DOFIN, ASE

An Agent-based Model for Monetary and Fiscal Policy Implications

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ABMs

- Agent-based models, Agent-based Computational Economics, Complex Systems

- **Agent** refers broadly to bundled data and behavioral methods representing an entity constituting part of a computationally constructed world.

- A **complex system** is a system which exhibits the following two properties as stated in Flake (1998):

    i. The system is composed of interacting units;

    ii. The system exhibits emergent properties.

Examples of ABM

- Social Interaction. Schelling (1971)
- Traffic flow
- Crowd dynamics
- Epidemiology
- Bidding behavior
- Trading behavior: Tesfatsion (2001)
- Innovation & industry evolution: Dosi

- Ashraf (2011)
- EURACE: Deissenberg (2008), Cincotti (2010), Dawid (2012)
- Lengnick (2013)

ABM properties

- ✓ Agents are autonomous
- ✓ Agents are heterogeneous
- ✓ Agents have bounded rationality and operate based on behavioral heuristics
- ✓ Agents are interdependent. Agents have direct interactions.
- ✓ Agents adapt.

- ❖ No representative agent assumption!
- ❖ Supply ≠ Demand!
- ❖ No rationality hypothesis!

Objectives in ABM research in economics

1. Empirical understanding
2. Normative understanding
3. Qualitative insight and theory generation
4. Methodological advancement

Model Description

- Starting point:

Dosi, G., Fagiolo, G., Napoletano, M., Roventini, A.(2013) (2010) (2008) (2006) (2005) …

- Heritage:
  - Schumpeter: technology-fueled economic growth
  - Keynes: demand-generation theory
  - Minsky: the lending view approach
- Contributions:
  - Used real data (required adaptation of the model)
  - Calibrated non-sensitive parameters
- Purpose: Policy experiments

Timeline of events

In any given time period (t) :

1. Policy variables are fixed.

2. Machine-tool firms perform R&D. Capital-good firms advertise their machines to consumption-good firms.

3. Consumption-good firms decide how much to produce and invest. When internal funds are not enough, firms borrow (up to a ceiling) from the bank.

4. Total credit provided by the bank to each firm is determined.

Timeline of events

5. In both industries firms hire workers and start producing.

6. Imperfectly competitive consumption-good market opens. The market shares of firms evolve according to their price competitiveness.

7. Firms in both sectors compute their net cash flow, pay back their due loans to the bank to the extent that they have cash flow to do that and deposit their savings, if any.

8. Entry and exit take place.

9. Machines ordered at the beginning of the period are delivered

Equations (selection) for K-good firms

$$RD_i(t) = vS_i(t-1),$$

$$IN_i(t) = \xi RD_i(t), \qquad IM_i(t) = (1-\xi) RD_i(t).$$

$$\theta_i^{in}(t) = 1 - e^{-\zeta_1 IN_i(t)}, \qquad \theta_i^{im}(t) = 1 - e^{-\zeta_2 IM_i(t)}$$

If successful

$$A_i^{in}(t) = A_i(t)(1 + x_i^A(t)),$$

$$B_i^{in}(t) = B_i(t)(1 + x_i^B(t)),$$

closest (A_i^τ, B_i^τ).

previous (A_i^τ, B_i^τ)

Choose $\min[p_i^h(t) + bc^h(A_i^h, t)], \quad h = \tau, in, im,$

$$c(A_i^\tau, t) = \frac{w(t)}{A_i^\tau}.$$

Equations (selection) for prices and profits

K-good firms

$$c_i(t) = \frac{w(t)}{B_i^\tau}.$$

$$p_i(t) = (1 + \mu_1)c_i(t).$$

C-good firms

$$c_j(t) = \frac{w(t)}{\pi_j(t)}.$$

$$\mu_j(t) = \mu_j(t-1)\left(1 + \upsilon\frac{f_j(t-1) - f_j(t-2)}{f_j(t-2)}\right)$$

$$p_j(t) = (1 + \mu_j(t))c_j(t).$$

After production and demand are det, compute:

$$S_i(t),\ c_i(t)Q_i(t)$$

$$\Pi_i(t) = S_i(t) - c_i(t)Q_i(t) - RD_i(t).$$

$$NW_i(t) = NW_i(t-1) + \Pi_i(t).$$

$$S_j(t) = p_j(t)D_j(t),\ PC_j(t) = c_j(t)Q_j(t)$$

$$\Pi_j(t) = S_j(t) - PC_j(t) - rDeb_j(t),$$

$$NW_j(t) = NW_j(t-1) + \Pi_j(t) - cI_j$$

Equations (selection) for C-good firms

$$D_j^e(t) = D_j(t-1), \rightarrow Q_j^d(t) = D_j^e(t) + N_j^d(t) - N_j(t-1),$$

$$RS_j(t) = \left\{ A_i^\tau \in \Xi_j(t) : \frac{p^*(t)}{c(A_{i,\tau},t) - c^*(t)} \le b \right\}$$

