Policy Design with Agent-Based Models

Jamel: a Java Agent-based Macro-Economic Laboratory

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From macro-econometric to DSGE models

(1970's stagflation, Lucas' critique (1976), 1979-1983 Volcker's disinflation)

	Keynesian models (e.g. $IS - LM$)	DSGE models (pre 2008-crisis)
Microeconomic foundations	missing	representative agent
Agents' behaviour	not modelled	maximisation, rational expectations
Macroeconomic relationships	postulated and estimated	mapping with individual behaviour
Source of fluctuations	exogenous shocks	exogenous shocks

What is this research about?

The 2008 crisis and the doubts on existing economic models

'When the crisis came, the serious limitation of existing models immediately became apparent. Macro models failed to predict the crisis and ... [to explain] what was happening [...]. The key lesson ... is the **danger of relying on a single tool, methodology or paradigm**.

The **atomistic, optimising agents** underlying existing models do not capture behavior during a crisis period. We need to deal better with **heterogeneity across agents and the interaction among those heterogeneous agents.** [...] **Agent-based modelling** dispenses with the optimisation assumption and allows for **more complex interactions** between agents.'

J.-C. Trichet, Governor of the ECB, Nov. 18, 2010, Frankfurt, Germany.

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- 'Cashless' economy: monetary phenomena cannot have long-lasting real effects.
- Further estimation and empirical validation issues (Fagiolo & Roventini 2017).

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1. A richer **financial** sector (financial-accelerator effects);
2. **Heterogeneous** agents (e.g. constrained/optimizers, bottom/top earners);
3. **Non-rational** expectations (e.g. adaptive learning, heuristics);
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3. conceptual restriction: business cycles still originate from **exogenous** shocks.

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- An **artificial laboratory** to compare and design macro policies.

A brief historical perspective

- **Bounded rationality** and 'satisfycing' (e.g. Simon 1955).
- Literature on **firms' behavior** and simulations in the early 1960s at the Carnegie Melon U.
  (e.g. Cohen 1960, Cyert and March, 1963).
- Development of the use of **simulations** in other fields (ranging from military war games to ecology), especially **social sciences** (e.g. Schelling 1971, 1978).
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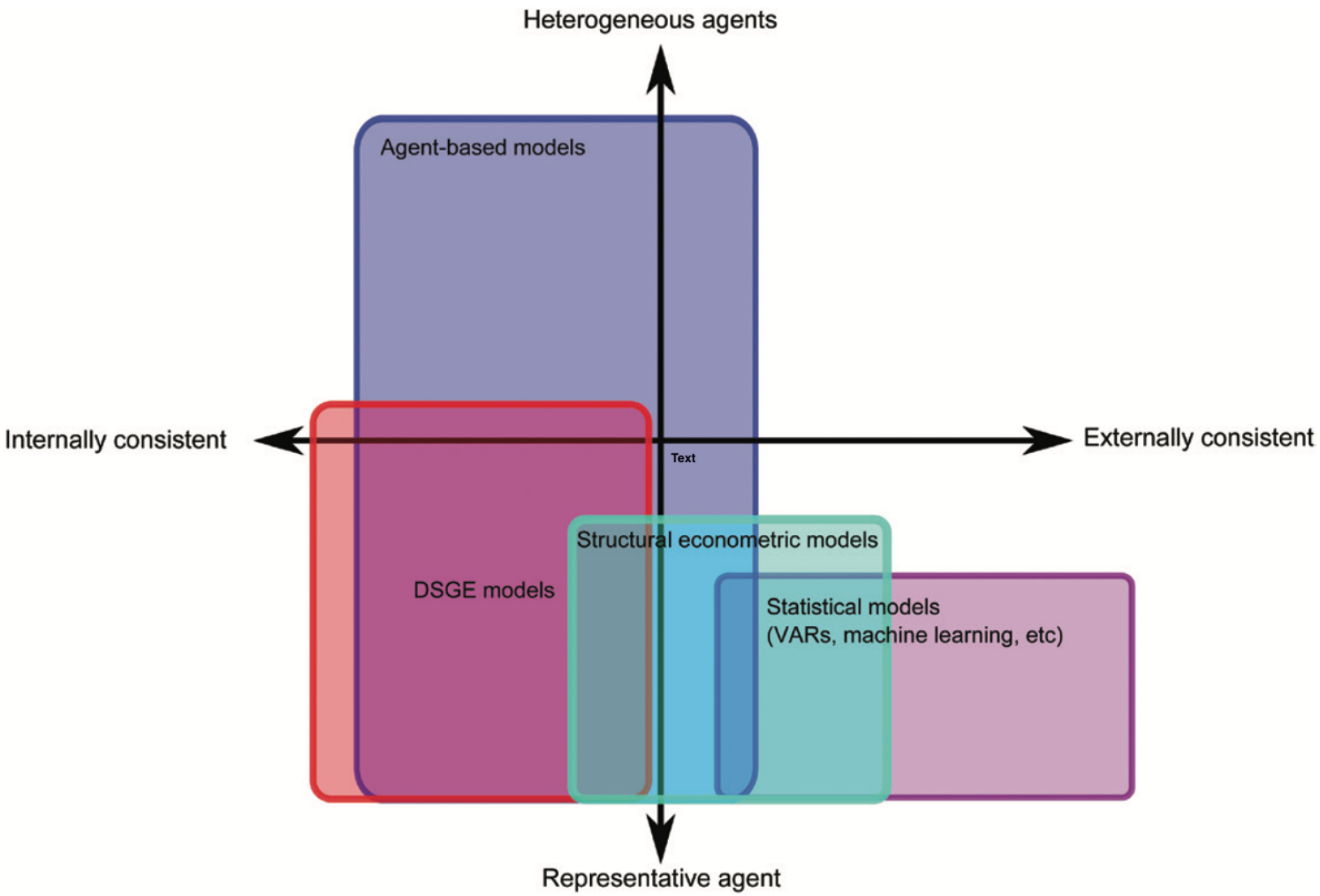
- **Macroeconomic Agent-Based Models (ABMs)**
  (a *non-exhaustive* list: Bruun (1999), Tesfatsion at U. Ohio (2006), Gallegati et al. at Marche Polytechnic U. (2003–), `Eurace` model (2008), Dosi et al. at Sant'Anna Pisa (`K+S model`, 2010–), Dawid et al. at U. Bielefeld (`Eurace@unibi` model, 2013–), Delli Gatti et al. at Catholic U. Milan (2012 –), Yildizoglu et al. at U. Bordeaux (2013–), Caiani et al. (2016).

ABMs with respect to DSGE models

(The 2007-8 financial crisis and the ensuing Great Recession.)

	Keynesian models (e.g. $IS - LM$)	DSGE models (post 2008-crisis)	Agent-based macro models
Microeconomic foundations	missing	Several (many) types of agents	interacting and heterogeneous agents
Agents' behaviour	not modelled	mostly maximisation, learning, imperfect information	procedural rationality, local information
Macroeconomic relationships	postulated and estimated	mapping from individual behaviour	emerging from individual and local interactions
Source of fluctuations	exogenous shocks	**exogenous shocks**	endogeneous: coordination issues

ABMs in the spectrum of macro models



Source: Haldane & Turrell (2018).

Limitations of ABMs and Challenges

1. '*Wilderness of bounded rationality*':
   - Empirical and experimental work can help restrict the degrees of freedom in the design of the agents' behavioral rules.
   - Estimation techniques, including Bayesian, can help reduce the number of arbitrarily fixed parameter values (Grazzini et al. 2017, Poledna et al. 2018).
   - **Over-parametrization**: evolutionary algorithms to make parameters *endogenous*.

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3. Challenge in **communication**: embedding the main mechanisms at play in a larger ABM into simpler frameworks.

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- Micro and macro **empirical** validation.

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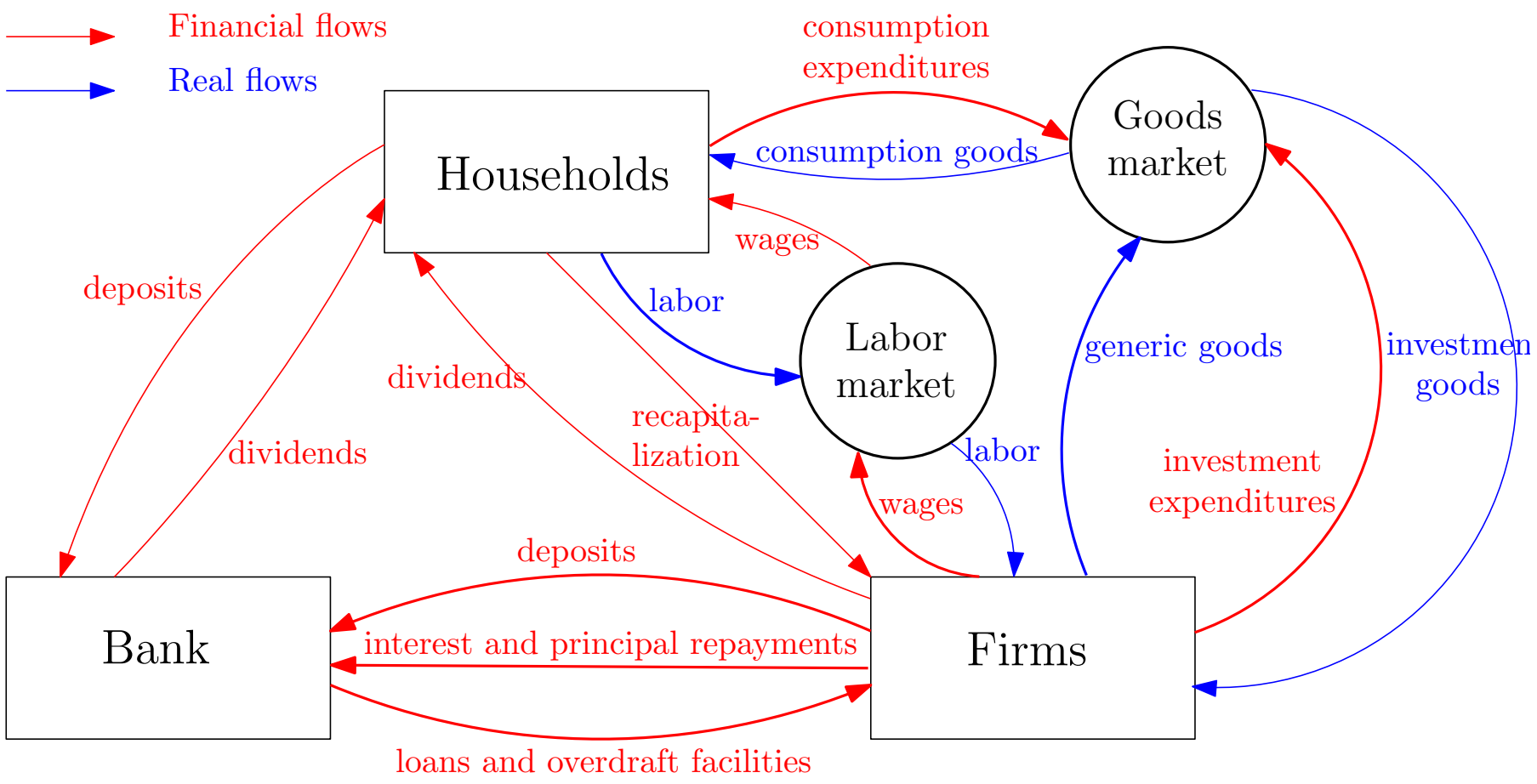
Different stages of the development of Jamel.

