

FIRMS' CLAIMS:

► Details

- Final good firms are perfectly competitive

$$y = k^\alpha (\exp\{z\}l)^{1-\alpha}.$$

- They issue claims to bankers to finance capital goods

$$R_K(\mathbf{S}', \mathbf{S}) = \frac{\alpha \frac{Y(\mathbf{S}')}{K} + (1 - \delta) Q_K(\mathbf{S}')}{Q_K(\mathbf{S})}.$$

- Price of capital varies because of capital adjustment costs.

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ADDITIONAL INFORMATION

- Default can occur in every period as follows

$$d' = \begin{cases} 1 & \text{if } \varepsilon'_d - \Psi(\mathbf{S}; \theta_2) \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

Conditional probability of a sovereign default

$$p(d' = 1|\mathbf{S}) = p^d(\mathbf{S}) = \frac{\exp\{\Psi(\mathbf{S}; \theta_2)\}}{1 + \exp\{\Psi(\mathbf{S}; \theta_2)\}}.$$

- For empirical analysis, $\Psi(\mathbf{S}, \theta_2) = s$.
- $\Delta z'$, s' and g' follow AR(1) with parameters $[\gamma, s^*, g^*, \{\rho_j, \sigma_j\}_{j=z,s,g}]$.
- The model state variables are $\mathbf{S} = [\Delta z, g, s, d, \tilde{K}, \tilde{B}, \tilde{P}]$.

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$$\mathbb{E}_t \left[\hat{\Lambda}_{t+1} R_{K,t+1} \right] = \mathbb{E}_t \left[\hat{\Lambda}_{t+1} R_t \right] + \lambda \mu_t.$$

Rearranging it

$$\mathbb{E}_t[R_{K,t+1}] - R_t = \underbrace{\frac{\lambda \mu_t}{\mathbb{E}_t[\hat{\Lambda}_{t+1}]} }_{\text{Liquidity premium}} - \underbrace{\frac{\text{cov}_t[\hat{\Lambda}_{t+1}, R_{K,t+1}]}{\mathbb{E}_t[\hat{\Lambda}_{t+1}]}}_{\text{Risk premium}}.$$

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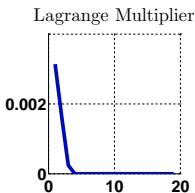
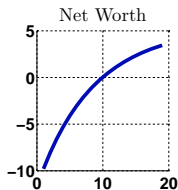
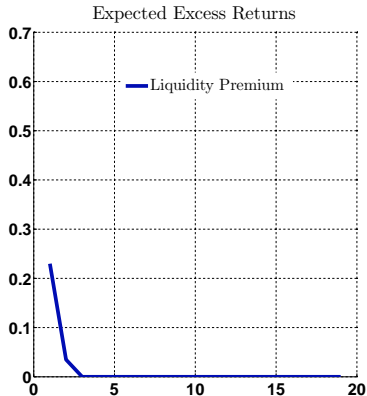
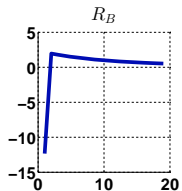
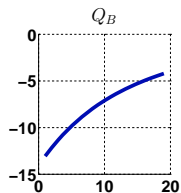
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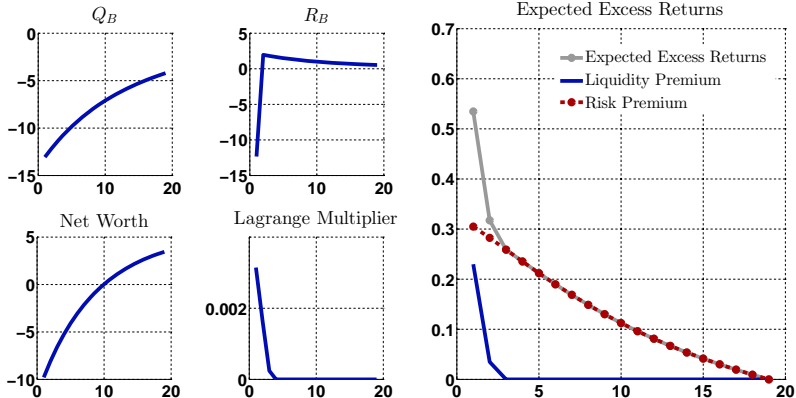
Impulse: sovereign default probabilities increase from 0.13% to 2.5%



s-shock tightens bank leverage constraints → liquidity premium rises.

THE RISK CHANNEL

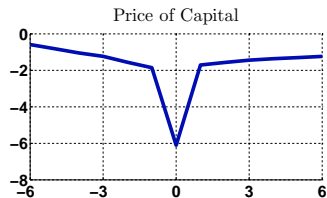
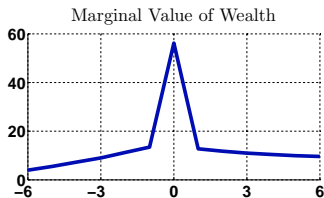
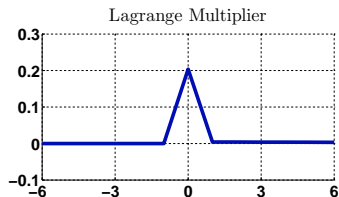
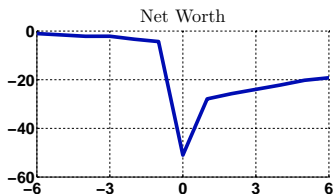
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s-shock raises the risk premium demanded to hold firms' claims.

THE RISK CHANNEL

Why is sovereign risk a priced-factor for corporate assets?