$$EI_j^d(t) = K_j^d(t) - K_j(t)$$

investment (I)

$$E_j(t) = -\omega_1 p_j(t) - \omega_2 l_j(t), \rightarrow \overline{E}(t) = \sum_{j=1}^{F_2} E_j(t) f_j(t-1).$$

$$f_j(t) = f_j(t-1)\left(1 + \chi \frac{E_j(t) - \overline{E}(t)}{\overline{E}(t)}\right) \rightarrow D_j(t) = f_j(t)C(t).$$

Equations (selection)

- The banking sector:

$$c_j(t)Q_j(t) + EI_j^d(t) + RI_j^d(t) \leq NW_j(t-1) + CD_j(t),$$

$$CD_j(t) \leq \lambda S_j(t-1).$$

$$MTC(t) = k\left(\sum_{i=1}^{F1} NW_i(t-1) + \sum_{j=1}^{F2} NW_j(t-1)\right)$$

$$\sum_{j=1}^{F2} Deb_j(t) = Loan(t) \leq MTC(t).$$

- Aggregate variables

$$C(t) = w(t)L^D(t) + w^u(Ls - L^D(t))$$

$$\sum_{i=1}^{F_1} Q_i(t) + \sum_{j=1}^{F_2} Q_j(t) = Y(t) \equiv C(t) + I(t) + \Delta N(t).$$

Initial data

- K-good firms: Cost, S, Q, NW

Data on R&D firms, 15 sectors

Source: INSSE, end of 2007

- Consumption-good firms: μ, f, S, NW, techno

Source: INSSE, end of 2007

Data on 44 sectors (CAEN1 divisions)

Excluded sectors: services (except IT&Com), agriculture

Initial data

- Quarterly GDP seasonally adjusted - for the objective function (calibration)

Source: INSSE

Period: 2008Q1-2013Q4

- The NBR monthly interest rate for monetary policy

Source: NBR

Period: 2008Q1-2013Q4

Model parameters

Number of agents in the model		
Description	Symbol	Value
Number of firms in capital-good industry	F1	15
Number of firms in consumption-good industry	F2	44
Number of commercial banks		1
Labor supply	Ls	6436500

Policy Parameters		
Description	Symbol	Value
Tax rate	tr	0.16
Unemployment subsidy rate	ϕ	0.75
Loan-to-value ratio	λ	2
Required reserve ratio	res	0.15
Bank mark-up coefficient	fi_L	0.026
Bank mark-down coefficient	fi_D	0.026

Model parameters

Benchmark parameters as in Dosi (2013)		
Description	Symbol	Value
R&D investment propensity	ν	0.04
R&D allocation to innovative search	ξ	0.5
Firm search capabilities parameters	ζ	0.3
Beta distribution parameters (innovation process)	a1,b1	(3,3)
Beta distribution support (innovation process)	a2,b2	[-0.15,0.15]
Consumption-good firm initial mark-up	μ0	0.2
Coefficient in the consumption-good firm mark-up rule	v	0.01
Competitiveness weights	Ω1, Ω2	1
Replicator dynamics coefficient	χ	1

Parameters requiring calibration	
Description	Symbol
Capital-good firm mark-up rate	μ1
Desired inventories	dinv
Payback period	b
Desired machine utilization rate	cu_d
Wage indexation coefficient	ϕ1

Methodology

- Validation method as in Klugl (2008) :

face validation, sensitivity analysis, calibration, statistical validation

- Calibration method as in Kirkpatrick (1983) :

Simulated annealing

At each iteration of the simulated annealing algorithm, a new point is randomly generated. The algorithm accepts all new points that lower the objective, but also, with a certain probability, points that raise the objective.

By accepting points that raise the objective, the algorithm avoids being trapped in local minima, and is able to explore globally for more possible solutions.