- A simple production economy for minimum wage policy (Seppecher 2012, Mac. Dyn.).
- Opinion dynamics, individual financial behaviors and complex aggregate pattern: switches between stability and deep recessions (Seppecher & Salle, 2015, Appl. Econ.).
- Three interdependent industrial sectors and dynamics of the relative prices (Seppecher, Salle & Lavoie 2018, Ind. & Corp. Ch.).
- Investment, financial accelerator and endogenous credit cycles (Seppecher, Salle & Lang 2018, JEEC).
- **Credit cycles and monetary policy: three-mandate-interest rate rules** (Salle & Seppecher, 2018, JEDC).

Architecture of the model



'Stabilizing an Unstable Complex Economy: On the limitations of simple rules', Salle I. & Seppecher P., 2018, *Journal of Econ. Dyn. and Control*, Vol. 91, pp. 289-317.

Agents' behaviors

Households

- Buy the goods for consumption: buffer-stock rule.
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The banking sector

- Provides credits to firms, hosts deposits, pays dividends.
- Foreclosure procedure (in case of firms' insolvency).

A central bank: follows a Taylor rule, imposes prudential policies.

Policies in the model

Macro and micro-prudential regulation constraints credit demand:

- When borrowing for investment, firms face a **cap on their debt-service-to-income ratio**.
- Firms are charged **endogenous risk premia** depending on their leverage.
- The banking sector complies with an **equity-to-risk-weighted-assets ratio** (Basel II and III).

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Monetary policy operates through the credit channel:

- Interest rates influence firms' risk-taking behavior and the service on their debt.
- The risk-free interest rate is set by the central bank in reaction to inflation, GDP growth and possibly an objective of financial stability, subject to the ZLB $\rightarrow$ **'lean vs. clean' debate**.

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3. **Prudential Policy** – Can micro and/or macro regulations help achieve financial stability? How do the performances of the prudential framework interact with the monetary policy rule?

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- The **straightforward aggregation** and the **numerical resolution** allow us to easily implement and tune a wide range of policy scenarios.
- The macro closure allows us to assess the effects of policies on a wide range of indicators **as in the real world** (unemployment costs of recessions).

Illustration: baseline simulation

ILLUSTRATION: the baseline scenario without leaning-against-the-wind policies.

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Empirical validation

The baseline simulation is able to generate realistic orders of magnitude of a large set of macro indicators, and reproduce **22 stylized facts**, incl. irregular fluctuations in real variables, Phillips and Beveridge curves (both slopes and rotation), persistent time series, non-normality of macro growth rates and micro distributions, cross-correlation patterns, Okun's law, etc.

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- The relative wage rigidity interrupts the bust. ▸ To policy results

Adaptation of the firms along a cycle

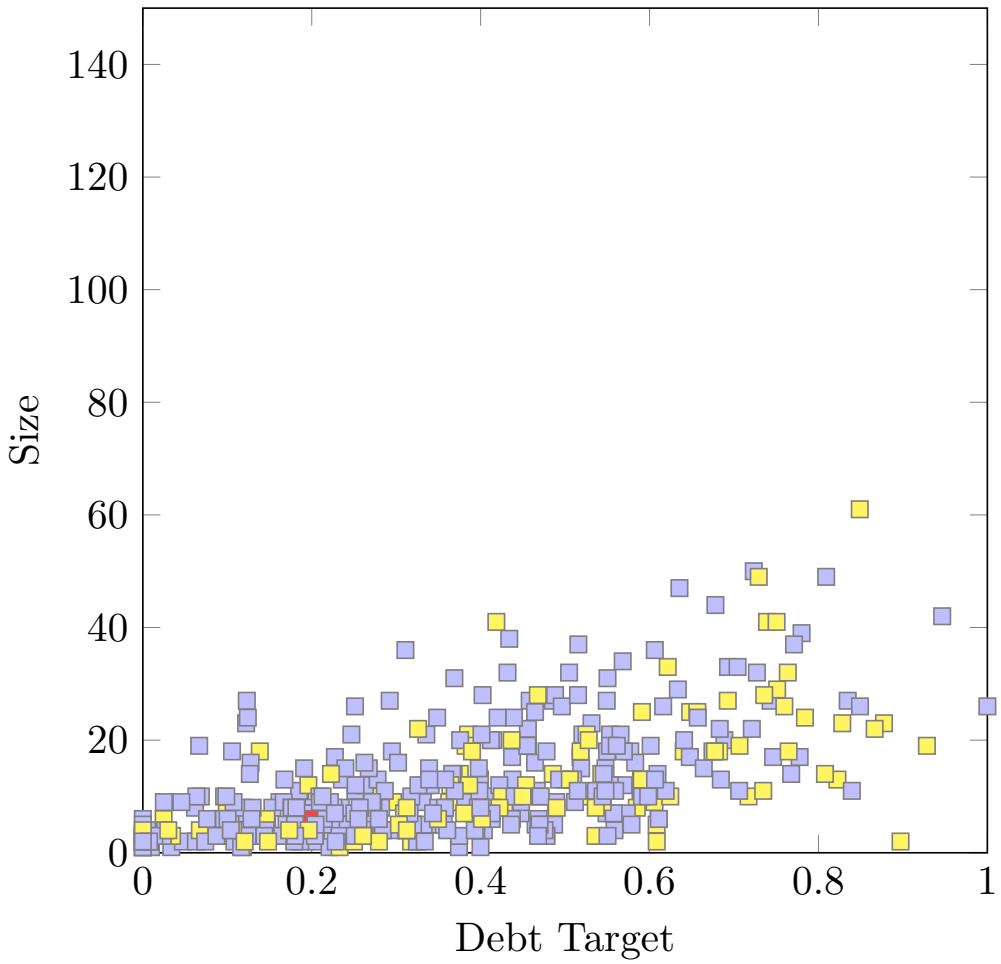

Figure: Start of the boom $t = 850$.

Progressive dispersion towards the top-right corner (big size, heavy debt).

Adaptation of the firms along a cycle

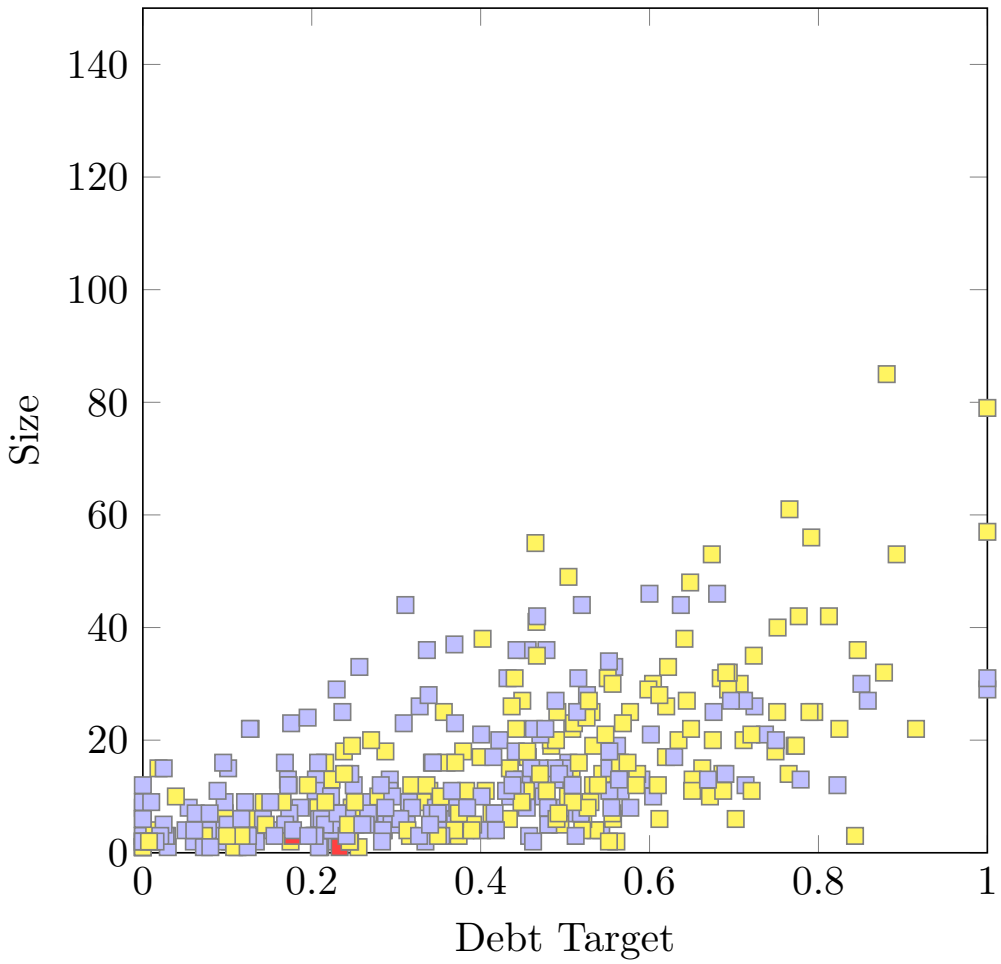

Figure: Boom dynamics $t = 900$.