In a sovereign default, capital pays out little when bankers need wealth.

Ex-ante, *precautionary motives* for bankers to deleverage.

ESTIMATION

EMPIRICAL ANALYSIS

The two channels reflect different motives for intermediaries.

- Liquidity channel \Rightarrow Reflects lack of funds to invest.
- Risk channel \Rightarrow Reflects lack of willingness to invest.

Empirical analysis:

- Estimate the structural model on Italian data (1999:Q1-2011:Q4).
- Measure the relative importance of two channels in 2010:Q1-2011:Q4.
- Evaluate effects of unconventional policies of 2012:Q1.

ESTIMATION STRATEGY

- $u(c, l) = \log(c) - \chi \frac{l^{1+\nu^{-1}}}{1+\nu^{-1}}$
- $\Phi\left(\frac{l}{K}\right) = a_1 \left(\frac{l}{K}\right)^{1-\xi} + a_2$
- Structural innovations are Gaussian

Parameters: $\theta = [\theta_1, \theta_2]$

$$\theta_1 = \underbrace{[\lambda, \psi, \xi, \sigma_z, \rho_z, \gamma, \pi, g^*, \rho_g, \sigma_g, \gamma_\tau, \nu, \alpha, \delta, \chi, \omega, \beta, \tau^*, \iota, a_1, a_2]}_{\text{Model without sovereign risk}}, \quad \theta_2 = \underbrace{[D, s^*, \rho_s, \sigma_s]}_{\text{Sovereign risk}}.$$

Estimate θ using two-step approach:

- 1 Estimate model without sovereign risk on sub-sample (1999:Q1-2009:Q4).
- 2 Estimate θ_2 using CDS spreads.

STEP 1: ESTIMATING MODEL WITHOUT SOVEREIGN RISK

$$\theta_1 = \underbrace{[\pi, g^*, \rho_g, \sigma_g, \gamma_t, \nu, \alpha, \frac{i^{bg}}{y^{bg}}, l^{bg}, lev^{bg}, R^{bg}, exp^{bg}, q_b^{bg}, adj^{bg}]_{\theta_1^*}}_{\theta_1^*} \underbrace{[\mu^{bg}, \psi, \xi, \sigma_z, \rho_z, \gamma]}_{\tilde{\theta}_1}$$

Determine θ_1^* using long run averages and balance sheet data

Parameters					Source
$\frac{i^{bg}}{y^{bg}}$	lev^{bg}	l^{bg}	R^{bg}	α	OECD, EU-KLEMS, ECB, BoI
0.20	4.34	0.32	1.0029	0.30	
exp^{bg}	π				EBA, Bankscope
0.076	0.056				
e^{g^*}	ρ_g	σ_g			OECD
0.21	0.97	0.009			
q_b^{bg}	adj^{bg}	ν	γ_τ		Normalizations, Previous Research
1	0	2	1		

STEP 1: MEASURING AGENCY COSTS

Estimate $\tilde{\theta}_1 = [\mu^{bg}, \psi, \xi, \sigma_z, \rho_z, \gamma]$ using MH algorithm.

$$\frac{\mathbb{E}_t[R_{j,t+1}] - R_t}{R_t} = \frac{\lambda}{\alpha_t} \frac{\mu_t}{(1 - \mu_t)} - \frac{\text{cov}_t[\hat{\Lambda}_{t+1}, R_{j,t+1}]}{\alpha_t(1 - \mu_t)}.$$

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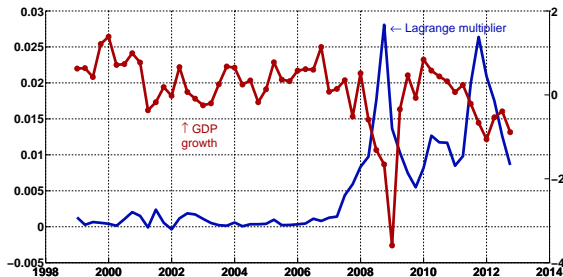
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Use $\mathbf{Y}_t = [\Delta Y_t, \mu_t]$ to evaluate likelihood $\mathcal{L}(\tilde{\theta}_1 | \mathbf{Y}^T)$.

STEP 2: ESTIMATE SOVEREIGN RISK

$$\theta_2 = [D, s^*, \rho_s, \sigma_s]$$

- Fix the “haircut” at 45%.
- Estimate $[s^*, \rho_s, \sigma_s]$ using actual probabilities of a sovereign default.

Equilibrium relationship:

$$\underbrace{\hat{p}_t^d}_{\text{Risk Neutral Probabilities}} \times \underbrace{\frac{\lambda[\text{lev}_t(1 - \mu_t) + \mu_t]}{R_t^f \mathbb{E}_t[\hat{\Lambda}_{t+1} | d_{t+1} = 1]}}_{\text{Risk Correction}} = \frac{e^{s_t}}{1 + e^{s_t}},$$

- 1 \hat{p}_t^d obtained from CDS spreads on 5yrs. Italian bonds.
- 2 Use empirical pricing kernel $\{\hat{\Lambda}_t\}$ to construct **Risk Correction**.

MEASUREMENT

MEASURING THE EFFECTS OF SOVEREIGN CREDIT RISK

What would have happened in absence of sovereign credit risk?

- 1 Given $\{\mathbf{Y}_t\} = \{\text{GDP Growth}_t, \mu_t, p_t^d\}$, filter shocks $\{\varepsilon_{j,t}\}_{t,j=z,g,s}$.
- 2 Feed the model with $\{\varepsilon_{j,t}, 0\}_{j=z,g}$ to generate counterfactual time series.
- 3 Difference between actual and counterfactuals isolates effect of sovereign credit risk.

