Modelling Occasionally Binding Constraints Using Regime-Switching

Andrew Binning[1] Junior Maih[2,3]

[1]Modelling & Research Team, The New Zealand Treasury

[2]Monetary Policy Department, Norges Bank

[3]BI, Norwegian Business School

Joint Vienna Macro Seminar
Institut Für Höhere Studien (Institute for Advanced Studies)
Vienna, May 29, 2018

Motivation

- Many important problems in macroeconomics can be framed or interpreted as occasionally binding constraints (OBCs)
- Common examples include:
  - Zero lower bound
  - Downward nominal wage rigidities
  - Borrowing/collateral constraints
  - Irreversible investment
  - Cash in advance constraint

Ways to Address the Problem I

- Eternally binding constraints (EBC)
  - Iacoviello (2005), Faia (2011)
- Smooth approximation of OBCs (penalty & linex functions)
  - Kim & Ruge-Murcia (2011), Den Haan & De Wind (2012), Brzoza-Brzezina et al. (2015)
- (Stochastic) Extended path
  - Adjemian & Juillard (2013), Coenen & Warne (2014)
- Anticipated shocks
  - Holden & Paetz (2012), Lindé et al. (2016)

Ways to Address the Problem II

- Occbin/piecewise linear
  - Guerrieri & Iacoviello (2015), Kulish et al. (2014)
- Global/projections/grid methods
  - Christiano & Fisher (2000), Fernández-Villaverde et al. (2015), Judd et al. (2012)
- Regime-Switching
  - Benigno et al. (2015), Binning & Maih (2016)

Why Regime Switching

- Lucas critique: ignoring (potential) changes in (policy) parameters can have severe consequences for forecasting and policy analysis.
- OBCs may depend on policy, eg ZLB, LTV ratio.
- Natural to think of past and expected future implementation of policy in terms of regimes governed by separate policy parameters.
- e.g. policy can determine when a constraint does and does not bind.
- Shock transmission mechanism and behavioral parameters can also change when the constraint is binding. e.g. agents take on more or less risk when a constraint binds, implies a change in relative risk aversion.

Why Regime Switching

- The framework naturally lends itself to scenarios such as staying longer than required at the ZLB (e.g. forward guidance).
- Stable solution, simulations (generally) stable, e.g. no forward guidance puzzles or numerical "pathologies".
- Solution methods and filters (estimation) easily extend to large models and higher order approximations.

Overview/Plan

- Types of constraints and their recasting into a regime-switching framework
- The generic regime-switching model
- Applications
- Comparison with other methods

Types of Constraints & Their Recasting into Regime-Switching

The Game Plan

The ideal procedure:

- analytical
- handles large state spaces/models
- accurate
- fast

The Game Plan

The ideal procedure:

- analytical
- handles large state spaces/models
- accurate
- fast

... does not exist

The Game Plan

Our poor-man strategy:

- Make the distinction between occasionally binding constraints that
  - contain choice variables
    $$A_t \leq B_t,$$
  - do not contain choice variables
    $$C_t = \max\left(D_t, F_t\right).$$
- Add transition probabilities
- Solve the resulting model with regime switches using the perturbation approach of Maih (2015)

Complementary Slackness Type Constraints

- Constraints that involve choice variables

$$A_t \leq B_t,$$

- A_t and/or B_t are (contain) choice variables.
  Kuhn-Tucker/complementary slackness conditions:

$$\lambda_t \left(A_t - B_t \right) = 0,$$

with

$$A_t < B_t, \quad \lambda_t = 0,$$

or

$$A_t = B_t, \quad \lambda_t > 0.$$

Complementary Slackness Type Constraints

- Can approximate complementary slackness type conditions using regime-switching with a two state Markov chain
- Binding (B) and non-binding (N), and a regime-switching parameter $\phi(s_t)$ with values

$$\phi(N) = 0, \quad \phi(B) = 1.$$

- The complementary slackness condition is replaced by

$$\phi(s_t)(A_t - B_t) + (1 - \phi(s_t))\lambda_t = 0.$$

- Benigno et al. (2015) use a similar approach

Transition Probabilities

- Transition matrix

$$\mathbb{Q}_{t,t+1} = \left[\begin{array}{cc} 1 - p_{NB,t} & p_{NB,t} \\ p_{BN,t} & 1 - p_{BN,t} \end{array} \right],$$

- Transition probabilities with choice variables (complementary slackness)

$$p_{NB,t} = \frac{\theta_{N,B}}{\theta_{N,B} + \exp\left(-\psi_{N,B}\left(A_t - B_t\right)\right)},$$

$$p_{BN,t} = \frac{\theta_{B,N}}{\theta_{B,N} + \exp\left(\psi_{B,N}\lambda_t\right)}.$$

Min/Max Constraints

- Can approximate min/max type constraints using regime-switching with a two state Markov chain
- Binding (B) and non-binding (N), and a regime-switching parameter $\phi(s_t)$ with values

$$\phi\left(N\right)=0, \quad \phi\left(B\right)=1.$$

- The constraint can be written as a simple min or max condition if it doesn't contain choice variables,

$$C_t=\max\left(D_t,F_t\right).$$

- While the min/max constraint is replaced by

$$C_t=\phi\left(s_t\right)D_t+\left(1-\phi\left(s_t\right)\right)F_t.$$

- This implies $C_t=D_t$ in the binding regime.

Transition Probabilities

- Transition matrix

$$\mathbb{Q}_{t,t+1} = \begin{bmatrix} 1 - p_{NB,t} & p_{NB,t} \\ p_{BN,t} & 1 - p_{BN,t} \end{bmatrix},$$

- Transition probabilities with min/max condition

$$p_{NB,t} = \frac{\theta_{N,B}}{\theta_{N,B} + \exp\left(\psi_{N,B}\left(F_t - D_t\right)\right)},$$

$$p_{BN,t} = \frac{\theta_{B,N}}{\theta_{B,N} + \exp\left(-\psi_{B,N}\left(F_t - D_t\right)\right)}.$$

The Generic Regime-Switching Model

Generic Model

- History is made of regimes with distinctive properties.

$$E_t \sum_{r_{t+1}=1}^{h} p_{r_t,r_{t+1}}\left(\mathcal{I}_t\right) f_{r_t}\left(x_{t+1}\left(r_{t+1}\right), x_t\left(r_t\right), x_{t-1}, \theta_{r_t}, \theta_{r_{t+1}}, \eta_t\right) = 0,$$

- E_t is the expectations operator and f_{r_t} is an $n_f \times 1$ vector of possibly nonlinear functions of their arguments
- $r_t = 1, 2, ..., h$ is the regime of a time t, x_t is an $n_x \times 1$ vector of all the endogenous variables and η_t is an $n_\eta \times 1$ vector of shocks with $\eta_t \sim N\left(0, I_{n_\eta}\right)$
- θ_{r_t} is an $n_\theta \times 1$ vector of parameter values in regime r_t
- $p_{r_t,r_{t+1}}\left(\mathcal{I}_t\right)$ is transition probability of going from regime r_t to regime $r_{t+1} = 1, 2, ..., h$ and :$\sum_{r_{t+1}=1}^{h} p_{r_t,r_{t+1}}\left(\mathcal{I}_t\right) = 1$

General Solution

- General solution takes the form

$$x_t(r_t) = \mathcal{T}^{r_t}(z_t),$$

- where the state vector is defined as follows

$$z_t \equiv \left[\begin{array}{ccc} x'_{t-1} & \sigma & \eta'_t \end{array} \right]',$$