Progressive dispersion towards the top-right corner (big size, heavy debt).

Adaptation of the firms along a cycle

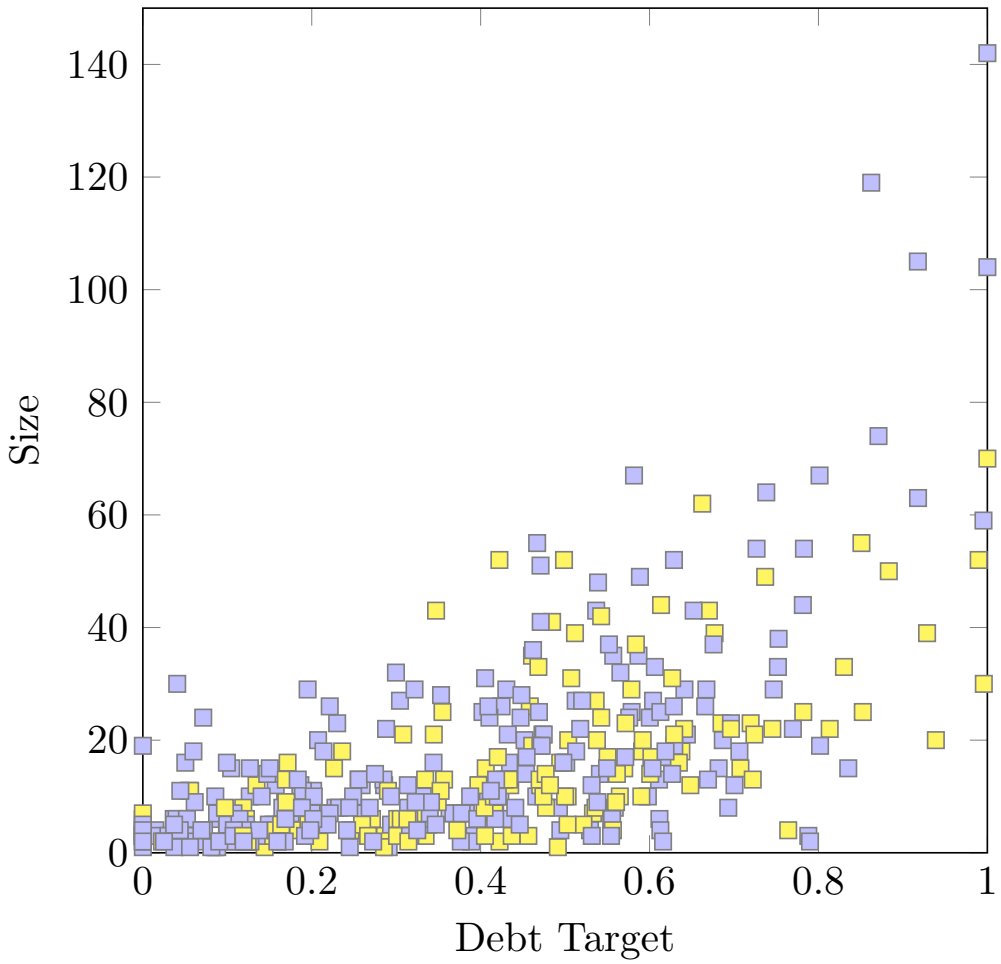

Figure: Top of the boom
$t = 950$.

Competitive and **risky** area.

Adaptation of the firms along a cycle

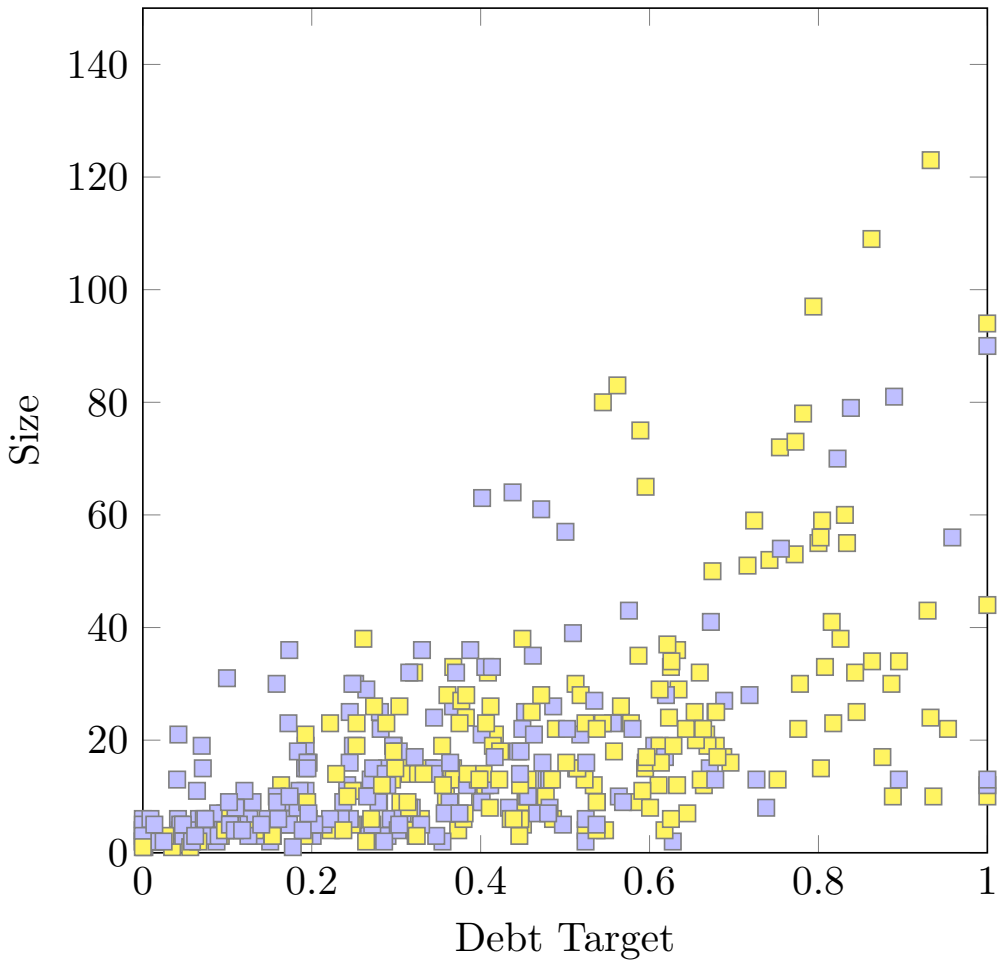

Figure: Start of the downturn $t = 1,000$.

Competitive and **risky** area.

Adaptation of the firms along a cycle

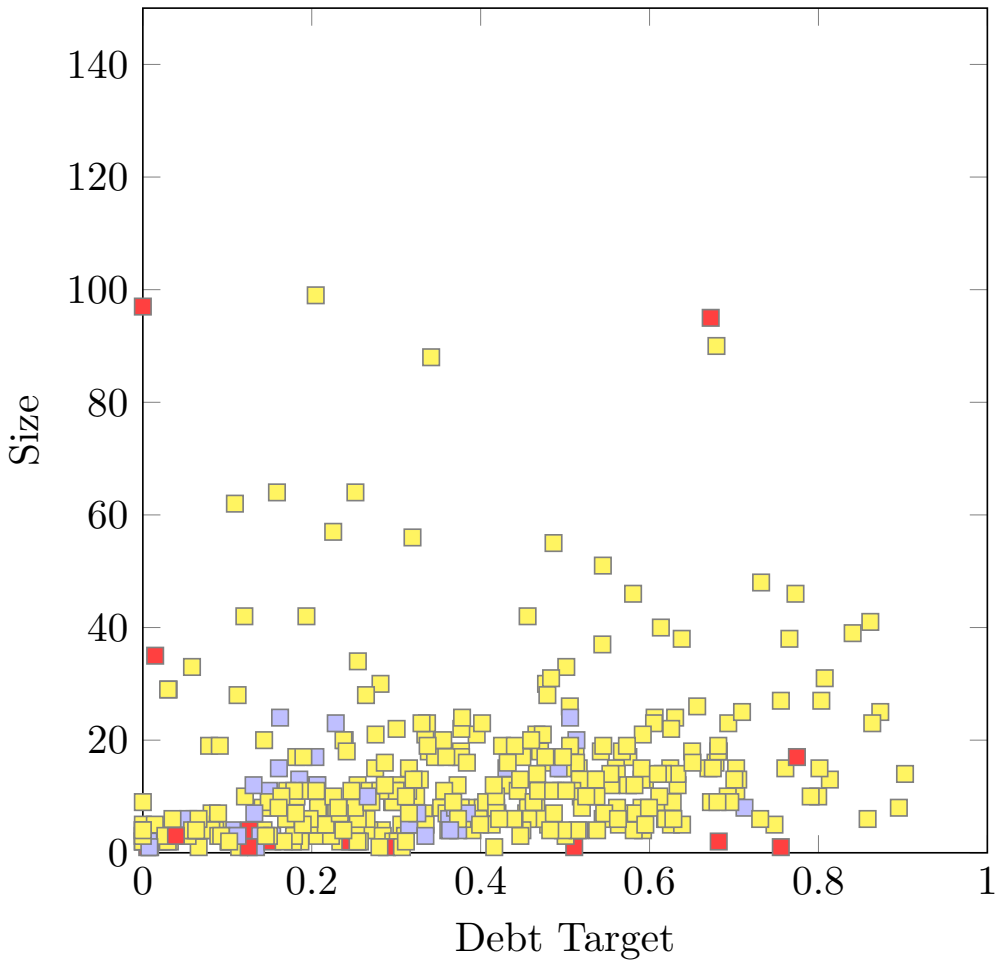

Figure: Bust dynamics $t = 1,050$.