Results

- Calibration results using mean square loss function for quarterly GDP

Parameter	Calibrated value	Initial value
dinv	0.1407	0.01
b	20	3
μ1	2.8574	0.04
cu_d	206.5381	100
ϕ1	0.1012	0.75

$$w(t) = w(t-1)\left(1+\phi_1 \frac{\overline{AB(t-1)}}{\overline{AB(t-2)}}\right)$$

$$N_j^d(t) = \text{dinv}\; D_j^e(t)$$

$$K^d(j,t) = \frac{Q^d(j,t)}{cu_d}$$

$$RS_j(t) = \left\{ A_i^\tau \in \Xi_j(t) : \frac{p^*(t)}{c(A_{i,\tau},t) - c^*(t)} \le b \right\}$$

$$p_i(t) = (1+\mu_1)c_i(t).$$

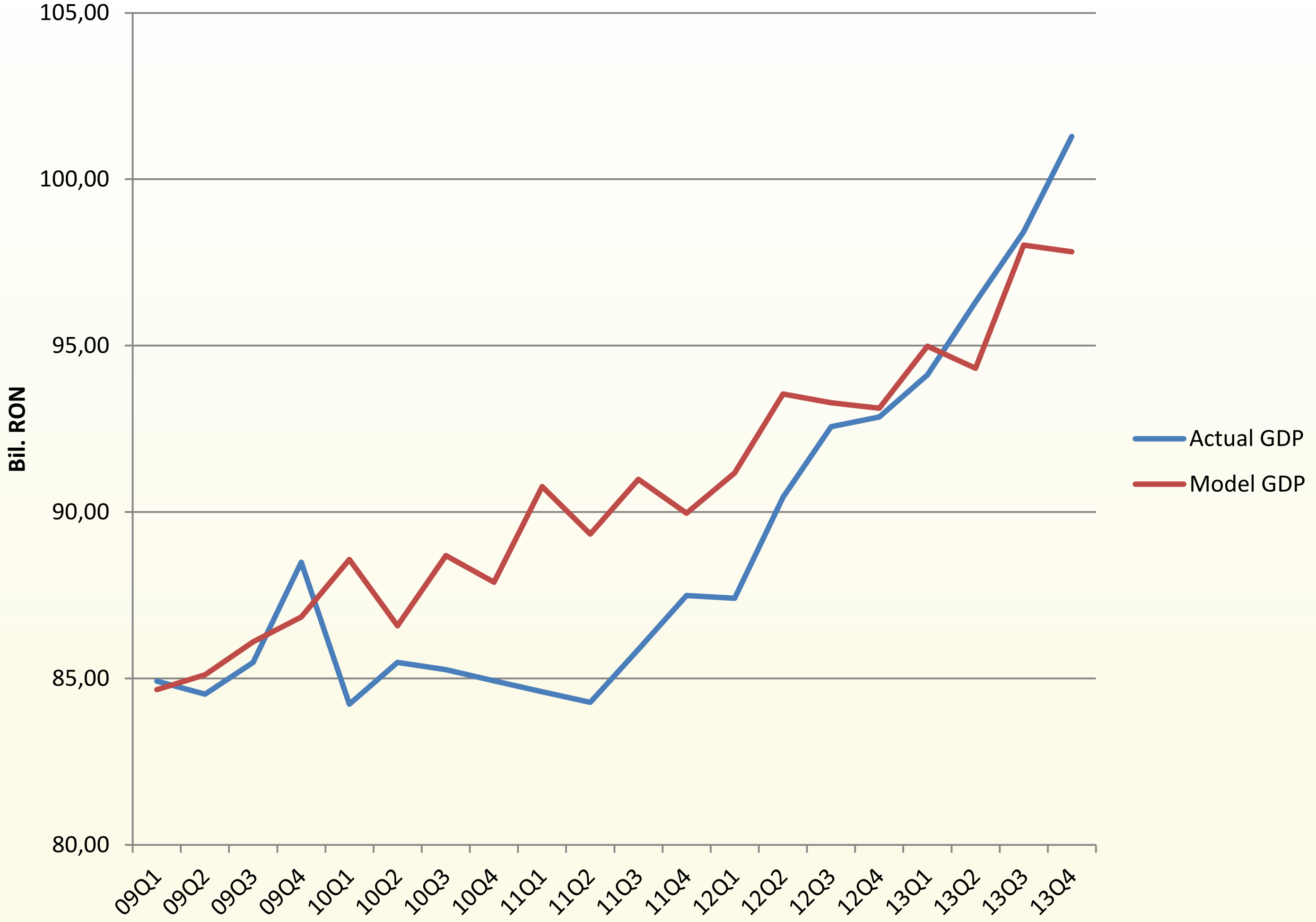
Results

- GDP trajectories (bil. RON)

- Due to simplifying initial assumptions (inventories and unfullfilled demand set to 0), the first 4 quarters are omitted from the policy analysis