Perturbation Solution

- pth order perturbation solution

$$\mathcal{T}^{r_t}(z) \simeq \mathcal{T}^{r_t}(\bar{z}_{r_t}) + \mathcal{T}_z^{r_t}(z - \bar{z}_{r_t}) + \frac{1}{2!}\mathcal{T}_{zz}^{r_t}(z - \bar{z}_{r_t})^{\otimes 2} + \ldots$$
$$\ldots + \frac{1}{p!}\mathcal{T}_{z^{(p)}}^{r_t}(z - \bar{z}_{r_t})^{\otimes p}.$$

calibrateProbs

Applications

Applications

- Zero Lower Bound
- Collateral/Borrowing constraints
- Downward nominal wage rigidities
- Irreversible investment(*)
- Higher-order perturbations
- All in one

Application 1: ZLB

Zero Lower Bound

- Binning & Maih (2016)
- Canonical three equation NK DSGE model, habit, indexation, smoothing
- Representative household, firms and monetary authority

Zero Lower Bound

- OBC on interest rate (ZLB)

$$R_t = \max\left(R_{ZLB}, R_t^*\right),$$

- Taylor rule

$$R_t^* = R_{t-1}^{*\rho_r}\left(R^*\left(\frac{\pi_t}{\pi}\right)^{\kappa_\pi}\left(\frac{\tilde{Y}_t}{\tilde{Y}_{t-1}}\right)^{\kappa_y}\right)^{1-\rho_r}\exp(\varepsilon_{R,t}),$$

- States

$$s_t = Z, N.$$

- Regime specific parameter

$$\mathbf{z}\left(N\right) = 0, \quad \mathbf{z}\left(Z\right) = 1,$$

- Regime-Switching approximation of the OBC

$$R_t = \mathbf{z}\left(s_t\right) R_{ZLB} + \left(1 - \mathbf{z}\left(s_t\right)\right) R_t^*.$$

Zero Lower Bound

- Transition matrix

$$\mathbb{Q}_{t,t+1} = \begin{bmatrix} 1 - p_{NZ,t} & p_{NZ,t} \\ p_{ZN,t} & 1 - p_{ZN,t} \end{bmatrix},$$

- Endogenous transition probabilities

$$p_{NZ,t} = \frac{\theta_{N,Z}}{\theta_{N,Z} + \exp\left(\psi_{N,Z}\left(R_t^* - R_{ZLB}\right)\right)},$$

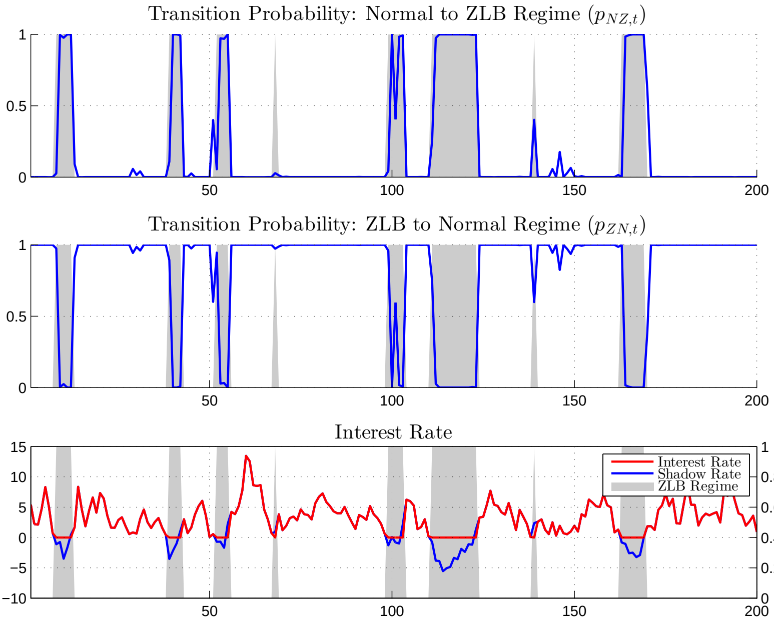
$$p_{ZN,t} = \frac{\theta_{Z,N}}{\theta_{Z,N} + \exp\left(-\psi_{Z,N}\left(R_t^* - R_{ZLB}\right)\right)}.$$

- Regime specific steady states

$$R(Z) = R_{ZLB}, \quad R(N) = R^* = \frac{\pi_t \mu_t}{\beta}, \text{ where } R_{ZLB} < R^*.$$

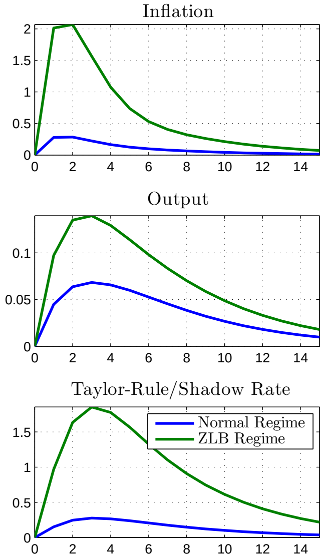
$$d(Z) = \frac{R^*}{R_{ZLB}} > 1, \quad d(N) = 1.$$

Zero Lower Bound: Transition Probabilities



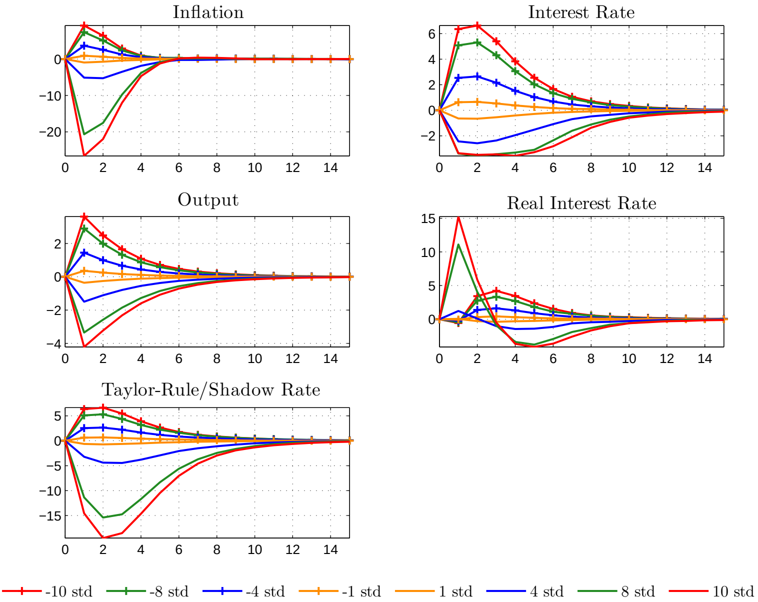
Zero Lower Bound

Impulse Responses (Regime Specific): Consumption Preference Shock



Zero Lower Bound

Impulse Responses (GIRF): Technology Shock



Application 2: Collateral/Borrowing Constraints

Collateral/Borrowing Constraints

- Iacoviello (2005)
- Households, Entrepreneurs, Firms, Monetary Authority
- Entrepreneurs impatient relative to households
- Entrepreneurs borrow from households subject to an occasionally binding collateral constraint

Collateral/Borrowing Constraints

- Occasionally binding collateral constraint

$$B_t \leq E_t \left\{ m \frac{Q_{t+1} H_t \pi_{t+1}}{R_t} \right\},$$

- Complementary slackness condition

$$\Omega_t \left(B_t - E_t \left\{ m \frac{Q_{t+1} H_t \pi_{t+1}}{R_t} \right\} \right) = 0,$$