Brutal/fast contraction towards the origin (decrease in capital and bankruptcies).

Adaptation of the firms along a cycle

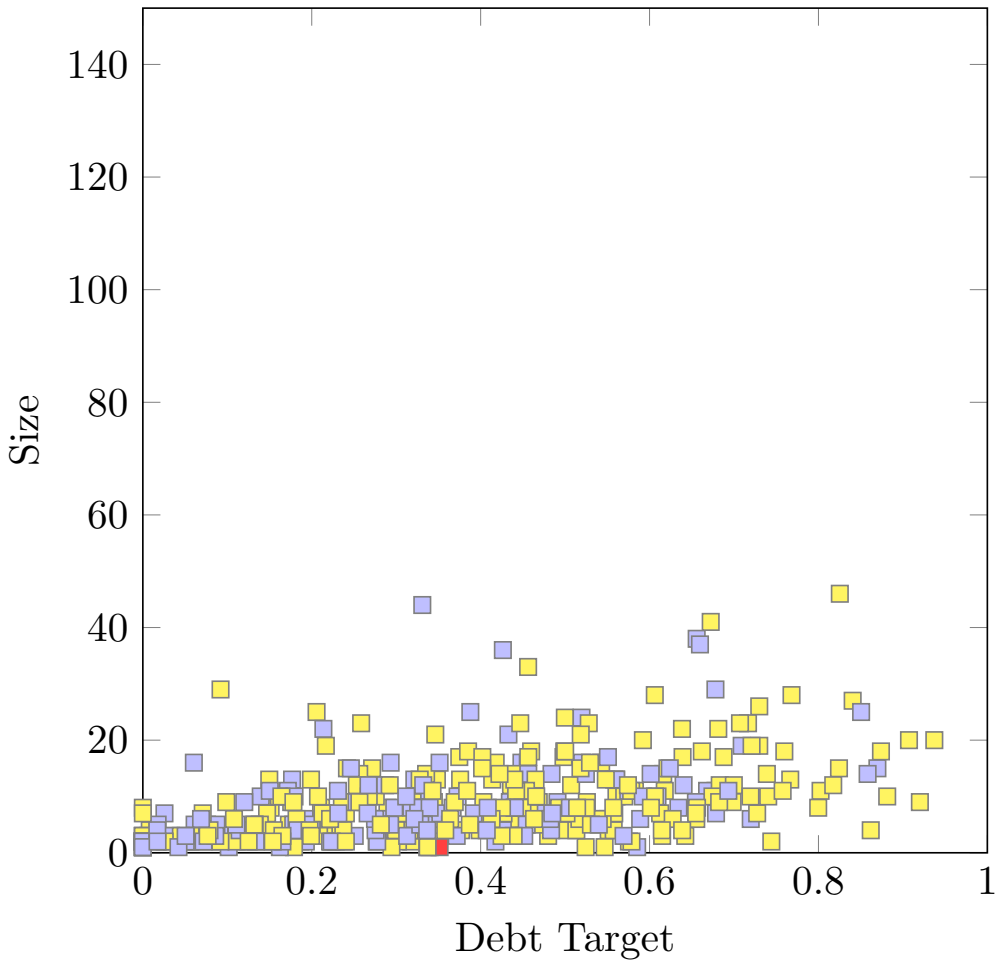

Figure: Bottom of the bust, $t = 1,110$.

The downturn leads to an **homogenization** of the behaviors: bankruptcies affect first the big firms.

Interpretation of agents' balance sheets

The networth has lost more than 30% of its value within 50 periods.

	Households	Firms	Banks	Σ
Work In Process		828,809.29		828,809.29
Inventories		766,196.57		766,196.57
Fixed Capital		1,526,549.43		1,526,549.43
Deposits	1,413,349.64	855,523.67	-2,268,873.31	0
Short Term Loans		-1,672,184.92	1,672,184.92	0
Long Term Loans		-875,731.31	875,731.31	0
Equities	1,708,205.65	-1,429,162.72	-279,042.92	0
Σ	3,121,555.28	0	0	3,121,555.28

Table: Balance sheet matrix, period 1000 (in real terms)

Interpretation of agents' balance sheets

The networth has lost more than 30% of its value within 50 periods.

	Households	Firms	Banks	Σ
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Equities	1,708,205.65	-1,429,162.72	-279,042.92	0
Σ	3,121,555.28	0	0	3,121,555.28

Table: Balance sheet matrix, period 1000 (in real terms)

	Households	Firms	Banks	Σ
Work In Process		700,091.60		700,091.60
Inventories		878,428.60		878,428.60
Fixed Capital		586,028.52		586,028.52
Deposits	1,039,460.42	603,749.48	-1,643,209.89	0
Short Term Loans		-1,529,421.24	1,529,421.24	0
Long Term Loans		-312,271.74	312,271.74	0
Equities	1,125,088.31	-926,605.22	-198,483.09	0
Σ	2,164,548.73	0	0	2,164,548.73

Table: Balance sheet matrix, period 1050 (in real terms)

Interpretation of agents' balance sheets

Collapse in investment, and decrease in capital due to non-renewal.

	Households	Firms	Banks	Σ
Work In Process		828,809.29		828,809.29
Inventories		766,196.57		766,196.57
Fixed Capital		1,526,549.43		1,526,549.43
Deposits	1,413,349.64	855,523.67	-2,268,873.31	0
Short Term Loans		-1,672,184.92	1,672,184.92	0
Long Term Loans		-875,731.31	875,731.31	0
Equities	1,708,205.65	-1,429,162.72	-279,042.92	0
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Long Term Loans		-312,271.74	312,271.74	0
Equities	1,125,088.31	-926,605.22	-198,483.09	0
Σ	2,164,548.73	0	0	2,164,548.73

Table: Balance sheet matrix, period 1050 (in real terms)

Interpretation of agents' balance sheets

Increase in inventories due to the drop in demand (excess supply).

	Households	Firms	Banks	Σ
Work In Process		828,809.29		828,809.29
Inventories		766,196.57		766,196.57
Fixed Capital		1,526,549.43		1,526,549.43
Deposits	1,413,349.64	855,523.67	-2,268,873.31	0
Short Term Loans		-1,672,184.92	1,672,184.92	0
Long Term Loans		-875,731.31	875,731.31	0
Equities	1,708,205.65	-1,429,162.72	-279,042.92	0
Σ	3,121,555.28	0	0	3,121,555.28

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Work In Process		700,091.60		700,091.60
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Fixed Capital		586,028.52		586,028.52
Deposits	1,039,460.42	603,749.48	-1,643,209.89	0
Short Term Loans		-1,529,421.24	1,529,421.24	0
Long Term Loans		-312,271.74	312,271.74	0
Equities	1,125,088.31	-926,605.22	-198,483.09	0
Σ	2,164,548.73	0	0	2,164,548.73

Table: Balance sheet matrix, period 1050 (in real terms)

Interpretation of agents' balance sheets

On the liabilities side, the drop in investment results in a drop of long-run loans.

	Households	Firms	Banks	Σ
Work In Process		828,809.29		828,809.29
Inventories		766,196.57		766,196.57
Fixed Capital		1,526,549.43		1,526,549.43
Deposits	1,413,349.64	855,523.67	-2,268,873.31	0
Short Term Loans		-1,672,184.92	1,672,184.92	0
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Long Term Loans		-312,271.74	312,271.74	0
Equities	1,125,088.31	-926,605.22	-198,483.09	0
Σ	2,164,548.73	0	0	2,164,548.73

Table: Balance sheet matrix, period 1050 (in real terms)

Interpretation of agents' balance sheets

and liquidity issues that translate into short-run loans due to the drop in sales.