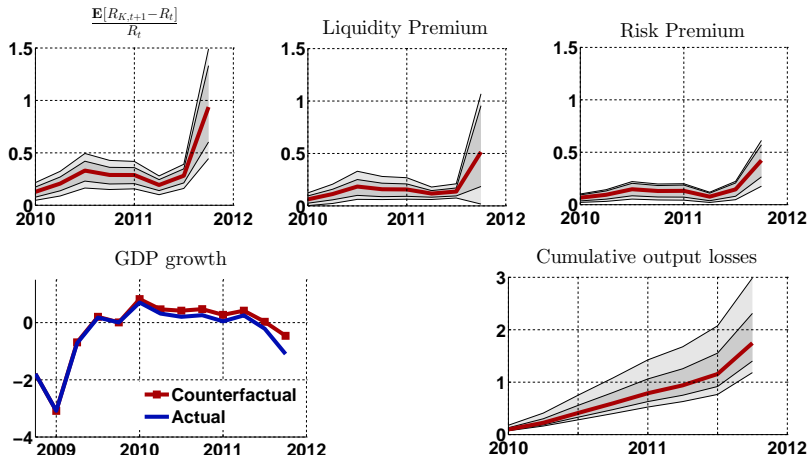
Variables of interest:

- Expected excess returns and their sources

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- GDP growth.

EXPECTED EXCESS RETURNS AND GDP GROWTH

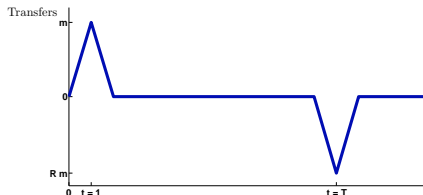


- Sovereign risk raises EER by 100bp. Risk channel explains 50%.
- Sovereign risk leads to 1.75% loss in output (2010-2011).

POLICY EVALUATION

REFINANCING OPERATIONS

- Government lends \bar{m} to bankers at $t = 1$. At $t = T$ bankers repay $R_m m$.
- At $t = 1$ agents fully informed.
- Policy (R_m, m, T) calibrated to the LTROs of the ECB.



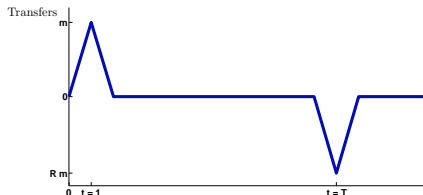
Quantitative experiments:

- 1 Simulate the model and select $\{S_i\}$ such that $\Delta Y_i (EER_i)$ is 2 st. dev. below (above) mean.
- 2 For each S_i , compute expected path under LTROs and in absence of it. Difference between paths reflects the effect of the intervention.
- 3 See how policy effects varies with $\{S_i\}$:

$$\delta(S_i) = \frac{\text{Risk Premium}_i}{EER_i} \in [0, 1]$$

REFINANCING OPERATIONS

- Government lends \bar{m} to bankers at $t = 1$. At $t = T$ bankers repay $R_m m$.
- At $t = 1$ agents fully informed.
- Policy (R_m, m, T) calibrated to the LTROs of the ECB.



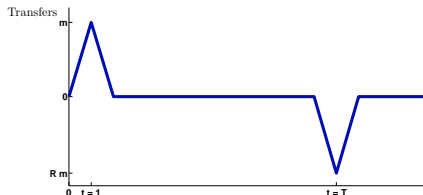
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- 1 Simulate the model and select $\{S_i\}$ such that ΔY_i (EER_i) is 2 st. dev. below (above) mean.
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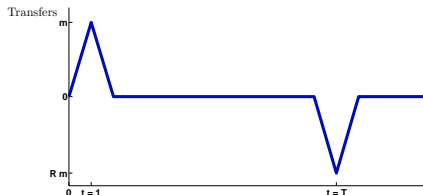
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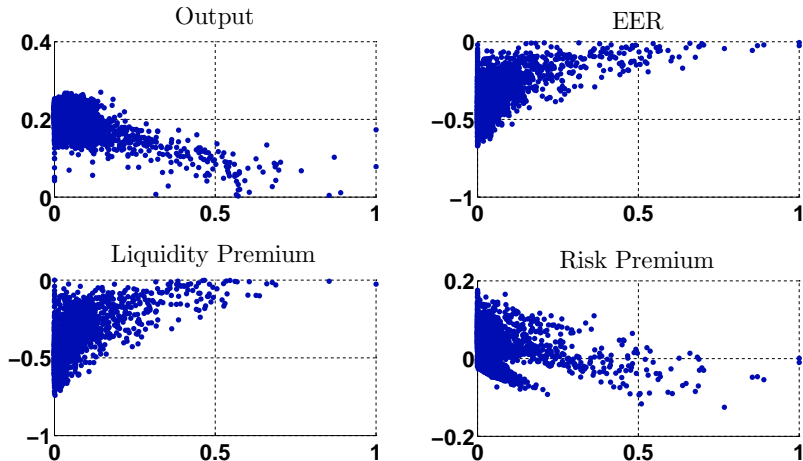
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EVALUATING REFINANCING OPERATIONS