- with

$$B_t - E_t \left\{ m \frac{Q_{t+1} H_t \pi_{t+1}}{R_t} \right\} = 0, \quad \Omega_t > 0,$$

- or

$$B_t - E_t \left\{ m \frac{Q_{t+1} H_t \pi_{t+1}}{R_t} \right\} < 0, \quad \Omega_t = 0.$$

Collateral/Borrowing Constraints

- introduce regime specific parameter

$$\mathbf{o}\left(N\right)=0,\quad \mathbf{o}\left(B\right)=1$$

- Replace complementary slackness condition with

$$\mathbf{o}(s_t)\left(B_t-E_t\left\{m\frac{Q_{t+1}H_t\pi_{t+1}}{R_t}\right\}\right)+\left(1-\mathbf{o}(s_t)\right)\Omega_t=0,$$

- Transition matrix

$$\mathbb{Q}_{t,t+1}=\left[\begin{array}{cc}1-p_{NB,t} & p_{NB,t}\\ p_{BN,t} & 1-p_{BN,t}\end{array}\right],$$

- Transition probabilities

$$p_{NB,t}=\frac{\theta_{N,B}}{\theta_{N,B}+\exp\left(-\psi_{N,B}B_t^*\right)},\quad p_{BN,t}=\frac{\theta_{B,N}}{\theta_{B,N}+\exp\left(\psi_{B,N}\hat{\Omega}_t\right)},$$

Collateral/Borrowing Constraints

- Leverage

$$B_t^* = B_t - E_t \left\{ m \frac{Q_{t+1} H_t \pi_{t+1}}{R_t} \right\},$$

- Multiplier

$$\hat{\Omega}_t,$$

Collateral/Borrowing Constraints

- Housing steady state

$$\frac{H_t}{Y_t} = \left(\frac{\varepsilon - 1}{\varepsilon}\right)\left(\frac{\gamma\nu}{Q_t\left(1-\gamma-(\beta-\gamma)\,m\right)}\right),$$

$$\frac{H_t}{Y_t} = \left(\frac{\varepsilon - 1}{\varepsilon}\right)\left(\frac{\gamma\nu}{(1-\gamma)Q_t}\right),$$

$$(1+\tau(s_t))\,\frac{Q_t}{C_t} = E_t\left\{\begin{array}{c}\frac{\gamma}{C_{t+1}}\left(\nu MC_{t+1}\frac{Y_{t+1}}{H_t} + (1+\tau(s_{t+1}))\,Q_{t+1}\right) + \ldots \\ \ldots + \Omega_t m Q_{t+1}\pi_{t+1}\end{array}\right\}.$$

$$\tau\left(s_t\right) = \mathbf{o}\left(s_t\right) m \left(\frac{\beta-\gamma}{1-\gamma}\right),$$

- Impatient households

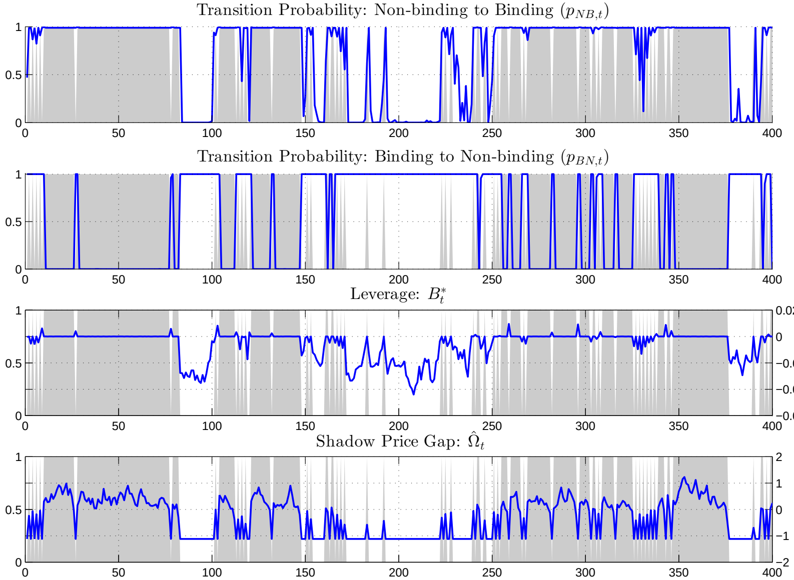
$$\frac{1}{C_t} = E_t\left\{\gamma\frac{R_t^*}{\pi_{t+1}C_{t+1}}\right\} + \Omega_t R_t,$$

$$R_t^* = R_t\psi_1,$$

$$\psi_1 = \mathbf{o}\left(s_t\right) + \left(1-\mathbf{o}\left(s_t\right)\right)\beta/\gamma,$$