	Households	Firms	Banks	Σ
Work In Process		828,809.29		828,809.29
Inventories		766,196.57		766,196.57
Fixed Capital		1,526,549.43		1,526,549.43
Deposits	1,413,349.64	855,523.67	-2,268,873.31	0
Short Term Loans		-1,672,184.92	1,672,184.92	0
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Equities	1,708,205.65	-1,429,162.72	-279,042.92	0
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Fixed Capital		586,028.52		586,028.52
Deposits	1,039,460.42	603,749.48	-1,643,209.89	0
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Long Term Loans		-312,271.74	312,271.74	0
Equities	1,125,088.31	-926,605.22	-198,483.09	0
Σ	2,164,548.73	0	0	2,164,548.73

Table: Balance sheet matrix, period 1050 (in real terms)

Analysis of monetary policy scenarios

Scenario	$\mathcal{F}_t$	ϕ_f
fragility	$\left(\frac{D_t}{\Pi_t} - 2\right)$	0.01
creditGrowth	$\log D_t - \log D_{t-12}$	1
	(yearly growth rate)	2
netWorth	$\left(\frac{A_t}{L_t} - 0.5\right)$	1.5
	(average, weighted by assets)	2.5
changeNetWorth	$\Delta \frac{A_t}{L_t}$	1.5
	(average, weighted by assets)	2.5
spreads	$\tilde{i}_t - i_t$	1
	(weighted by firms' categories)	2
changeSpreads	$\Delta(\tilde{i}_t - i_t)$	1
	(weighted by firms' categories)	2

Overview of the results – baseline

Various indicators to measure the real costs of recessions.

Scenario	Nb. of recessions	Duration	Depth	Breadth	Max. Financial fragility	Nb. of bankrupcies	sd. GDP growth	sd. inflation	sd. nom. int. rate	Credit cyclicality	Nb. systemic crises
Baseline ($\phi_f = 0$)	10 (0.76)	85.5 (8.35)	0.32 (0.02)	19.6 (3.06)	14.3 (14.8)	12.4 (3.3)	0.012 (0.000)	0.053 (0.003)	0.006 (0.000)	9.54 (0.74)	0
fragility	8.3* (0.89)	129*** (20.2)	0.39*** (0.04)	37*** (7.9)	82.5*** (53.9)	43** (14.3)	0.013** (0.000)	0.061* (0.006)	0.012** (0.004)	8.49** (0.79)	18
creditGrowth ($\phi_f = 1$)	9.79 (0.9)	95.6** (11.5)	0.31 (0.03)	22.1 (5)	18.4 (11.3)	12.4 (4.5)	0.012 (0.001)	0.051 (0.007)	0.01** (0.000)	8.17*** (0.72)	1
creditGrowth ($\phi_f = 2$)	9.9 (0.79)	94.5** (9.5)	0.29** (0.02)	20.5 (3.4)	43.5 (115.7)	10.9 (3.2)	0.012 (0.000)	0.047 (0.003)	0.011 (0.000)	7.67*** (0.82)	1
netWorth ($\phi_f = 1.5$)	11.3*** (0.55)	70*** (3.7)	0.28*** (0.01)	13.8*** (1.24)	5.67*** (0.27)	3.8*** (1.18)	0.011** (0.000)	0.058 (0.002)	0.007* (0.000)	8.15*** (0.58)	0
netWorth ($\phi_f = 2.5$)	11.5** (0.73)	67*** (4.9)	0.27*** (0.018)	13*** (1.9)	5.14*** (0.31)	2.96*** (1.05)	0.011** (0.000)	0.061 (0.002)	0.007** (0.001)	7.54*** (0.7)	0
changeNetWorth ($\phi_f = 1.5$)	10.6 (0.82)	77.5** (6.6)	0.31** (0.02)	16.7*** (2.5)	7.7*** (2.6)	7.8*** (2.8)	0.011** (0.000)	0.054 (0.002)	0.007* (0.000)	9.38* (0.8)	1
changeNetWorth ($\phi_f = 2.5$)	10.5 (0.8)	76.6** (6.6)	0.3*** (0.02)	16.5** (3.3)	6.8*** (2.3)	7*** (4.3)	0.012 (0.001)	0.055 (0.006)	0.007** (0.000)	9.02*** (0.79)	0
spreads ($\phi_f = 1$)	9.9 (0.8)	88.1 (10.5)	0.33 (0.02)	21 (4.7)	50 (97.9)	13.9 (5)	0.012 (0.001)	0.056 (0.005)	0.006 (0.000)	9.46 (1.06)	3
spreads ($\phi_f = 2$)	10 (0.76)	87.3 (10.9)	0.33 (0.02)	20.7 (4.65)	37.6 (74)	13.4 (4.95)	0.012 (0.000)	0.054 (0.004)	0.006 (0.000)	9.4 (0.92)	0
changeSpreads ($\phi_f = 1$)	9.9 (0.95)	89 (10.3)	0.33 (0.02)	21.45 (4.48)	90.8 (206.9)	13.7 (4.4)	0.012 (0.001)	0.056 (0.005)	0.007 (0.000)	9.52 (0.73)	2
changeSpreads ($\phi_f = 2$)	9.9 (1)	88.5 (12.3)	0.33 (0.03)	20.7 (4.46)	70.8 (224)	13.7 (3.65)	0.012 (0.000)	0.053 (0.003)	0.006 (0.000)	9.54 (0.64)	2

Overview of the results – debt-to-profit ratio

Because financial fragility is lagging, it is the worse indicator of financial imbalances.

Scenario	Nb. of recessions	Duration	Depth	Breadth	Max. Financial fragility	Nb. of bankrupcies	sd. GDP growth	sd. inflation	sd. nom. int. rate	Credit cyclicality	Nb. systemic crises
Baseline ($\phi_f = 0$)	10	85.5	0.32	19.6	14.3	12.4	0.012	0.053	0.006	9.54	0
	(0.76)	(8.35)	(0.02)	(3.06)	(14.8)	(3.3)	(0.000)	(0.003)	(0.000)	(0.74)	
fragility	8.3*	129***	0.39***	37***	82.5***	43**	0.013**	0.061*	0.012**	8.49**	18
	(0.89)	(20.2)	(0.04)	(7.9)	(53.9)	(14.3)	(0.000)	(0.006)	(0.004)	(0.79)	
creditGrowth ($\phi_f = 1$)	9.79	95.6**	0.31	22.1	18.4	12.4	0.012	0.051	0.01**	8.17***	1
	(0.9)	(11.5)	(0.03)	(5)	(11.3)	(4.5)	(0.001)	(0.007)	(0.000)	(0.72)	
creditGrowth ($\phi_f = 2$)	9.9	94.5**	0.29**	20.5	43.5	10.9	0.012	0.047	0.011	7.67***	1
	(0.79)	(9.5)	(0.02)	(3.4)	(115.7)	(3.2)	(0.000)	(0.003)	(0.000)	(0.82)	
netWorth ($\phi_f = 1.5$)	11.3***	70***	0.28***	13.8***	5.67***	3.8***	0.011**	0.058	0.007*	8.15***	0
	(0.55)	(3.7)	(0.01)	(1.24)	(0.27)	(1.18)	(0.000)	(0.002)	(0.000)	(0.58)	
netWorth ($\phi_f = 2.5$)	11.5**	67***	0.27***	13***	5.14***	2.96***	0.011**	0.061	0.007**	7.54***	0
	(0.73)	(4.9)	(0.018)	(1.9)	(0.31)	(1.05)	(0.000)	(0.002)	(0.001)	(0.7)	
changeNetWorth ($\phi_f = 1.5$)	10.6	77.5**	0.31**	16.7***	7.7***	7.8***	0.011**	0.054	0.007*	9.38*	1
	(0.82)	(6.6)	(0.02)	(2.5)	(2.6)	(2.8)	(0.000)	(0.002)	(0.000)	(0.8)	
changeNetWorth ($\phi_f = 2.5$)	10.5	76.6**	0.3***	16.5**	6.8***	7***	0.012	0.055	0.007**	9.02***	0
	(0.8)	(6.6)	(0.02)	(3.3)	(2.3)	(4.3)	(0.001)	(0.006)	(0.000)	(0.79)	
spreads ($\phi_f = 1$)	9.9	88.1	0.33	21	50	13.9	0.012	0.056	0.006	9.46	3
	(0.8)	(10.5)	(0.02)	(4.7)	(97.9)	(5)	(0.001)	(0.005)	(0.000)	(1.06)	
spreads ($\phi_f = 2$)	10	87.3	0.33	20.7	37.6	13.4	0.012	0.054	0.006	9.4	0
	(0.76)	(10.9)	(0.02)	(4.65)	(74)	(4.95)	(0.000)	(0.004)	(0.000)	(0.92)	
changeSpreads ($\phi_f = 1$)	9.9	89	0.33	21.45	90.8	13.7	0.012	0.056	0.007	9.52	2
	(0.95)	(10.3)	(0.02)	(4.48)	(206.9)	(4.4)	(0.001)	(0.005)	(0.000)	(0.73)	
changeSpreads ($\phi_f = 2$)	9.9	88.5	0.33	20.7	70.8	13.7	0.012	0.053	0.006	9.54	2
	(1)	(12.3)	(0.03)	(4.46)	(224)	(3.65)	(0.000)	(0.003)	(0.000)	(0.64)	

Overview of the results – credit growth

Because credit growth is partly redundant with GDP growth (almost coincident), no significant improvement w.r.t. two-mandate rule.