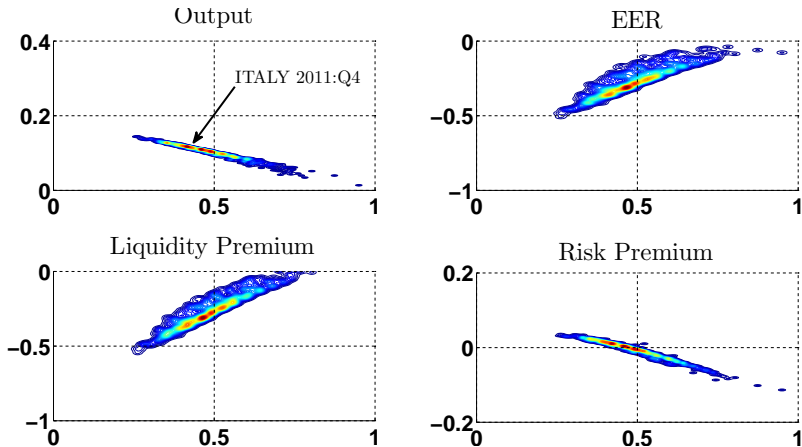
Report average effects



- High state dependence: LTROs have weak effects when $\delta(S_i)$ large.
- High risk premia \Rightarrow Low incentives to lend to firms.

EVALUATING REFINANCING OPERATIONS

Calculate policy effects sampling from $p(\mathbf{S}_{2011:Q4} | \mathbf{Y}^{2011:Q4})$



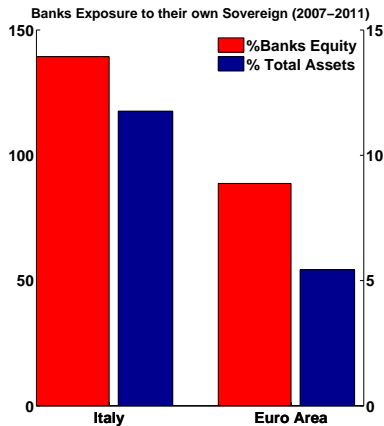
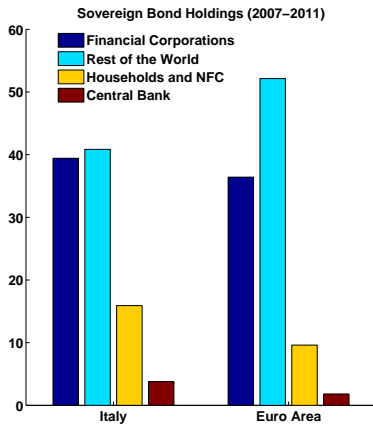
- Model predicts an average impact on output (EER) of 0.1% (-0.3%).
- High risk premia signal that LTROs has weak stimulative effects.

CONCLUSIONS

- Equilibrium model to study the propagation of sovereign credit risk.
 - Liquidity channel → It reflects lack of funds to invest.
 - Risk channel → It reflects lack of willingness to invest.
- Both channels empirically relevant in the Italian crisis.
- *Their measurement provides key information for predicting policy effects.*

SUPPLEMENTARY MATERIAL

GOVERNMENT BOND HOLDINGS



HOUSEHOLDS' PROBLEM

- Households choose consumption (c), savings (b') and labor (l).
- Savings via risk free bonds offered by bankers belonging to other households.

$$v(b; \mathbf{S}) = \max_{b' \geq 0, c \geq 0, l \in [0,1]} \left\{ u(c, 1-l) + \beta \mathbb{E}_{\mathbf{S}}[v(b'; \mathbf{S}')] \right\},$$

$$c + \frac{1}{R(\mathbf{S})} b' \leq W(\mathbf{S})l + \Pi(\mathbf{S}) + b - \tau(\mathbf{S}),$$

$$\mathbf{S}' = \Gamma(\mathbf{S}).$$

Optimality:

$$\mathbb{E}_{\mathbf{S}}[\Lambda(\mathbf{S}', \mathbf{S})R(\mathbf{S})] = 1 \quad u_l(c, 1-l) = W(\mathbf{S})u_c(c, 1-l),$$

where $\Lambda(\mathbf{S}', \mathbf{S}) = \beta \frac{u_c(c', 1-l')}{u_c(c, 1-l)}$.

BANKERS: DETAILS

Guess that the value function is $v(n, \mathbf{S}) = \alpha(\mathbf{S})n$. Conditions for optimum:

$$\mathbb{E}_{\mathbf{S}} \left\{ \Lambda(\mathbf{S}', \mathbf{S}) \left[(1 - \psi) + \psi \alpha(\mathbf{S}') \right] [R_j(\mathbf{S}', \mathbf{S}) - R(\mathbf{S})] \right\} = \lambda \mu(\mathbf{S}) \quad j = \{B, K\}$$

$$\mu(\mathbf{S}) \left(\alpha(\mathbf{S})n - \lambda \sum_{j=\{B, K\}} Q_j(\mathbf{S}) a_j \right) = 0$$

Substituting the guess:

$$\underbrace{v_b(n, \mathbf{S})}_{\alpha(\mathbf{S})n} = \underbrace{\max_{a_B, a_K} \left\{ \sum_{j=\{B, K\}} \mathbb{E}_{\mathbf{S}} \left\{ \Lambda(\mathbf{S}', \mathbf{S}) [(1 - \psi) + \psi \alpha(\mathbf{S}')] [R_j(\mathbf{S}', \mathbf{S}) - R(\mathbf{S})] \right\} Q_j(\mathbf{S}) a_j \right\}}_{\mu(\mathbf{S}) \alpha(\mathbf{S})n} + \underbrace{\mathbb{E}_{\mathbf{S}} \left\{ \Lambda(\mathbf{S}', \mathbf{S}) [(1 - \psi) + \psi \alpha(\mathbf{S}')] \right\} R(\mathbf{S})n}_{\mathbb{E}_{\mathbf{S}} \{ \Lambda(\mathbf{S}', \mathbf{S}) [(1 - \psi) + \psi \alpha(\mathbf{S})] \} R(\mathbf{S})n}$$