Quarter	Actual GDP	Model GDP
08Q1	82.02	85.84
08Q2	86.90	64.51
08Q3	89.05	84.48
08Q4	89.04	81.50
09Q1	84.91	84.66
09Q2	84.53	85.11
09Q3	85.48	86.10
09Q4	88.49	86.85
10Q1	84.22	88.58
10Q2	85.48	86.58
10Q3	85.26	88.69
10Q4	84.93	87.89
11Q1	84.60	90.77
11Q2	84.28	89.34
11Q3	85.88	90.99
11Q4	87.49	89.97
12Q1	87.41	91.17
12Q2	90.44	93.55
12Q3	92.57	93.28
12Q4	92.86	93.12
13Q1	94.12	94.99
13Q2	96.31	94.32
13Q3	98.42	98.02
13Q4	101.28	97.82

Results


105,00
100,00
95,00
90,00
85,00
80,00
Bil. RON
09Q1
09Q2
09Q3
09Q4
10Q1
10Q2
10Q3
10Q4
11Q1
11Q2
11Q3
11Q4
12Q1
12Q2
12Q3
12Q4
13Q1
13Q2
13Q3
13Q4
Actual GDP
Model GDP

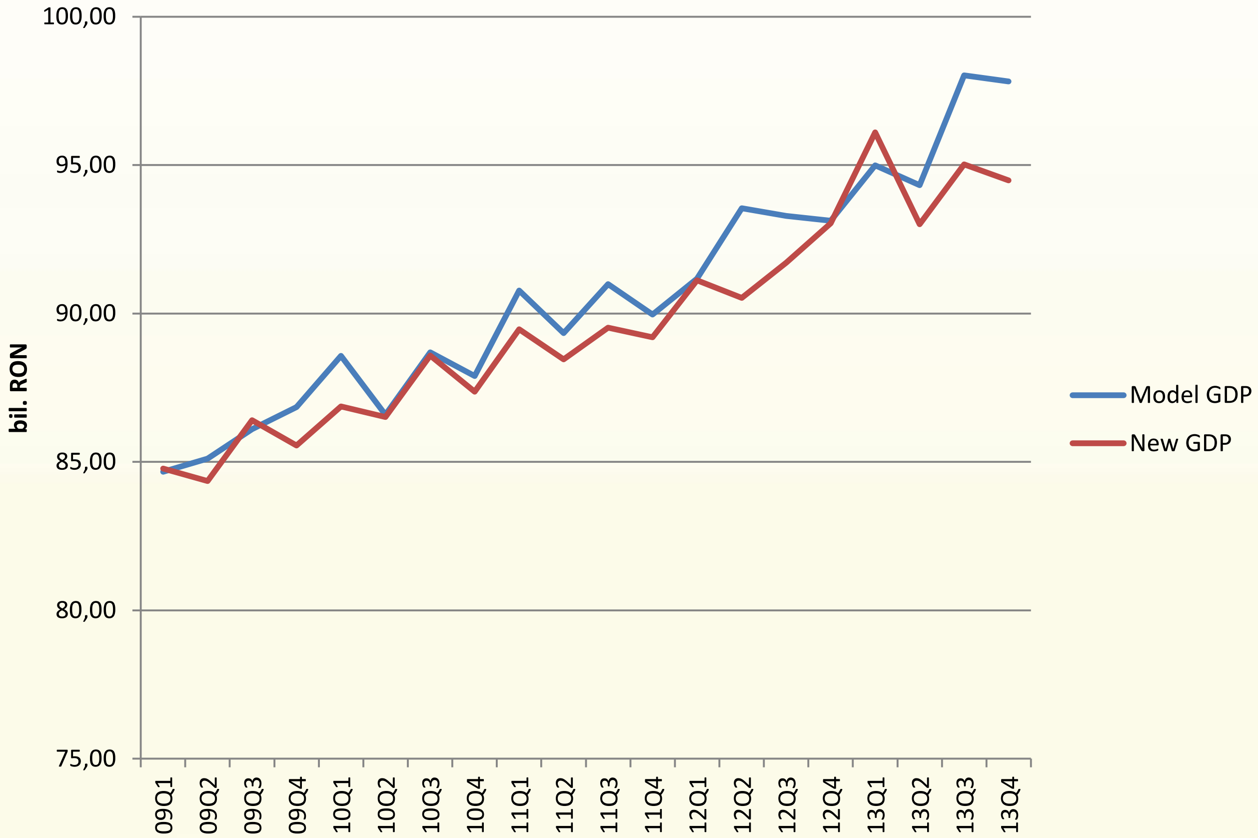
Results

- correlation structure of output

	Y				
	t-6	t-3	t	t+3	t+6
Consumption	0.831941	0.703794	0.964814	0.66077	0.842
Investment	-0.00342	0.007651	0.219066	0.055884	0.003783
Productivity	0.672643	0.679625	0.697397	0.836591	0.846507
Price	-0.77964	-0.79729	-0.80851	-0.85623	-0.87549
Mark-up	-0.76459	-0.77653	-0.78503	-0.87509	-0.8802