Scenario	Nb. of recessions	Duration	Depth	Breadth	Max. Financial fragility	Nb. of bankrupcies	sd. GDP growth	sd. inflation	sd. nom. int. rate	Credit cyclicality	Nb. systemic crises
Baseline ($\phi_f = 0$)	10	85.5	0.32	19.6	14.3	12.4	0.012	0.053	0.006	9.54	0
	(0.76)	(8.35)	(0.02)	(3.06)	(14.8)	(3.3)	(0.000)	(0.003)	(0.000)	(0.74)	
fragility	8.3*	129***	0.39***	37***	82.5***	43**	0.013**	0.061*	0.012**	8.49**	18
	(0.89)	(20.2)	(0.04)	(7.9)	(53.9)	(14.3)	(0.000)	(0.006)	(0.004)	(0.79)	
creditGrowth ($\phi_f = 1$)	9.79	95.6**	0.31	22.1	18.4	12.4	0.012	0.051	0.01**	8.17***	1
	(0.9)	(11.5)	(0.03)	(5)	(11.3)	(4.5)	(0.001)	(0.007)	(0.000)	(0.72)	
creditGrowth ($\phi_f = 2$)	9.9	94.5**	0.29**	20.5	43.5	10.9	0.012	0.047	0.011	7.67***	1
	(0.79)	(9.5)	(0.02)	(3.4)	(115.7)	(3.2)	(0.000)	(0.003)	(0.000)	(0.82)	
netWorth ($\phi_f = 1.5$)	11.3***	70***	0.28***	13.8***	5.67***	3.8***	0.011**	0.058	0.007*	8.15***	0
	(0.55)	(3.7)	(0.01)	(1.24)	(0.27)	(1.18)	(0.000)	(0.002)	(0.000)	(0.58)	
netWorth ($\phi_f = 2.5$)	11.5**	67***	0.27***	13***	5.14***	2.96***	0.011**	0.061	0.007**	7.54***	0
	(0.73)	(4.9)	(0.018)	(1.9)	(0.31)	(1.05)	(0.000)	(0.002)	(0.001)	(0.7)	
changeNetWorth ($\phi_f = 1.5$)	10.6	77.5**	0.31**	16.7***	7.7***	7.8***	0.011**	0.054	0.007*	9.38*	1
	(0.82)	(6.6)	(0.02)	(2.5)	(2.6)	(2.8)	(0.000)	(0.002)	(0.000)	(0.8)	
changeNetWorth ($\phi_f = 2.5$)	10.5	76.6**	0.3***	16.5**	6.8***	7***	0.012	0.055	0.007**	9.02***	0
	(0.8)	(6.6)	(0.02)	(3.3)	(2.3)	(4.3)	(0.001)	(0.006)	(0.000)	(0.79)	
spreads ($\phi_f = 1$)	9.9	88.1	0.33	21	50	13.9	0.012	0.056	0.006	9.46	3
	(0.8)	(10.5)	(0.02)	(4.7)	(97.9)	(5)	(0.001)	(0.005)	(0.000)	(1.06)	
spreads ($\phi_f = 2$)	10	87.3	0.33	20.7	37.6	13.4	0.012	0.054	0.006	9.4	0
	(0.76)	(10.9)	(0.02)	(4.65)	(74)	(4.95)	(0.000)	(0.004)	(0.000)	(0.92)	
changeSpreads ($\phi_f = 1$)	9.9	89	0.33	21.45	90.8	13.7	0.012	0.056	0.007	9.52	2
	(0.95)	(10.3)	(0.02)	(4.48)	(206.9)	(4.4)	(0.001)	(0.005)	(0.000)	(0.73)	
changeSpreads ($\phi_f = 2$)	9.9	88.5	0.33	20.7	70.8	13.7	0.012	0.053	0.006	9.54	2
	(1)	(12.3)	(0.03)	(4.46)	(224)	(3.65)	(0.000)	(0.003)	(0.000)	(0.64)	

Overview of the results – spreads

The same goes for reacting to credit spreads: the indicator is too coincident to break down the pro-cyclicality of credit bubble.

Scenario	Nb. of recessions	Duration	Depth	Breadth	Max. Financial fragility	Nb. of bankrupcies	sd. GDP growth	sd. inflation	sd. nom. int. rate	Credit cyclicality	Nb. systemic crises
Baseline ($\phi_f = 0$)	10	85.5	0.32	19.6	14.3	12.4	0.012	0.053	0.006	9.54	0
	(0.76)	(8.35)	(0.02)	(3.06)	(14.8)	(3.3)	(0.000)	(0.003)	(0.000)	(0.74)	
fragility	8.3*	129***	0.39***	37***	82.5***	43**	0.013**	0.061*	0.012**	8.49**	18
	(0.89)	(20.2)	(0.04)	(7.9)	(53.9)	(14.3)	(0.000)	(0.006)	(0.004)	(0.79)	
creditGrowth ($\phi_f = 1$)	9.79	95.6**	0.31	22.1	18.4	12.4	0.012	0.051	0.01**	8.17***	1
	(0.9)	(11.5)	(0.03)	(5)	(11.3)	(4.5)	(0.001)	(0.007)	(0.000)	(0.72)	
creditGrowth ($\phi_f = 2$)	9.9	94.5**	0.29**	20.5	43.5	10.9	0.012	0.047	0.011	7.67***	1
	(0.79)	(9.5)	(0.02)	(3.4)	(115.7)	(3.2)	(0.000)	(0.003)	(0.000)	(0.82)	
netWorth ($\phi_f = 1.5$)	11.3***	70***	0.28***	13.8***	5.67***	3.8***	0.011**	0.058	0.007*	8.15***	0
	(0.55)	(3.7)	(0.01)	(1.24)	(0.27)	(1.18)	(0.000)	(0.002)	(0.000)	(0.58)	
netWorth ($\phi_f = 2.5$)	11.5**	67***	0.27***	13***	5.14***	2.96***	0.011**	0.061	0.007**	7.54***	0
	(0.73)	(4.9)	(0.018)	(1.9)	(0.31)	(1.05)	(0.000)	(0.002)	(0.001)	(0.7)	
changeNetWorth ($\phi_f = 1.5$)	10.6	77.5**	0.31**	16.7***	7.7***	7.8***	0.011**	0.054	0.007*	9.38*	1
	(0.82)	(6.6)	(0.02)	(2.5)	(2.6)	(2.8)	(0.000)	(0.002)	(0.000)	(0.8)	
changeNetWorth ($\phi_f = 2.5$)	10.5	76.6**	0.3***	16.5**	6.8***	7***	0.012	0.055	0.007**	9.02***	0
	(0.8)	(6.6)	(0.02)	(3.3)	(2.3)	(4.3)	(0.001)	(0.006)	(0.000)	(0.79)	
spreads ($\phi_f = 1$)	9.9	88.1	0.33	21	50	13.9	0.012	0.056	0.006	9.46	3
	(0.8)	(10.5)	(0.02)	(4.7)	(97.9)	(5)	(0.001)	(0.005)	(0.000)	(1.06)	
spreads ($\phi_f = 2$)	10	87.3	0.33	20.7	37.6	13.4	0.012	0.054	0.006	9.4	0
	(0.76)	(10.9)	(0.02)	(4.65)	(74)	(4.95)	(0.000)	(0.004)	(0.000)	(0.92)	
changeSpreads ($\phi_f = 1$)	9.9	89	0.33	21.45	90.8	13.7	0.012	0.056	0.007	9.52	2
	(0.95)	(10.3)	(0.02)	(4.48)	(206.9)	(4.4)	(0.001)	(0.005)	(0.000)	(0.73)	
changeSpreads ($\phi_f = 2$)	9.9	88.5	0.33	20.7	70.8	13.7	0.012	0.053	0.006	9.54	2
	(1)	(12.3)	(0.03)	(4.46)	(224)	(3.65)	(0.000)	(0.003)	(0.000)	(0.64)	

Overview of the results – net worth

Reacting to the growing financial imbalances along booms includes predictive power, acts upon risk exposure and incentives to seek higher leverages.

Scenario	Nb. of recessions	Duration	Depth	Breadth	Max. Financial fragility	Nb. of bankrupcies	sd. GDP growth	sd. inflation	sd. nom. int. rate	Credit cyclicality	Nb. systemic crises
Baseline ($\phi_f = 0$)	10	85.5	0.32	19.6	14.3	12.4	0.012	0.053	0.006	9.54	0
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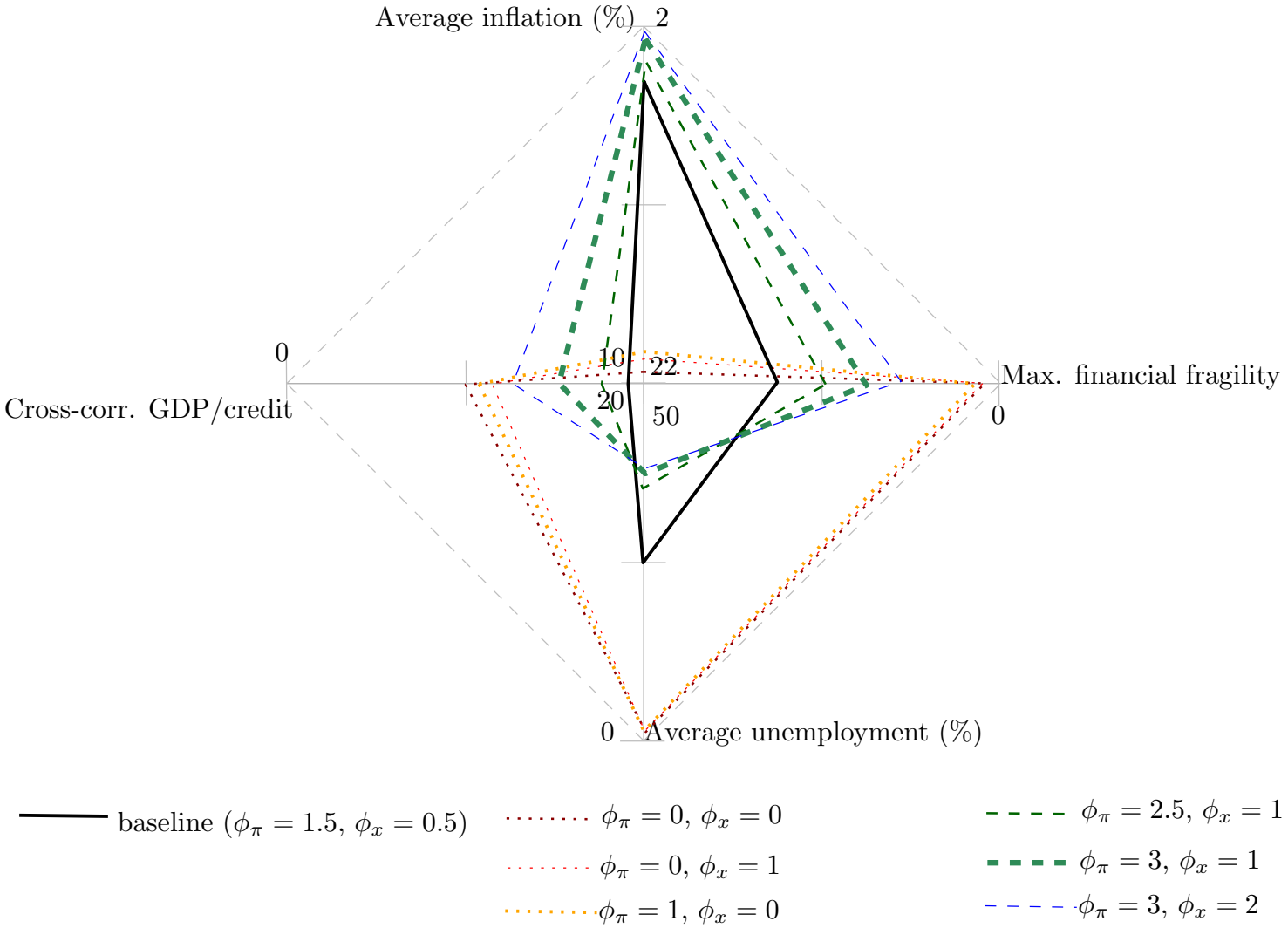
▸ (skip robustness to prudential framework)