BANKERS: DETAILS

Solving for $\alpha(\mathbf{S})$, we obtain:

$$\alpha(\mathbf{S}) = \frac{\mathbb{E}_{\mathbf{S}'}\{\Lambda(\mathbf{S}', \mathbf{S})[(1 - \psi) + \psi\alpha(\mathbf{S}')]\}R(\mathbf{S})}{1 - \mu(\mathbf{S})}$$

The guess is verified if $\mu(\mathbf{S}) < 1$. From complementary slackness:

$$\mu(\mathbf{S}) = \max \left\{ 1 - \frac{\mathbb{E}_{\mathbf{S}'}\{\Lambda(\mathbf{S}', \mathbf{S})[(1 - \psi) + \psi\alpha(\mathbf{S}')]\}R(\mathbf{S})n}{\lambda \left(\sum_{j=\{B,K\}} Q_j(\mathbf{S})a_j \right)}, 0 \right\} < 1$$

PRODUCTION

- Final good firms perfectly competitive. Cobb-Douglas production

$$y = k^{\alpha}(e^z l)^{1-\alpha}.$$

- z follows

$$\Delta z' = \gamma(1 - \rho_z) + \rho_z \Delta z + \sigma_z \varepsilon'_z.$$

- Issue claims to bankers to finance capital goods

$$R_K(\mathbf{S}', \mathbf{S}) = \frac{(1 - \delta)Q_K(\mathbf{S}') + \alpha \frac{Y(\mathbf{S}')}{K}}{Q_K(\mathbf{S})}$$

- Price of capital varies because of capital adjustment costs, $\Phi\left(\frac{i}{K}\right)$.

CAPITAL GOOD PRODUCERS

- Demand final output. New capital goods sold to final good firms.
- Optimization problem

$$\max_{i \geq 0} Q_K(\mathbf{S})k' - i.$$

- Production of new capital

$$k' = \Phi \left(\frac{i}{K} \right) K,$$

- In equilibrium

$$Q_K(\mathbf{S}) = \frac{1}{\Phi' \left(\frac{I(\mathbf{S})}{K} \right)}.$$

THE GOVERNMENT

- Spending-output ratio is e^g , with $g \sim AR(1)$. Lump sum taxes are given by $\tau(\mathbf{S}) = \tau^*Y + \gamma_\tau B$, with $\gamma_\tau > 0$.
- Long term bonds indexed by (π, ι)
 - 1 Fraction π of bonds matures and pays principal.
 - 2 Fraction $(1 - \pi)$ of bonds does not mature: pays ι and $Q_b(\mathbf{S}')$.
 - 3 In default ($d = 1$), government writes off $D \in [0, 1]$ on bondholders.
- The budget constraint is

$$Q_B(\mathbf{S}) \left[\underbrace{B' - (1 - \pi)B[1 - dD]}_{\text{Newly issued bonds}} \right] = \left[\underbrace{\pi B}_{\text{Principal}} + \underbrace{(1 - \pi)\iota B}_{\text{Coupons}} \right] [1 - dD] - \underbrace{[\tau(\mathbf{S}) - e^g Y(\mathbf{S})]}_{\text{Primary surplus}}.$$

RECURSIVE COMPETITIVE EQUILIBRIUM

A Recursive Competitive Equilibrium of the economy is a set of

- price functions $\hat{\Lambda}, \hat{Q}_B, \hat{Q}_K, \hat{R}_B, \hat{W}, \hat{R}$,
- choice functions $\hat{b}, \hat{k}, \hat{y}, \hat{c}, \hat{l}, \hat{i}, \hat{k}', \hat{a}_K, \hat{a}_B$,
- value functions \hat{v}_b, \hat{v}_h ,
- aggregate laws of motions $\hat{B}', \hat{K}', \hat{N}', \hat{\Pi}$,

such that:

1 Given prices and aggregate laws of motion

- $\hat{v}_h, \hat{b}, \hat{c}, \hat{l}$ solve the household's problem.
- $\hat{l}, \hat{k}, \hat{y}$ solve the final good producer's problem.
- \hat{i}, \hat{k}' solves the capital good producer's problem.
- $\hat{v}_b, \hat{a}_K, \hat{a}_B, \hat{b}$ solve the banker's problem.

2 Aggregate laws of motion consistent with individual decisions and laws of motion of the government.

3 All markets clear.

NUMERICAL SOLUTION

Let $x(\mathbf{S})$ be a control variable. Approximate its law of motion as

$$x(\mathbf{S}) = (1 - d)\gamma_0^{x'}\mathbf{T}(\mathbf{S}^*) + d\gamma_1^{x'}\mathbf{T}(\mathbf{S}^*),$$

where $\mathbf{S}^* = [\Delta z, g, s, \tilde{K}, \tilde{B}, \tilde{P}]$ and $\mathbf{T}(\cdot)$ a set of Chebyshev's polynomials.

SPECIFICS

Model solution: $\{\gamma_0^x, \gamma_1^x\}_x$ s.t. equilibrium conditions satisfied at $\{\mathbf{S}_i^*\}_i$.