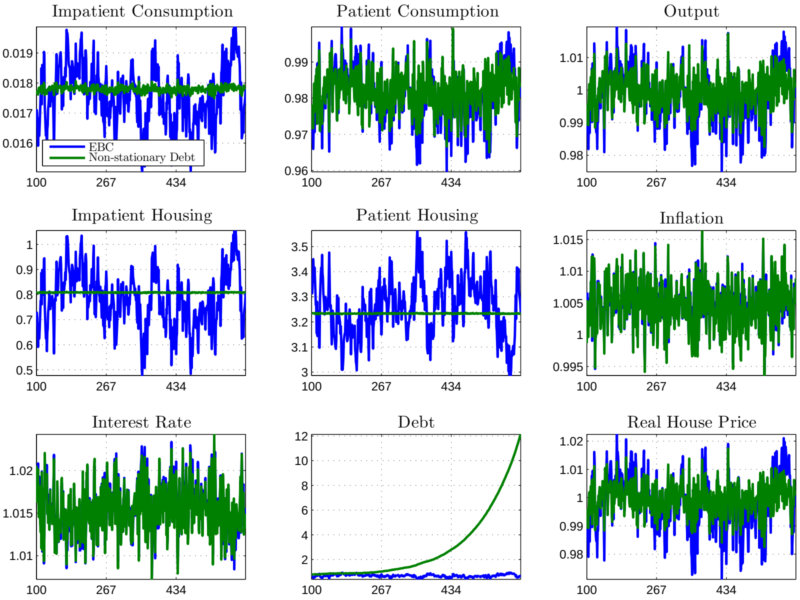
Collateral/Borrowing Constraints

Transition Probabilities & Their Determinants



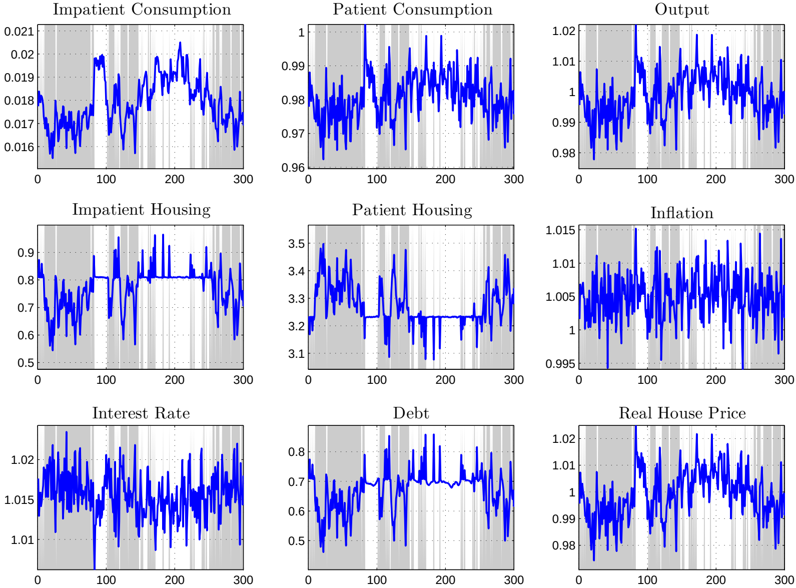
Collateral/Borrowing Constraints

Eternally Binding Constraint vs Non-stationary Debt



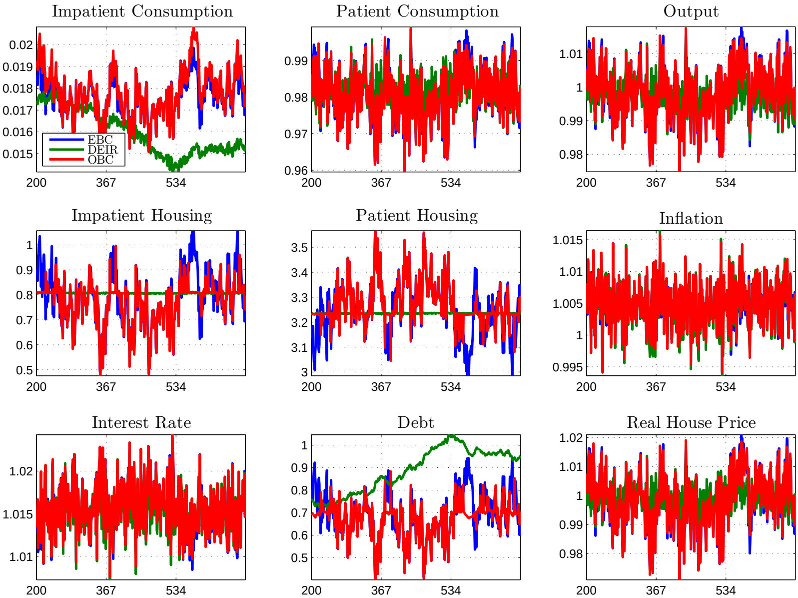
Collateral/Borrowing Constraints

Key Model Variables Against Regimes



Collateral/Borrowing Constraints

A Comparison: EBC, DEIR & OBC



Collateral/Borrowing Constraints

Optimal LTV rule

- State dependent LTV

$$m_t = m \left(\frac{Y_t}{Y}\right)^{\phi_Y} \left(\frac{Q_t}{Q}\right)^{\phi_Q} \left(\frac{B_t}{B}\right)^{\phi_B}.$$

- which implies

$$B_t \leq m_t \frac{Q_{t+1} H_t \pi_{t+1}}{R_t},$$

$$(1+\tau(s_t))\frac{Q_t}{C_t} = E_t \left\{ \begin{array}{c} \frac{\gamma}{C_{t+1}} \left(\nu MC_{t+1}\frac{Y_{t+1}}{H_t} + (1+\tau(s_{t+1}))\, Q_{t+1}\right) + \ldots \\ \ldots + \Omega_t m_t Q_{t+1}\pi_{t+1} \end{array} \right\}.$$

Collateral/Borrowing Constraints

Optimal LTV rule

- Implementable rules imply loss function

$$\tilde{\mathbb{L}} = \sum_{t=0}^{T} \left[\mathbb{L}_t + \mathbf{I}(m_t)\,\mathbb{P}\right],$$

$$\mathbb{L}_t = E_t \left\{ \sum_{t=0}^{\infty} \beta^t \left[\hat{\pi}_t^2 + \omega_Y \hat{Y}_t^2 + \omega_B \hat{B}_t^2 \right] \right\},$$

- where

$$\mathbf{I}(m_t) = \begin{cases} 1 & \text{if } m_t < 0, \\ 1 & \text{if } m_t > 1, \\ 0 & \text{if } 0 \leq m_t \leq 1. \end{cases}$$

- $T = 10{,}000$, $\mathbb{P} = 1000$, $\omega_Y = 1$ $\omega_B = 0.25$

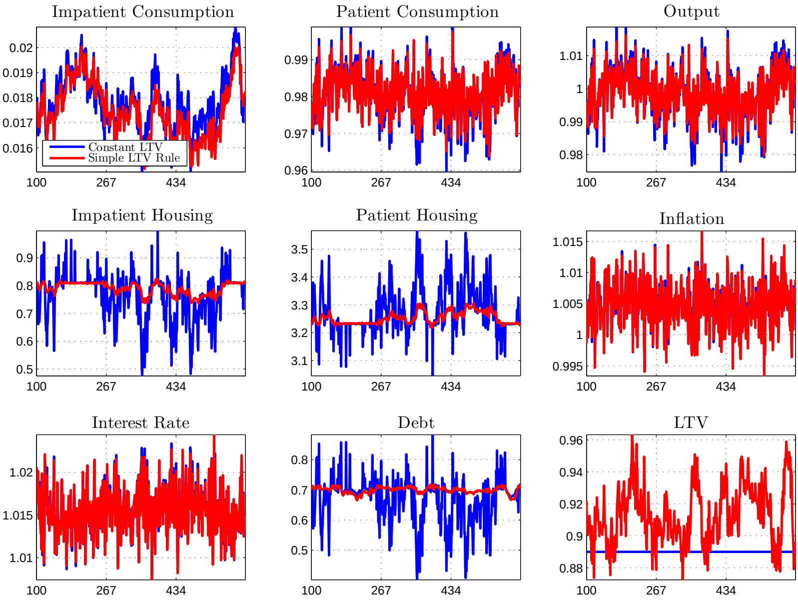
Optimal LTV Rule

$$m_t = m\left(\frac{Y_t}{Y}\right)^{\phi_Y}\left(\frac{Q_t}{Q}\right)^{\phi_Q}\left(\frac{B_t}{B}\right)^{\phi_B}.$$

- The parameters that minimize the loss function are $\phi_Y = 1.4279$, $\phi_Q = -2.9293$ and $\phi_B = -1.2839$.

Collateral/Borrowing Constraints

A Constant LTV Ratio vs. A Simple Implementable LTV Rule



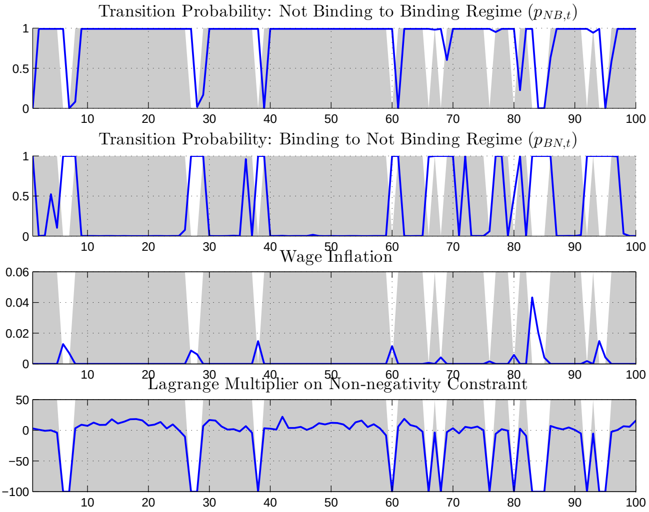
Application 3: Downward Nominal Wage Rigidities

Downward Nominal Wage Rigidities

- Basic NK DSGE model with sticky wages
- Introduce a constraint that prevents wages from falling
- Amano & Gnocchi (2017)