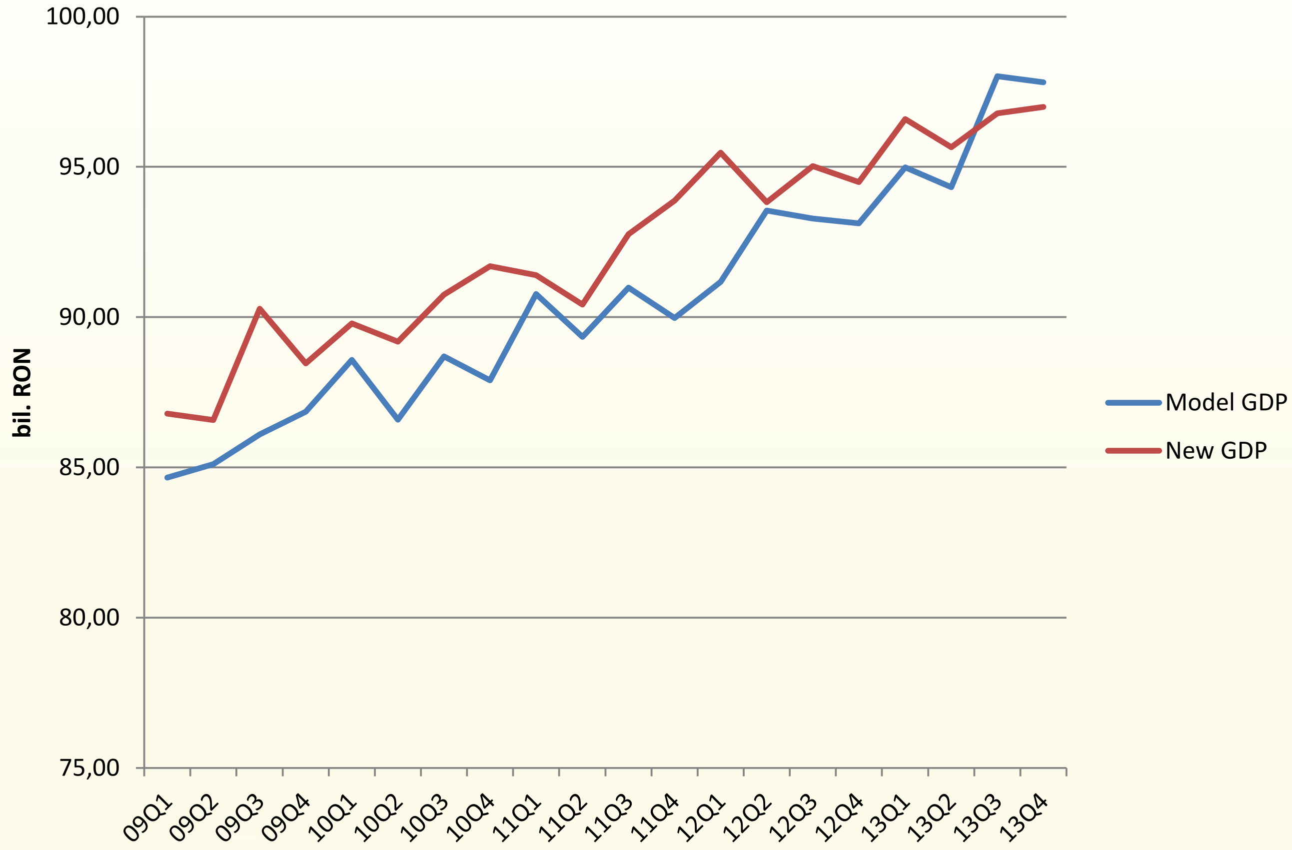
Results

- what if the tax rate was 0.2 instead of 0.16 ?