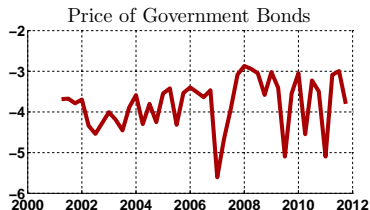
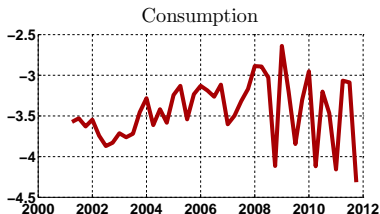
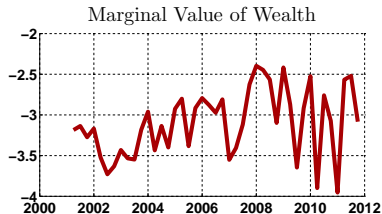
Choice of $\{\mathbf{S}_i^*\}_i$ and $\mathbf{T}(\cdot)$: Smolyak method (Krueger and Kubler, 2003).

Expectations: "Precomputation of integrals" (Judd et al., 2012).

Finding the zeros: Newton's method ($4 \times 389 \times 2 = 3112$ equations).

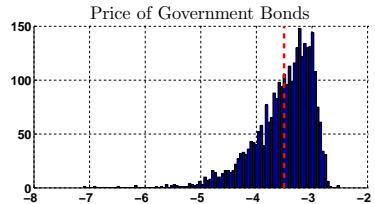
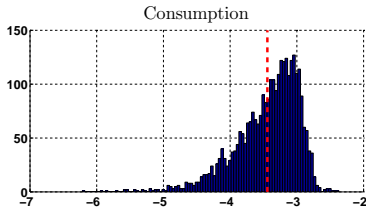
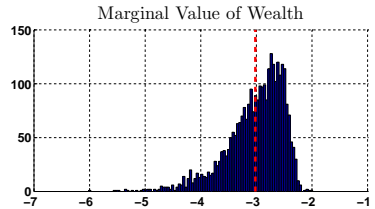
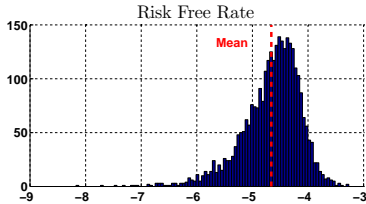
NUMERICAL SOLUTION: ACCURACY

Euler Equation Errors in empirically relevant regions of state space



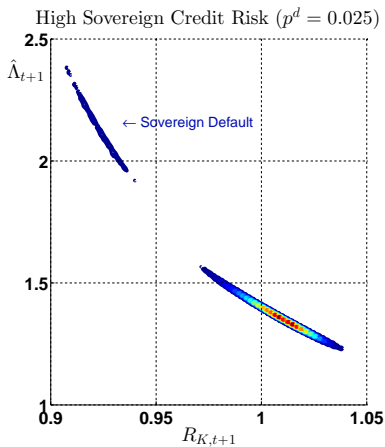
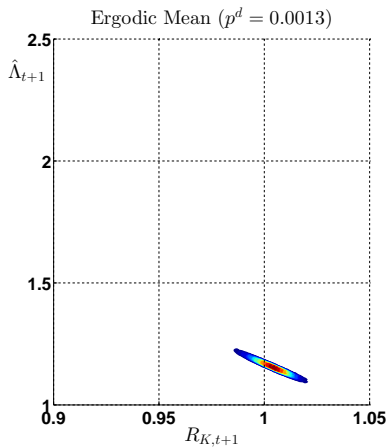
NUMERICAL SOLUTION: ACCURACY

Assess the accuracy of the numerical solution using Euler Equation Errors

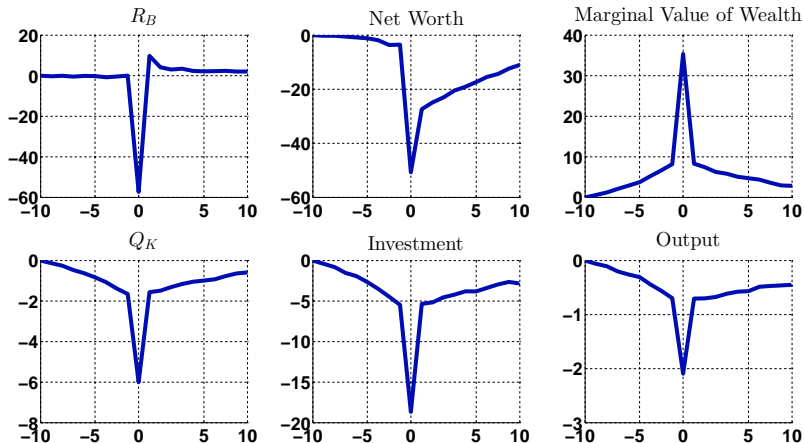


THE RISK CHANNEL

Why is $\text{cov}_t(\hat{\Lambda}_{t+1}, R_{K,t+1})$ sensitive to sovereign credit risk?



A TYPICAL SOVEREIGN DEFAULT



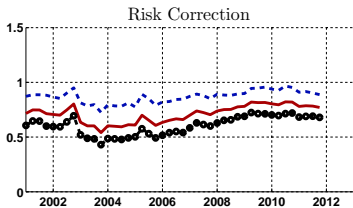
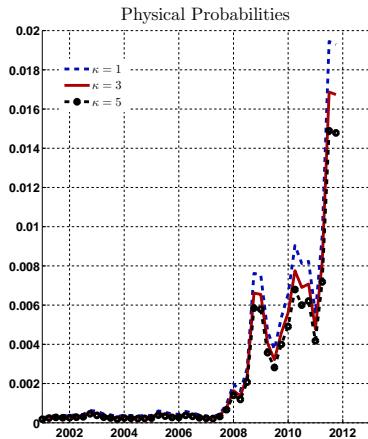
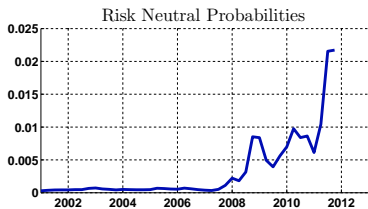
- Haircut on gov. bonds tightens bank leverage constraint.
- Capital accumulation declines.
- Decline in Tobin's Q amplifies effects.