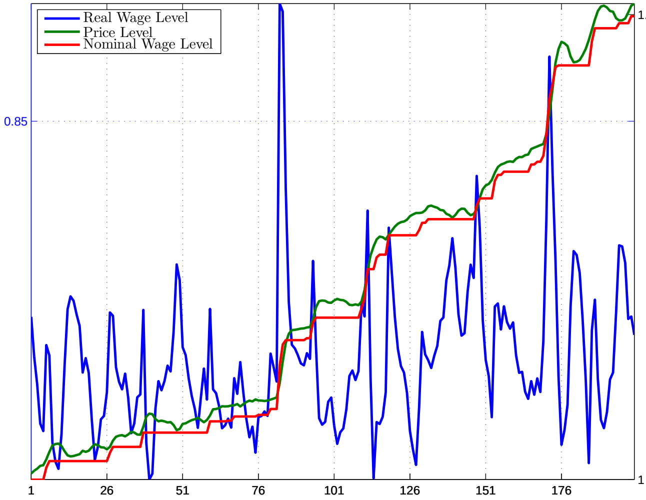
Downward Nominal Wage Rigidities

Transition Probabilities



Downward Nominal Wage Rigidities

Evolution of the Wage and Price Level



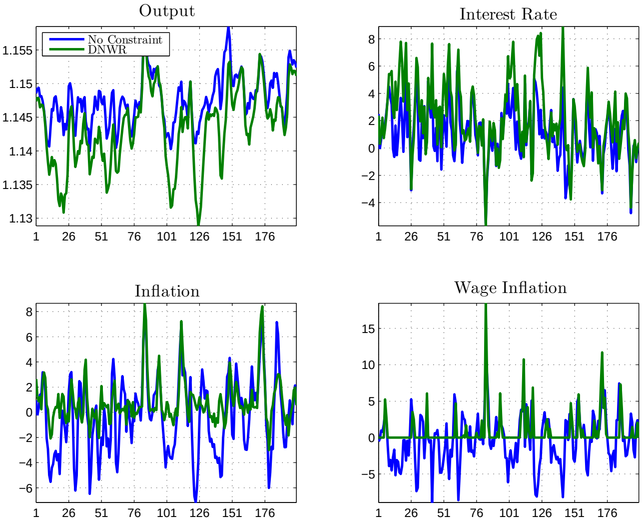
Downward Nominal Wage Rigidities

Evolution of the Wage and Price Level

- In a model with an inflation target of zero, downward nominal wage rigidity introduces positive wage and price inflation.

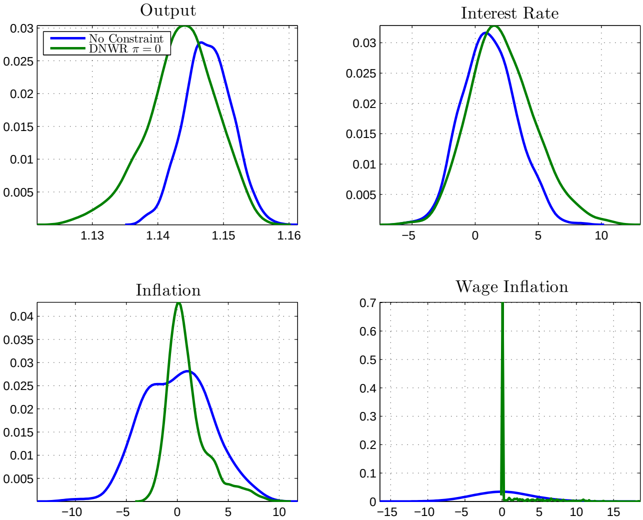
Downward Nominal Wage Rigidities

Model Simulations: No Constraint vs. Downward Nominal Wage Rigidity



Downward Nominal Wage Rigidities

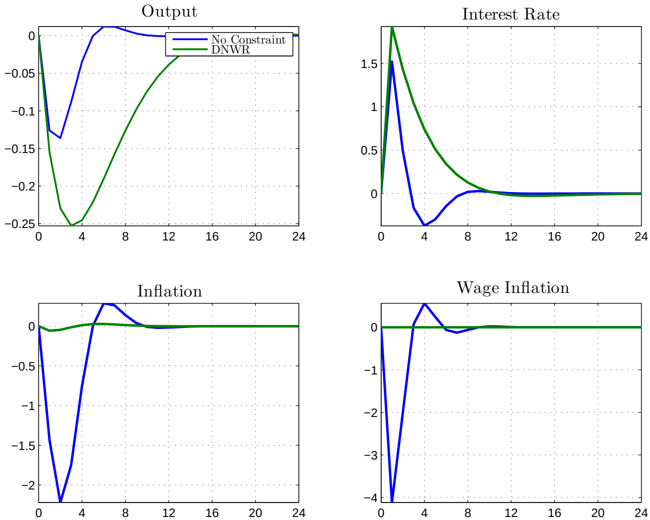
Distributions: No Constraint vs. Downward Nominal Wage Rigidity



Downward Nominal Wage Rigidities

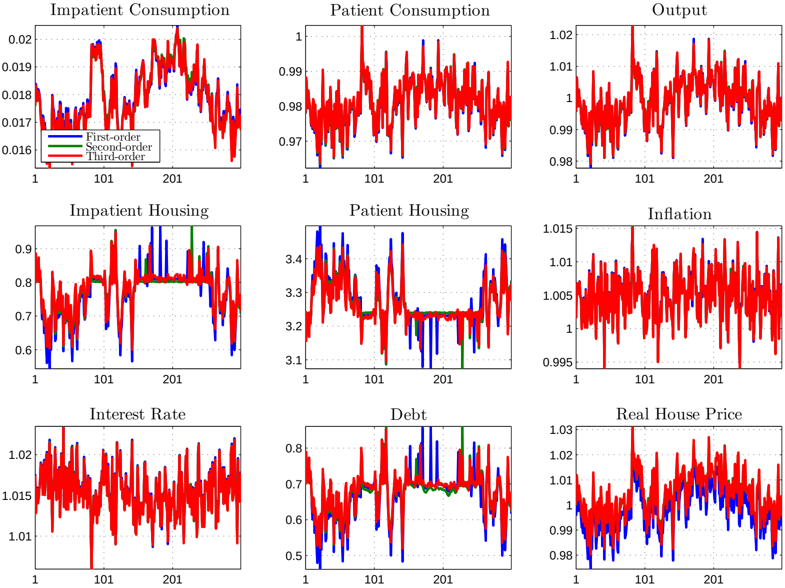
Regime Specific IRFs: (Contractionary) Monetary Policy Shock

irreversInvest

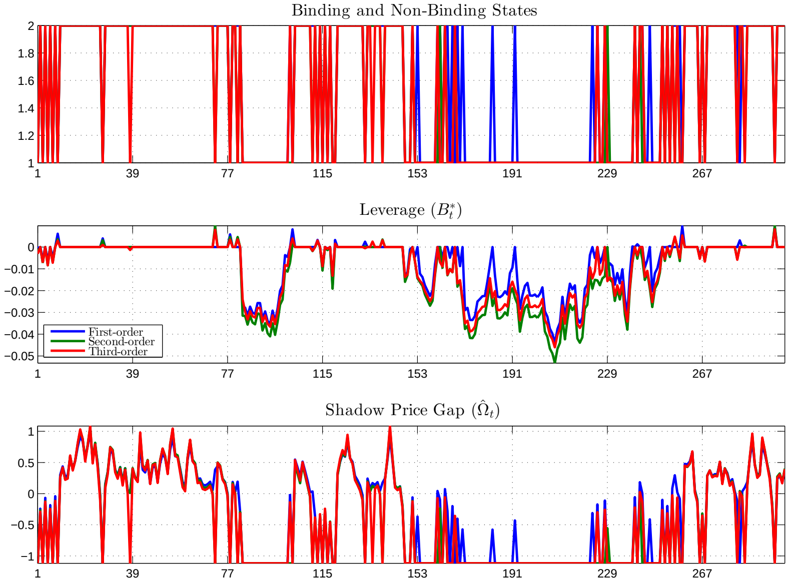


Higher-order expansions

Higher-order Approximations (Iacoviello 2005)