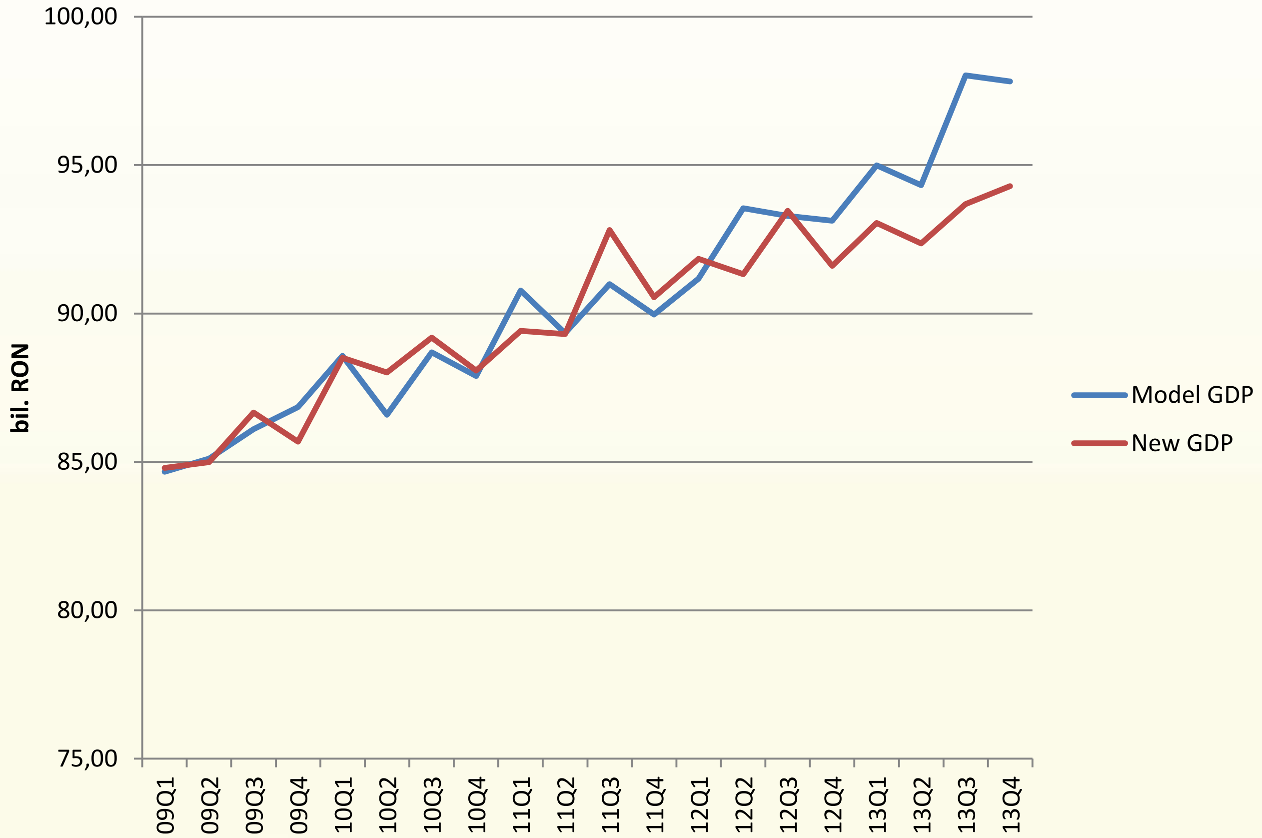
Results

- what if the tax rate was 0.12 instead of 0.16 ?