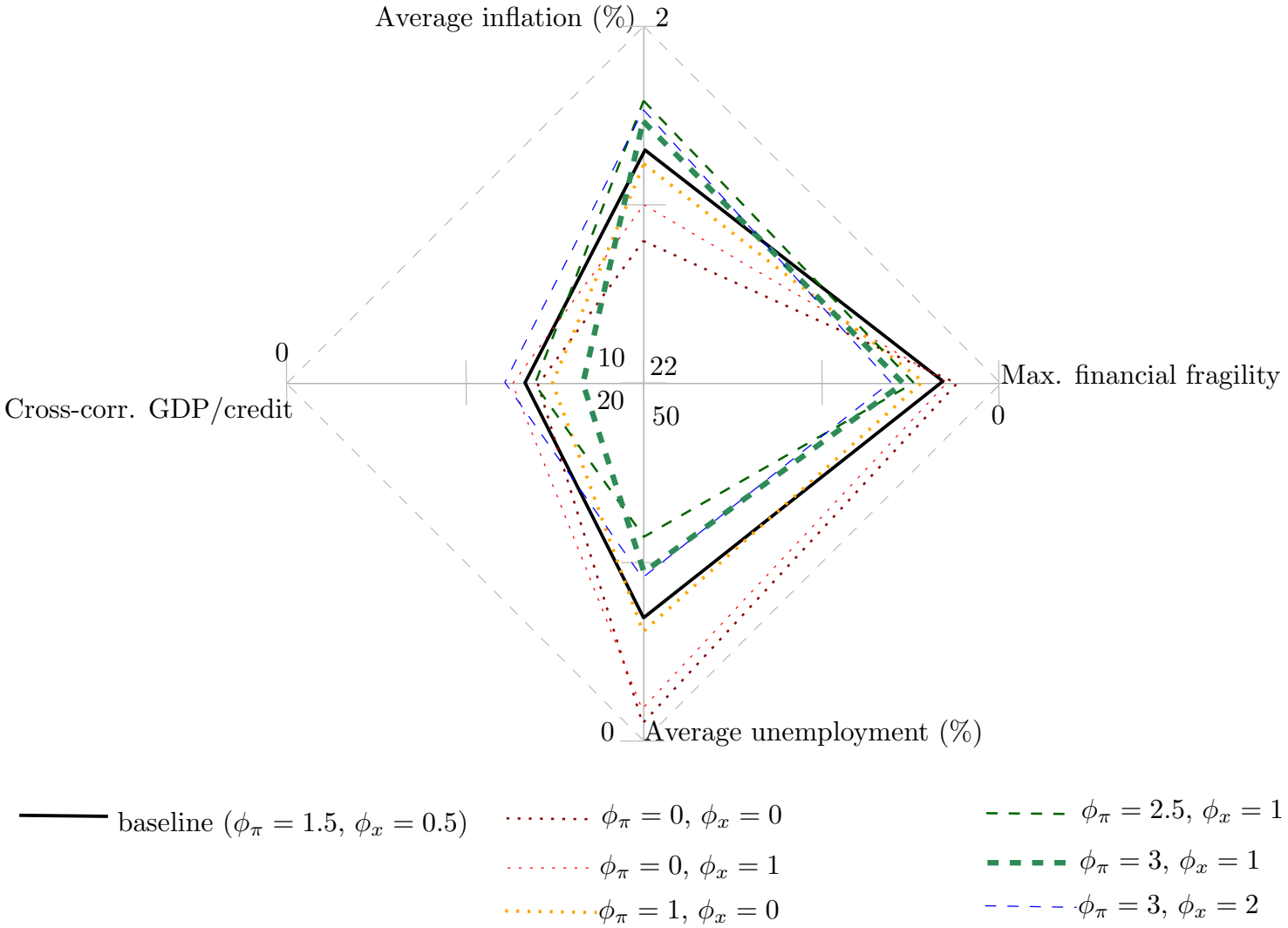
Robustness to alternative two-mandate rules

The Taylor principle works in our model, conflicting objectives between inflation and employment.



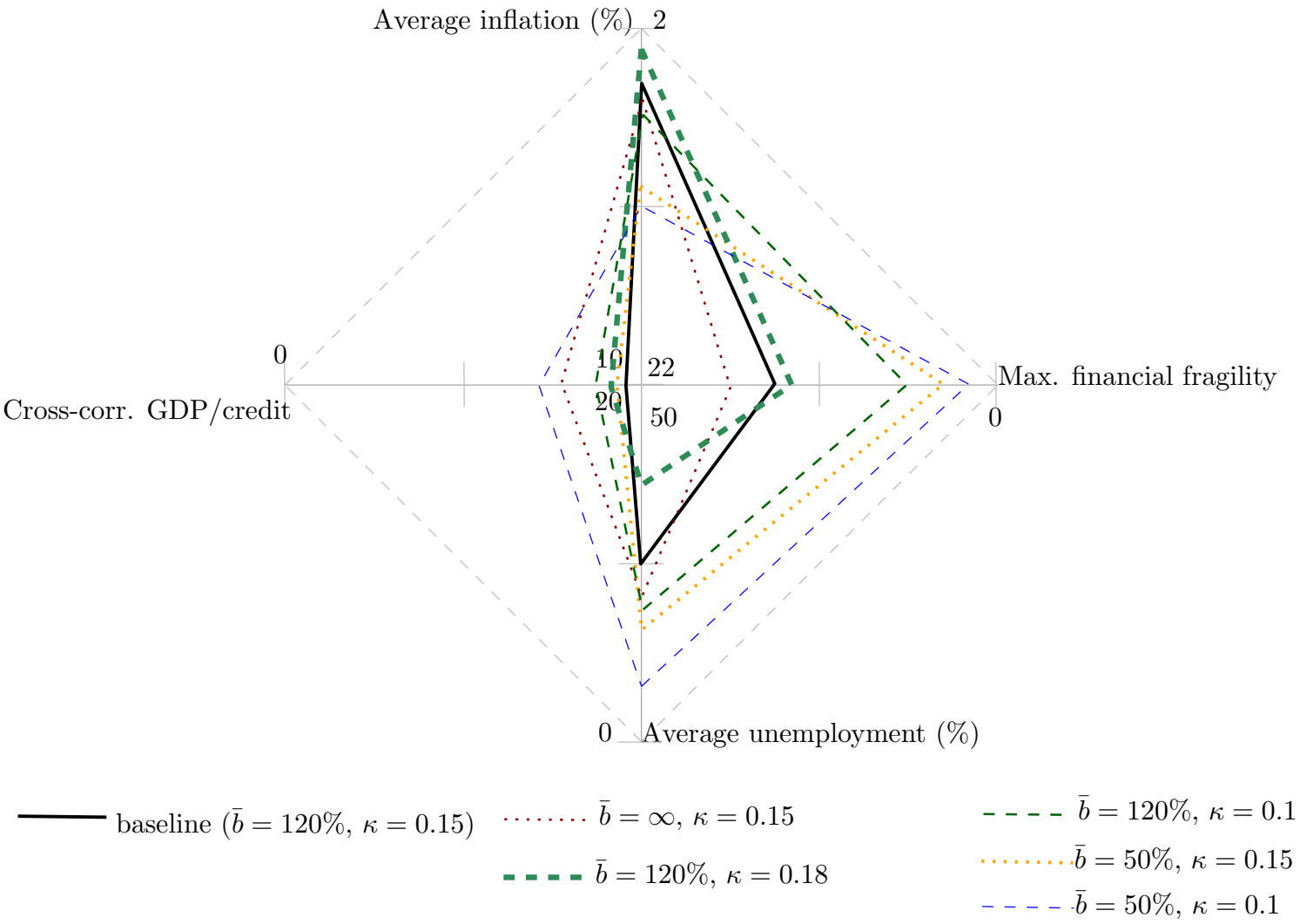
Robustness to alternative three-mandate rules

The trade-off inflation/employment is attenuated with a three-mandate rule.