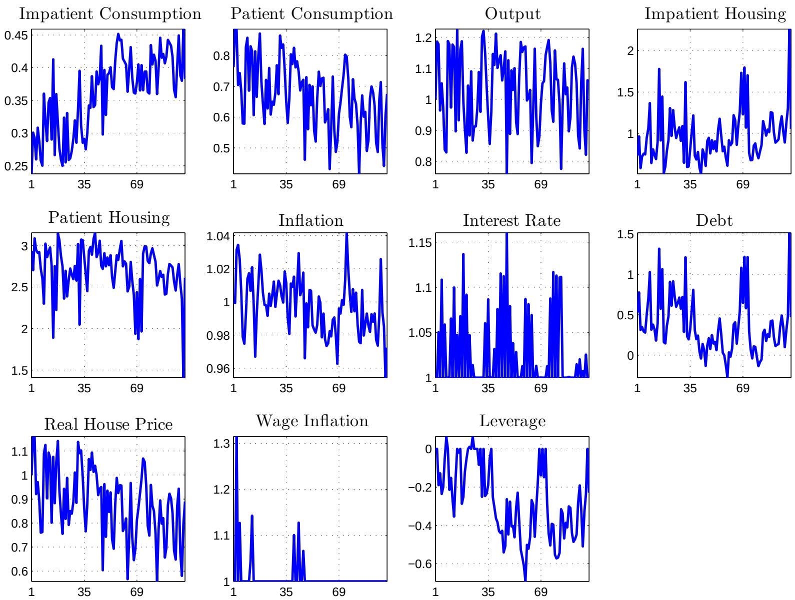


Higher-order Approximations (Iacoviello 2005)



All in

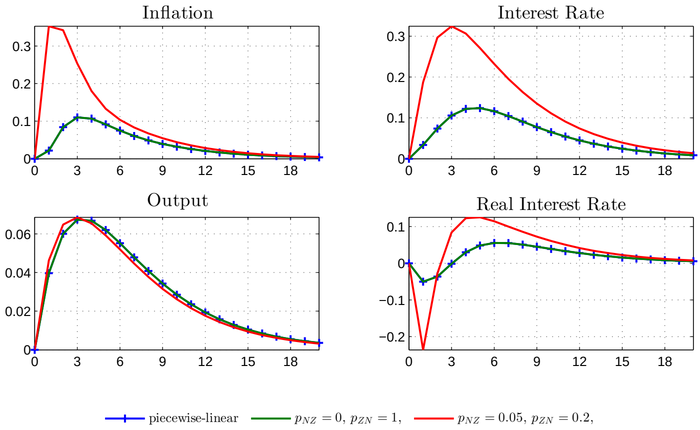
All In (Iacoviello 2005 with ZLB, DNWR & Collateral Constraints)



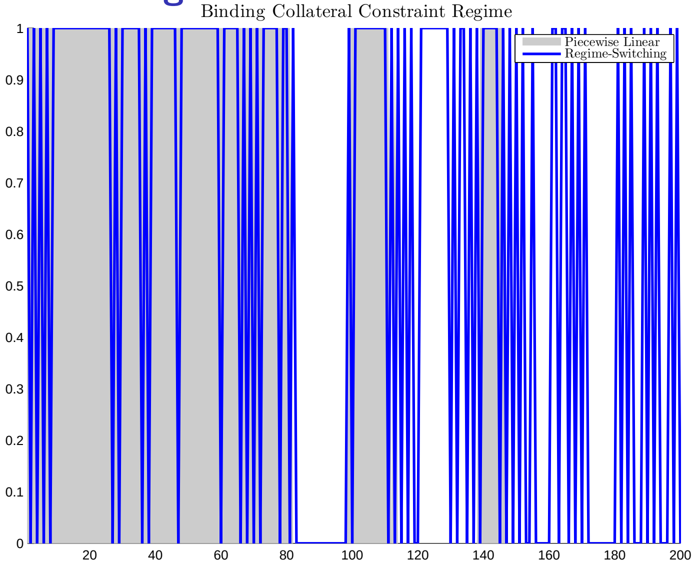
Comparison with alternative approaches

Regime switching vs Piecewise linear

ZLB model: Consumption Preference Shock in Normal Times



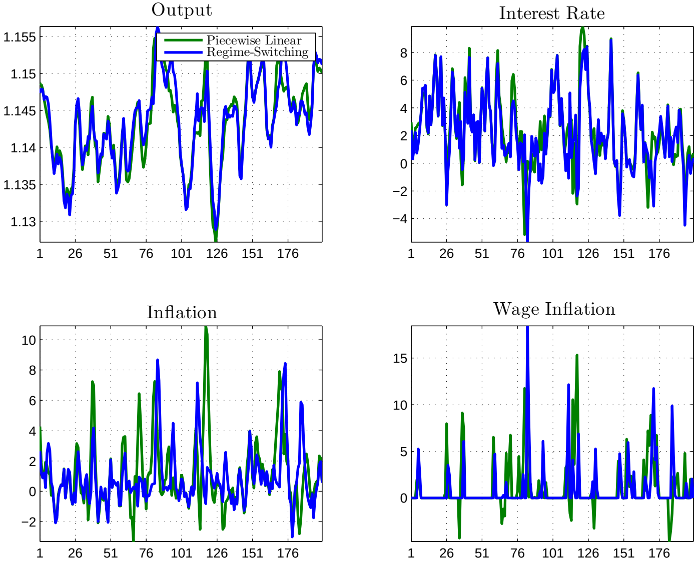
Regime switching vs Piecewise linear



More volatility in the switches between regimes with the regime-switching model

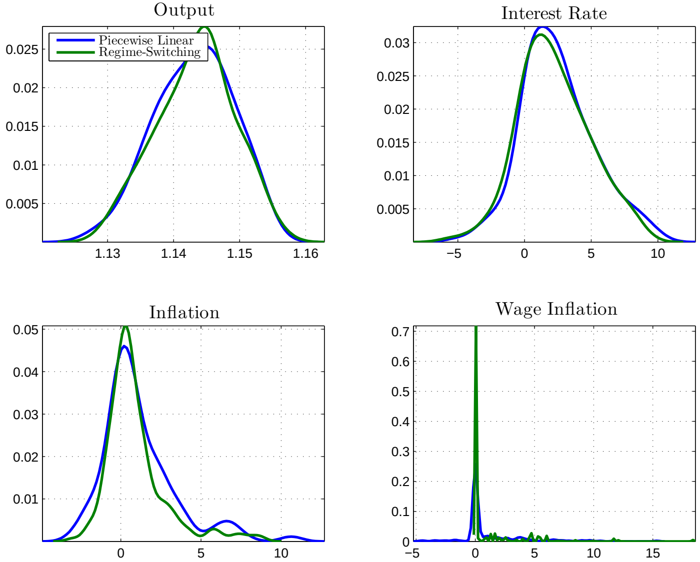
Regime switching vs Piecewise linear

Downward Nominal wage rigidity: Simulations



Regime switching vs Piecewise linear

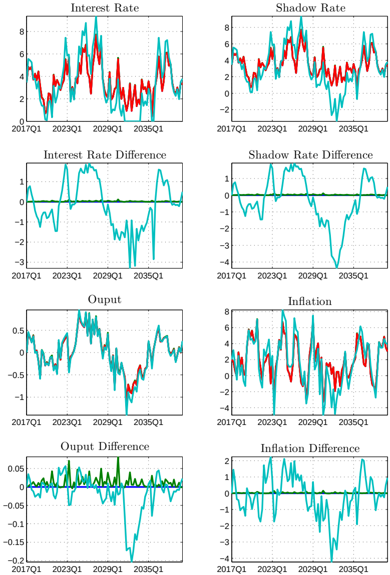
Downward Nominal wage rigidity: distribution