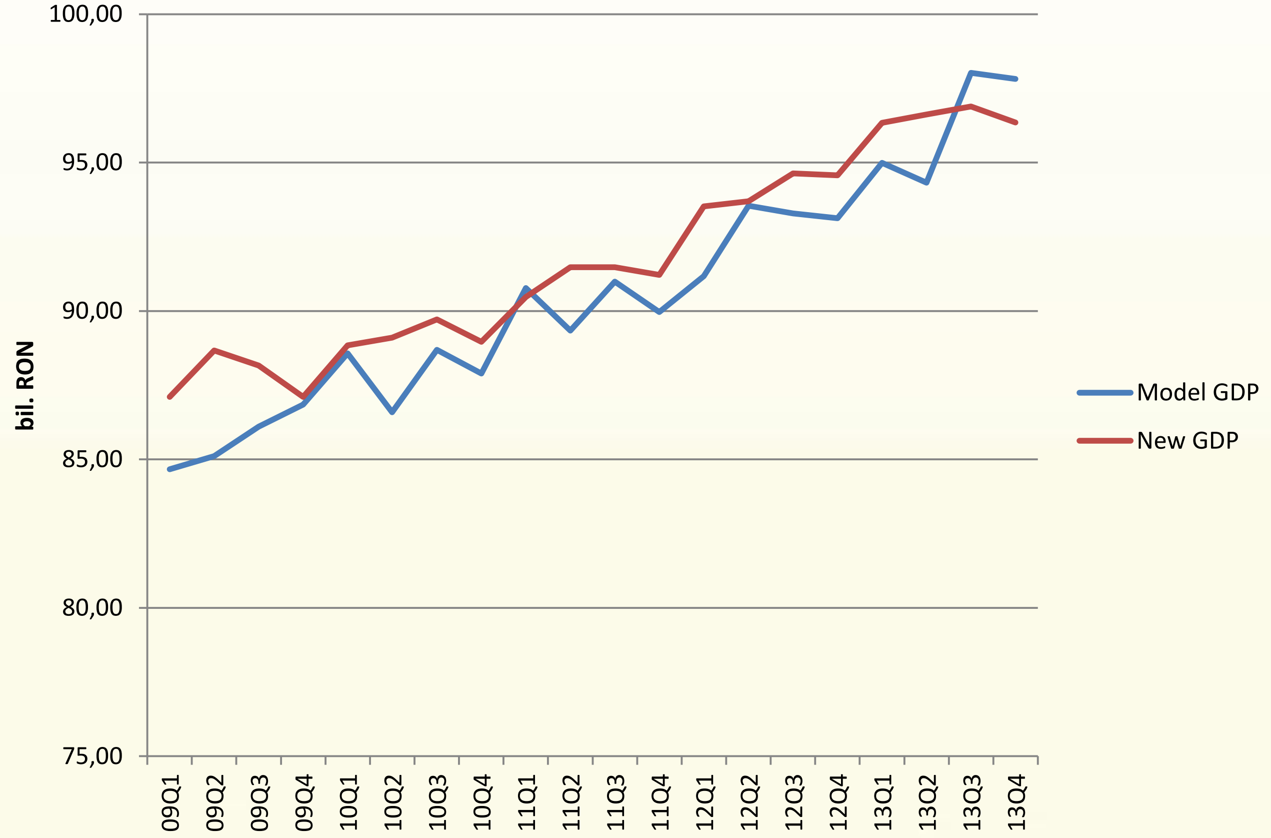
Results

- what if the unemp. subsidy rate was 0.8 instead of 0.75 ?