BANKS EXPOSURE TO DOMESTIC GOVERNMENT

- Holdings of government debt: 2010 EBA stress test.
- Total Assets: Bankscope.

	3Mo	1Yr	2Yr	3Yr	5Yr	10Yr	15Yr	Tot.	Tot. Assets
Intesa	17.18	9.31	2.46	4.87	7.71	6.42	10.12	58.08	658.76
Unicredit	17.78	9.85	2.78	6.12	4.24	5.90	1.44	48.11	929.49
MPS	5.61	4.96	3.92	3.57	1.35	3.71	8.91	32.03	240.70
BPI	3.90	1.65	1.15	3.64	0.78	0.39	0.25	11.76	134.17
UBI	1.27	3.56	0.22	0.30	0.54	2.47	1.76	10.11	129.80
Total	45.75	29.32	10.53	18.5	14.61	18.89	22.48	160.01	2092.99

PROBABILITY OF SOVEREIGN DEFAULT



ESTIMATION STRATEGY: STEP 1

- $\tilde{\theta}_1 = [\mu^{bg}, \psi, \xi, \sigma_z, \rho_z, \gamma]$ estimated using \mathbf{Y}_T .

$$\mathbf{Y}_t = f_{\tilde{\theta}_1}(\mathbf{S}_t) + \eta_t \quad \eta_t \sim \mathcal{N}(\mathbf{0}, \Sigma)$$

$$\mathbf{S}_t = g_{\tilde{\theta}_1}(\mathbf{S}_{t-1}, \varepsilon_t) \quad \varepsilon_t \sim \mathcal{N}(\mathbf{0}, \mathbf{I})$$

- **Likelihood evaluation:** Auxiliary Particle Filter ($\Sigma_{i,i} = 0.25 \times \text{Var}[\mathbf{Y}_i^T]$).
- **Prior:** Presample information for $[\rho_z, \sigma_z, \gamma]$, previous research for ξ , uniform for (μ^{bg}, ψ) .
- **Posterior Sampler:** Random Walk Metropolis Hastings.

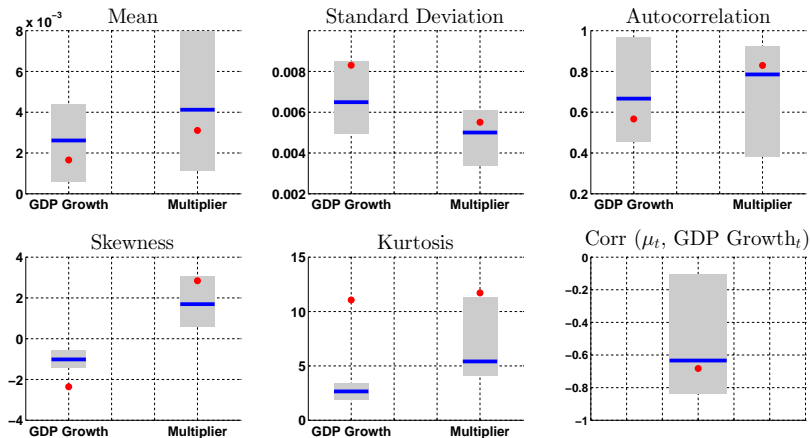
ESTIMATES

Prior and Posterior Statistics for $\tilde{\theta}_1$ and θ_2

Parameter	Prior	Para 1	Para 2	Posterior Mean	90% Credible Set
$\mu^{bg} \times 100$	Uniform	0	∞	0.37	[0.11,0.66]
ψ	Uniform	0	1	0.97	[0.92,0.98]
ξ	Beta	0.5	0.25	0.43	[0.19,0.86]
$\gamma \times 400$	Normal	1.25	0.5	0.98	[0.17,1.80]
ρ_z	Beta	0.3	0.25	0.51	[0.20,0.74]
$\sigma_z \times 100$	Inverse Gamma	0.75	2	0.55	[0.44,0.74]
s^*	Normal	-7	5	-6.67	[-9.17,-4.11]
ρ_s	Beta	0.5	0.3	0.97	[0.93,0.99]
σ_s	Inverse Gamma	0.75	4	0.41	[0.35,0.49]

- Agency costs small around balanced growth path.
- Sovereign risk persistent. Default probabilities 0.13% at ergodic mean.

PREDICTIVE CHECKS: GDP GROWTH AND MULTIPLIER



- Captures key moments of $[\text{GDP growth}_t, \mu_t]$.
- Does not fully capture high order moments of GDP growth.

PREDICTIVE CHECKS: DEFAULT PROBABILITIES

Statistic	Data	Posterior Median	90% Credible Set
Median	0.07	0.25	[0.01,6.81]
Mean	0.53	0.53	[0.03,11.7]
Standard Deviation	0.76	0.63	[0.03,13.5]
Autocorrelation	0.91	0.83	[0.69,0.94]
Skewness	2.03	2.04	[0.96,3.78]
Kurtosis	7.37	7.23	[3.04,20.1]

- The logistic-AR(1) model captures time variation in sovereign credit risk.

MODELING REFINANCING OPERATIONS

- Government lends m at R_m . Maximum loan: \bar{m} .
- Balance sheet: $Q_b(\mathbf{S})a_b + Q_k(\mathbf{S})a_k = n + m + b'$.
- Bankers can not walk away with m .