Ext. path, piecewise Linear and regime switching

ZLB model: small shocks $\sigma = 0.00375$

Appendix Further Comparison



Key:

Blue = linearized model solved using the extended path algorithm,

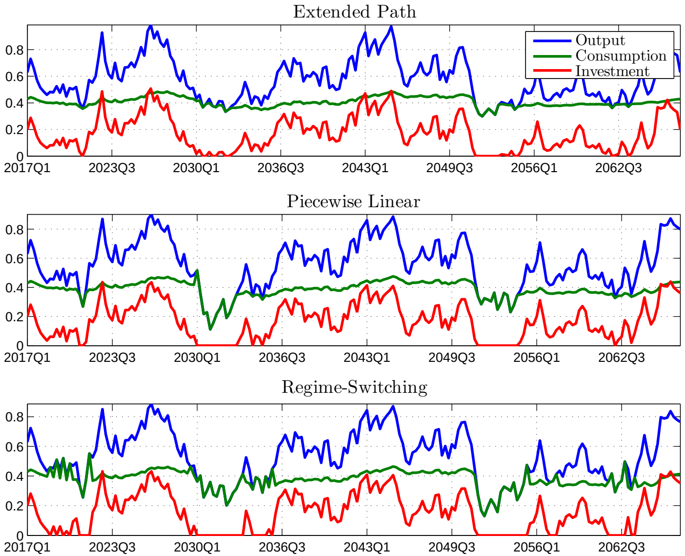
Green = non-linear model solved using the extended path algorithm,

Red = piecewise linear solution,

Turquoise = Regime-switching with endogenous transition probabilities.

Ext. Path, piecewise Linear and regime switching

Irreversible Investment model



Conclusion

Conclusion

- Show how to model occasionally binding constraints in DSGE models using regime-switching.
- Large models, accommodates complementary slackness problems, higher-order of perturbation solutions and multiple constraints simultaneously.
- solve four well known problems: the ZLB on interest rates, Collateral constraints, DNWR and irreversible investment.
- All codes have been implemented in Matlab using the RISE toolbox.

References I

Adjemian, S. & Juillard, M. (2013). Stochastic Extended Path Approach. Unpublished manuscript.

Amano, R. & Gnocchi, S. (2017). Downward Nominal Wage Rigidity Meets the Zero Lower Bound. Tech. rep.

Benigno, G., Foerester, A., Otrok, C., Rebucci, A., & Young, E. R. (2015). Estimating macroeconomic models of financial crises: An endogenous regime switching approach. Tech. rep.

Binning, A. & Maih, J. (2016). Implementing the zero lower bound in an estimated regime-switching DSGE model. Working Paper 2016/3, Norges Bank. URL https://ideas.repec.org/p/bno/worpap/2016_03.html.

Brzoza-Brzezina, M., Kolasa, M., & Makarski, K. (2015). A penalty function approach to occasionally binding credit constraints. *Economic Modelling*, *51*(C), 315–327. URL https://ideas.repec.org/a/eee/ecmode/v51y2015icp315-327.html.

Christiano, L. & Fisher, J. (2000). Algorithms for solving dynamic models with occasionally binding constraints. *Journal of Economic Dynamics and Control*, *24*(8), 1179–1232. URL http://EconPapers.repec.org/RePEc:eee:dyncon:v:24:y:2000:i:8:p:1179-1232.

Coenen, G. & Warne, A. (2014). Risks to Price Stability, the Zero Lower Bound, and Forward Guidance: A Real-Time Assessment. *International Journal of Central Banking*, *10*(2), 7–54. URL https://ideas.repec.org/a/ijc/ijcjou/y2014q2a1.html.

Den Haan, W. J. & De Wind, J. (2012). Nonlinear and stable perturbation-based approximations. *Journal of Economic Dynamics and Control*, *36*(10), 1477–1497. URL http://EconPapers.repec.org/RePEc:eee:dyncon:v:36:y:2012:i:10:p:1477-1497.

Faia, E. (2011). Macroeconomic and welfare implications of financial globalization. *Journal of Applied Economics*, *14*, 119–144. URL http://EconPapers.repec.org/RePEc:cem:jaecon:v:14:y:2011:n:1:p:119-144.

Fernández-Villaverde, J., Gordon, G., Guerrón-Quintana, P., & Rubio-Ramírez, J. F. (2015). Nonlinear adventures at the zero lower bound. *Journal of Economic Dynamics and Control*, *57*(C), 182–204. URL https://ideas.repec.org/a/eee/dyncon/v57y2015icp182-204.html.

Guerrieri, L. & Iacoviello, M. (2015). OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily. *Journal of Monetary Economics*, *70*(C), 22–38. URL https://ideas.repec.org/a/eee/moneco/v70y2015icp22-38.html.

Holden, T. & Paetz, M. (2012). Efficient Simulation of DSGE Models with Inequality Constraints. Quantitative Macroeconomics Working Papers 21207b, Hamburg University, Department of Economics. URL https://ideas.repec.org/p/ham/qmwops/21207b.html.

Iacoviello, M. (2005). House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle. *American Economic Review*, *95*(3), 739–764. URL https://ideas.repec.org/a/aea/aecrev/v95y2005i3p739-764.html.

Judd, K. L., Maliar, L., & Maliar, S. (2012). Merging Simulation and Projection Approaches to Solve High-Dimensional Problems. NBER Working Papers 18501, National Bureau of Economic Research, Inc. URL https://ideas.repec.org/p/nbr/nberwo/18501.html.

Kim, J. & Ruge-Murcia, F. J. (2011). Monetary policy when wages are downwardly rigid: Friedman meets Tobin. *Journal of Economic Dynamics and Control*, *35*(12), 2064–2077. URL https://ideas.repec.org/a/eee/dyncon/v35y2011i12p2064-2077.html.

Kulish, M., Morley, J., & Robinson, T. (2014). Estimating DSGE models with forward guidance. Discussion Papers 2014-32A, School of Economics, The University of New South Wales. URL https://ideas.repec.org/p/swe/wpaper/2014-32a.html.

Lindé, J., Smets, F., & Wouters, R. (2016). Challenges for Central Banks' Macro Models. Working Paper Series 323, Sveriges Riksbank (Central Bank of Sweden). URL https://ideas.repec.org/p/hhs/rbnkwp/0323.html.