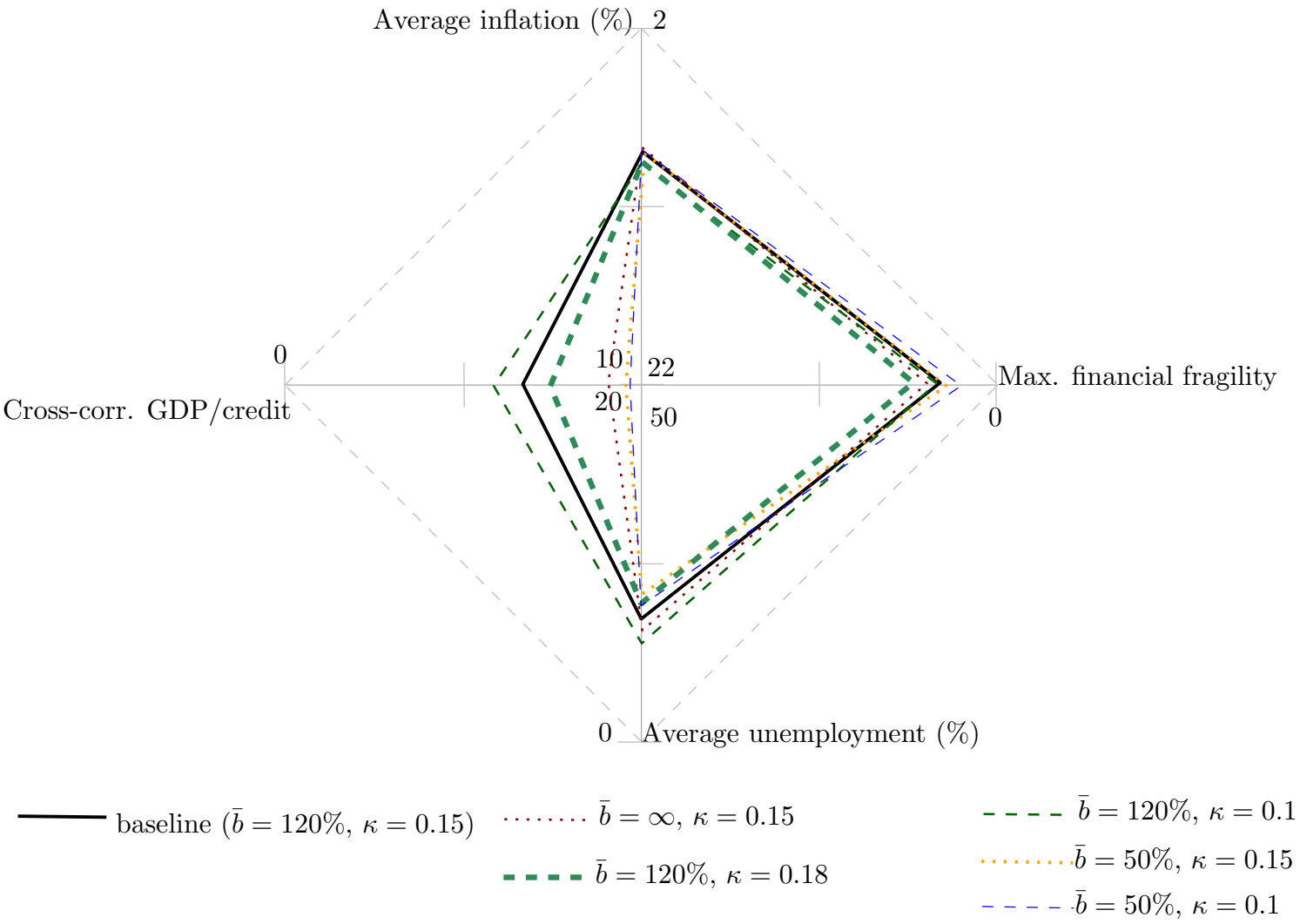
Prudential framework and two-mandate rules

Jointly tightening credit conditions and relaxing capital requirement achieves similar performances as a three-mandate rule.



Prudential framework and three-mandate rules

The performances of a three-mandate rule are rather independent from the prudential framework.



Elements for policy discussion

Leaning-against-the-wind limits financial fragility

The leverage of the firms is the only early indicator of the growing financial fragility along booms.

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Leaning-against-the-wind is not 'the' answer to financial crises

Yet, the employment costs of financial recessions remain systematic.

Possible extensions of the model

- A **'minimal-model' approach**: if a policy does not work in a stylized model, how confident to be that it will in a (much) more complex real-world economy?

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- Disaggregating the banking sector with **heterogeneous, competing and interdependent banks**:
  - Endogenous risk-taking on the supply side of the credit market, competition for loan provisions pushes risk premia down along booms and may further destabilize the system.
  - Contagion in the inter-bank market, CB as lender-of-last-resort.
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- Adding a housing market with mortgages: households' debt and leverage may feedback into aggregate demand.
- Any other ingredient relevant for policy design.

Thank you for your attention

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Questions & Comments:

ISalle@bank-banque-canada.ca

Firms' investment and debt strategies

Decision-making

- Strategy: $E_{j,t}^{T} \equiv (1 - \ell_{j,t}^{T})A_{j,t}$
  ($A_{j,t}$: total assets, $E_{j,t}^{T}$: equity target, $\ell_{j,t} \in [0,1]$: debt target)

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- Net present value analysis: expected demand, real interest rates and profitability $\rightarrow$ decides how many machines to purchase.
- Buys the homogeneous good that is immediately transformed at no cost into machines.
- $\ell^T_{j,t}$ **evolves according to the social learning process.**

Modeling learning in a complex system

Learning or **adaptation**?

- **Learning** has been associated to **convergence** to equilibrium.

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- We introduce a learning model as a **constant adaptation** process to the new market conditions that micro behaviors contribute to create → **feedback behaviors/environment**.
- A **collective** adaptation model: rationality not into the individual behavior.

'Success is discovered by the economic system through a blanketing shotgun process, not by the individual through a converging search.'

(Alchian 1950, p. 219)

Modeling learning in a complex system

Main features

- **Endogenous** and **dynamic heterogeneity** in financial behaviors of firms.
- This heterogeneity is driven by two opposite forces:
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  - **Converging force** (exploitation) through market pressure: imitation occurs only in the case of bankruptcy, based on a *randomly chosen* firm.
    $\rightarrow$ drives the tendency to deleverage along busts.
  - **Diverging forces** (exploration): constant 'trial-and-error' process and mistakes in copies (**zero on average** at the population level).
    $\rightarrow$ drives the tendency to increase leverage along booms.
- Adaptability of the system is crucial: the strongest force is exploration.

Firms' investment and debt strategies

Illustration from an individual in a baseline simulation

back

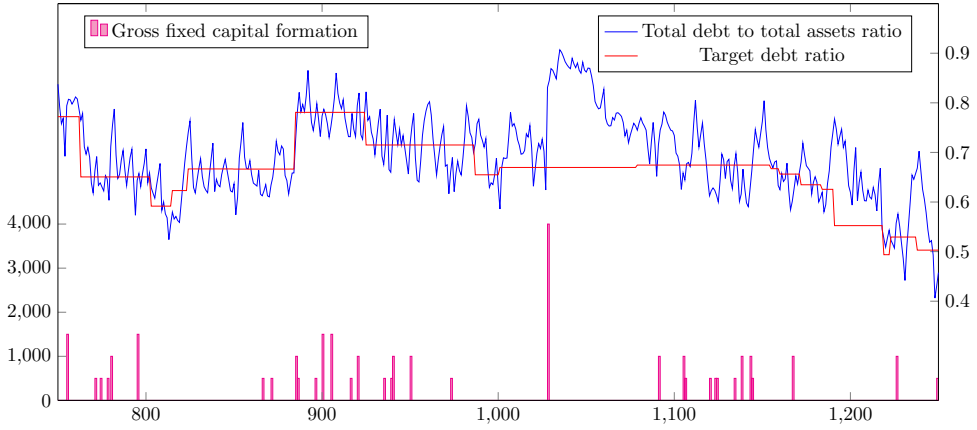

Figure: Investment and debt ratios

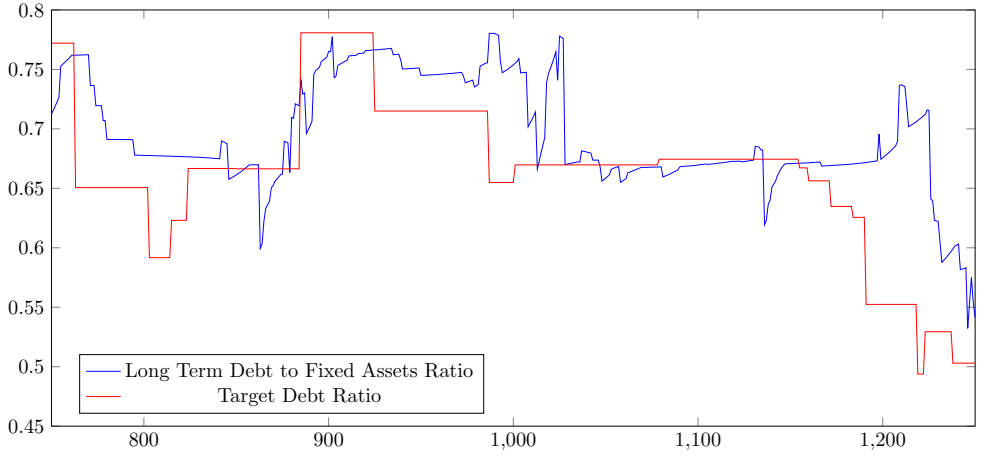

Figure: Fixed assets financing