Bankers' decision problem:

$$v_b(n; \mathbf{S}) = \max_{\{a_j, m \geq 0\}} \mathbb{E}_{\mathbf{S}} \left\{ \Lambda(\mathbf{S}', \mathbf{S}) [(1 - \psi)n' + \psi v_b(n'; \mathbf{S}')] \right\}$$

$$n' = \sum_{j=\{b,k\}} [R_j(\mathbf{S}', \mathbf{S}) - R(\mathbf{S})] Q_j(\mathbf{S}) a_j + [R(\mathbf{S}) - R_m] m + R(\mathbf{S}) n$$

$$v_b(n; \mathbf{S}) \geq \lambda \left[\sum_{j=\{b,k\}} Q_j(\mathbf{S}) a_j - m \right]$$

$$m \leq \bar{m} \quad \text{with multiplier} \quad \chi(\mathbf{S})$$

$$\mathbf{S}' = \Phi(\mathbf{S})$$

LONGER TERM REFINANCING OPERATIONS

Refinancing Operations in Europe

- Banks put collateral with the ECB and receive cash loans.
- Two types: Main Refinancing Operations (week maturity) and Longer-term Refinancing Operations (three months maturity).

In 2012:Q1 the ECB launched two exceptional LTROs

- **Long maturity** (36 months) and **Fixed interest rate** (average of MROs).
- Italian banks bid roughly 300b euros (20% of Italian GDP).

MODELING REFINANCING OPERATIONS

First order condition w.r.t. m

$$\mathbb{E}_{\mathbf{S}} \left\{ \Lambda(\mathbf{S}', \mathbf{S}) \left[(1 - \psi) + \psi \frac{\partial v_b(n'; \mathbf{S})}{\partial n'} \right] \right\} [R(\mathbf{S}) - R_m] + \lambda \mu(\mathbf{S}) = \chi(\mathbf{S})$$

It can be showed that $v_b(n; \mathbf{S}) = \alpha(\mathbf{S})n + x(\mathbf{S})$, where $x(\mathbf{S}) \geq 0$.

Leverage constraints (for $m > 0$)

$$\frac{\sum_j Q_j(\mathbf{S}) a_j}{n} \leq \frac{\alpha(\mathbf{S})}{\lambda} + \frac{x(\mathbf{S})}{\lambda} + \bar{m}$$

ROs have two direct implications

- 1 **LEVERAGE EFFECTS:** They relax bankers' leverage constraints
- 2 **RECAPITALIZATION EFFECTS:** If $R_m < R(\mathbf{S})$, net worth grows faster

LTROs: COMPUTATIONAL DETAILS

We solve for $\{c_t(\mathbf{S}), R_t(\mathbf{S}), \alpha_t(\mathbf{S}), q_t(\mathbf{S})\}_{t=1}^T$ as follows

PERIOD T : Solve the model using $\{c(\mathbf{S}), R(\mathbf{S}), \alpha(\mathbf{S}), q(\mathbf{S})\}$ to form expectations. The multiplier is modified as follows

$$\mu_T(\mathbf{S}) = \max \left\{ 1 - \frac{\mathbb{E}_{\mathbf{S}} \{ \Lambda_{T+1}(\mathbf{S}') [(1-\psi) + \psi \alpha_{T+1}(\mathbf{S})] \} R_T(\mathbf{S}) (N' - m)}{\lambda \left(Q_{b,T}(\mathbf{S}) B'_T + Q_{k,T}(\mathbf{S}) K'_T \right)}, 0 \right\}$$

Denote the solution by $\{c_T(\mathbf{S}), R_T(\mathbf{S}), \alpha_T(\mathbf{S}), q_T(\mathbf{S})\}$

PERIOD $t = T - 1, \dots, 1$: Solve the model using $\{c_{t+1}(\mathbf{S}), R_{t+1}(\mathbf{S}), \alpha_{t+1}(\mathbf{S}), q_{t+1}(\mathbf{S})\}$ to form expectations. The multiplier is modified as follows

$$\mu_t(\mathbf{S}) = \max \left\{ \frac{\lambda \left(TA_t(\mathbf{S}) - m \mathbf{1}_{t=1} \right) - \mathbb{E}_{\mathbf{S}} \{ \Lambda_{t+1}(\mathbf{S}') [(1-\psi) + \psi \alpha_{t+1}(\mathbf{S})] \} R_t(\mathbf{S}) (N' + m \mathbf{1}_{t=1}) - \psi \mathbb{E}_{\mathbf{S}} [\Lambda_{t+1}(\mathbf{S}') \alpha_{t+1}(\mathbf{S}') x_{t+1}(\mathbf{S}')]}{\lambda \left(Q_{b,t}(\mathbf{S}) B'_t + Q_{k,t}(\mathbf{S}) K'_t \right)}, 0 \right\}$$

where x_t follows the recursion $x_t(\mathbf{S}) = \frac{\lambda m \mu_t(\mathbf{S}) + \psi \mathbb{E}_{\mathbf{S}} [\Lambda_{t+1}(\mathbf{S}') \alpha_{t+1}(\mathbf{S}') x_{t+1}(\mathbf{S}')]}{1 - \mu_t(\mathbf{S})}$. The initial condition of this recursion is $x_T(\mathbf{S}) = -\alpha_T(\mathbf{S})m$. Store the solution $\{c_t(\mathbf{S}), R_t(\mathbf{S}), \alpha_t(\mathbf{S}), q_t(\mathbf{S}), x_t(\mathbf{S})\}$