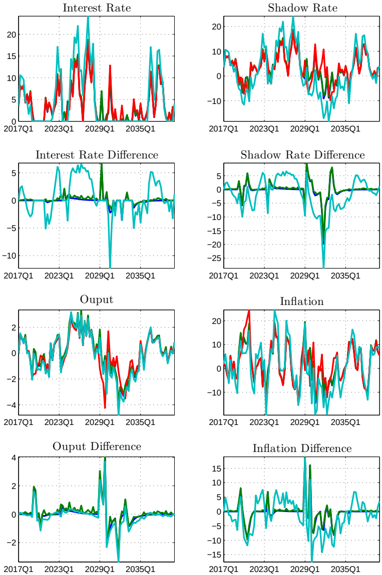
Maih, J. (2015). Efficient perturbation methods for solving regime-switching DSGE models. Working Paper 2015/01, Norges Bank. URL http://ideas.repec.org/p/bno/worpap/2015_01.html.

Appendix

Ext. path, piecewise Linear and regime switching

ZLB model: Large shocks: $\sigma = 0.0125$

Back



Key:

Blue = linearized model solved using the extended path algorithm,

Green = non-linear model solved using the extended path algorithm,

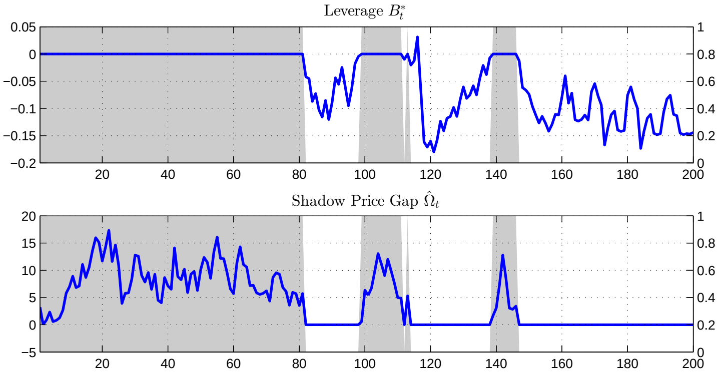
Red = piecewise linear solution,

Turquoise = Regime-switching with endogenous transition probabilities.

Comparison With Other Methods

Piecewise Linear Regimes

Back

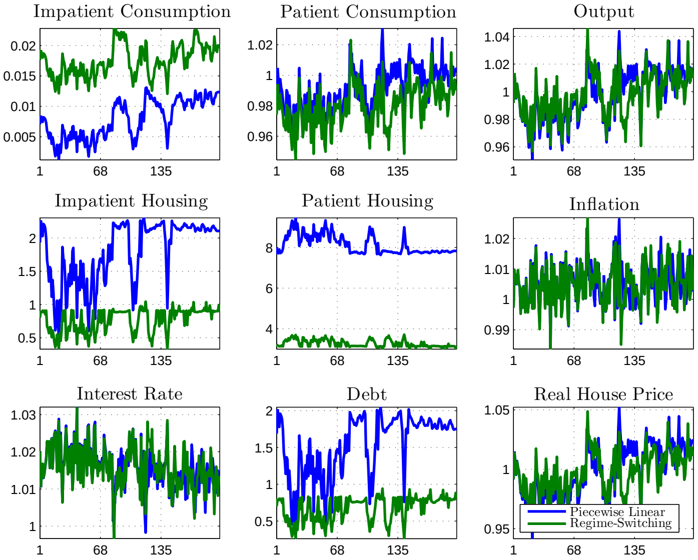


- "Regimes" are more precise compared with regime-switching

Comparison With Other Methods

Comparing Solution Methods

Back



Comparison with Other Methods

- Steady state housing different because we add subsidy to ensure the steady state is the same as the non-binding in the regime-switching model.
- In piece wise linear model is linearized around the binding steady-state.
- There is more volatility in the piece-wise linear model

Back

Calibrating Endogenous Probabilities

Assume the endogenous transition probability

$$p(\alpha, \gamma, x) = \frac{\alpha}{\alpha + \exp(\gamma(x - x_1))}$$

when $x \to x_1$,

$$\Rightarrow p = \frac{\alpha}{\alpha + 1}$$

if

$$p \to 0, \Rightarrow \alpha = \text{small} \Rightarrow p = \frac{\text{small}}{\text{small} + 1}$$

else

$$p \to 1, \Rightarrow \alpha = \text{large} \Rightarrow p = \frac{\text{large}}{\text{large} + 1}$$

Calibrating Endogenous Probabilities

when $x - x_1 \to$ large ,

$$p = \frac{\alpha}{\alpha + \exp\left(\gamma \text{large}\right)}$$

if

$$p \to 0, \Rightarrow \gamma = \text{large} \Rightarrow p = \frac{\alpha}{\alpha + \text{large}}$$

else

$$p \to 1, \Rightarrow \gamma = -\text{large} \Rightarrow p = \frac{\alpha}{\alpha + \text{really small}}$$

perturbation solution

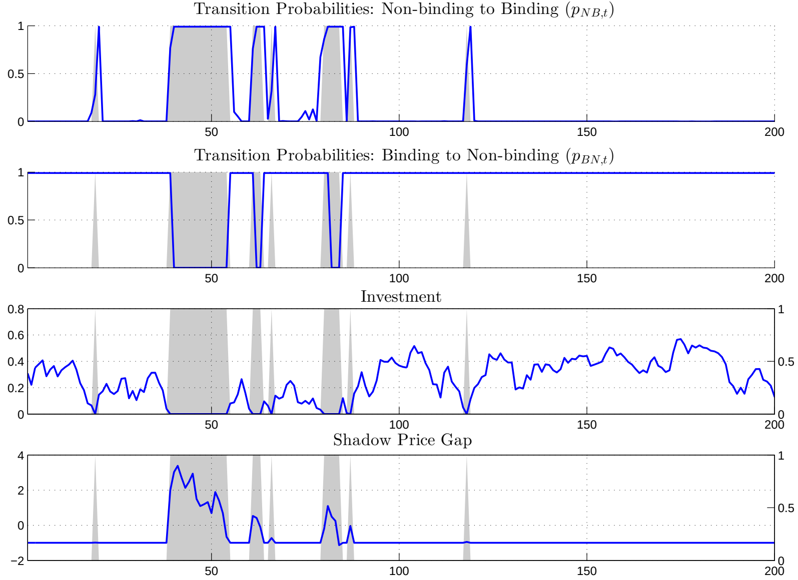
Application 4: Irreversible Investment

Irreversible Investment

- Basic RBC model as used by Adjemian & Juillard (2013) and Christiano & Fisher (2000)
- Households and firms

Irreversible Investment

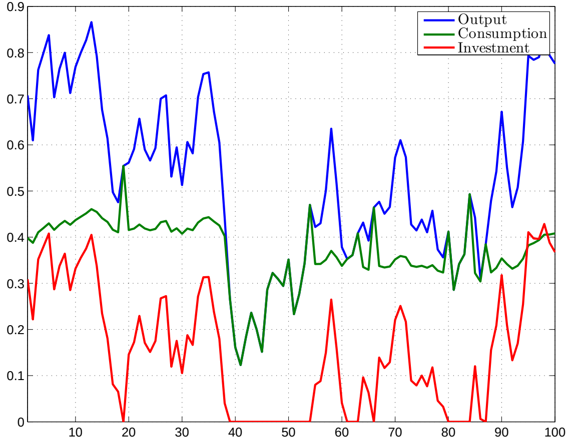
Transition Probabilities & Their Determinants



Irreversible Investment

A Simulation With Irreversible Investment

downWageNomRigid



Extra slides

Alternative treatment of transition Probabilities

- The probabilities could be estimated
- We have procedures with non-parametric transition probabilities
- The procedure is very slow at the moment and does not always work well in the sense of solving the model at each iteration