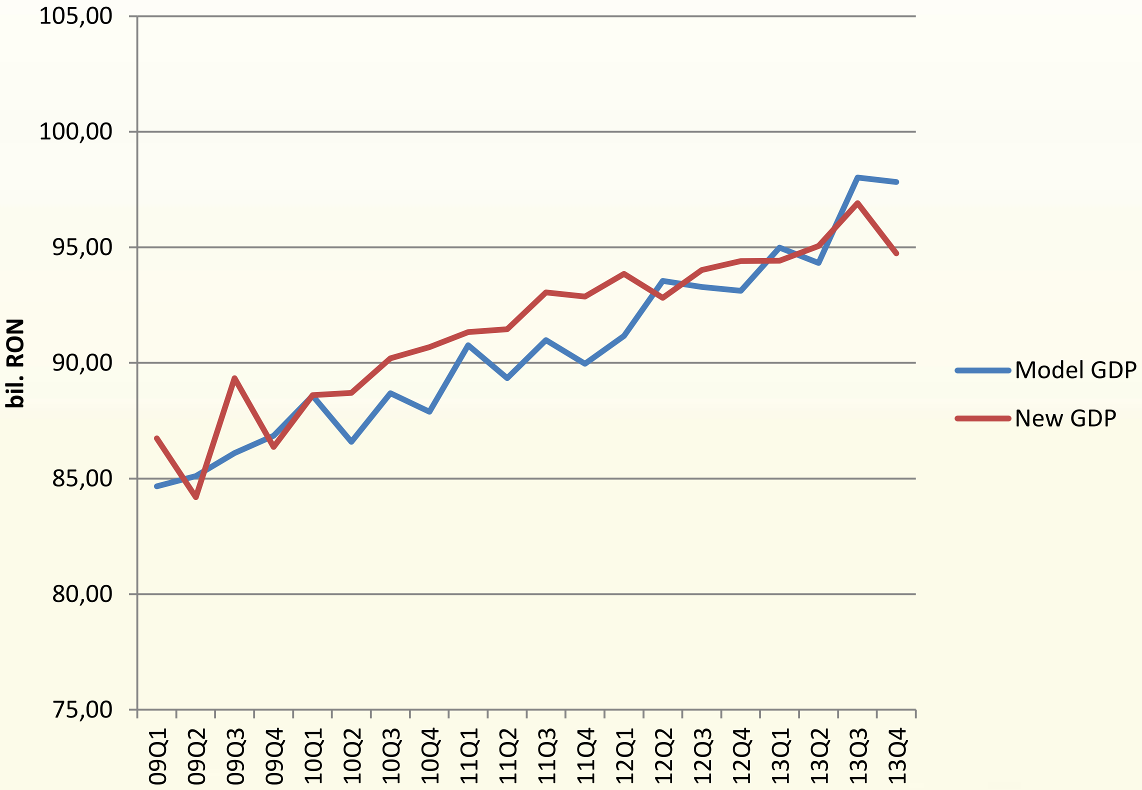
Results

- what if the unemp. subsidy rate was 0.7 instead of 0.75 ?



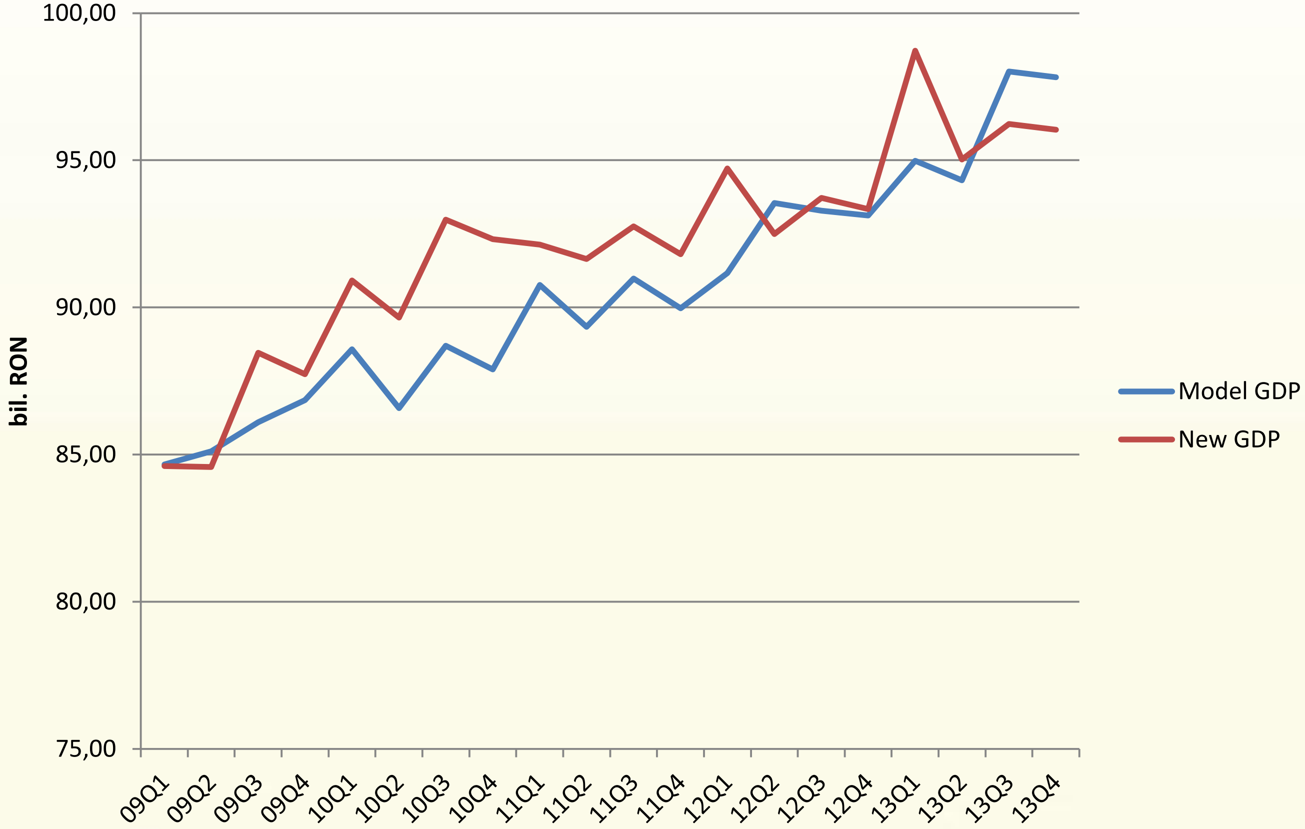
Results

- what if the central bank began decreasing the interest rate 3M sooner ?



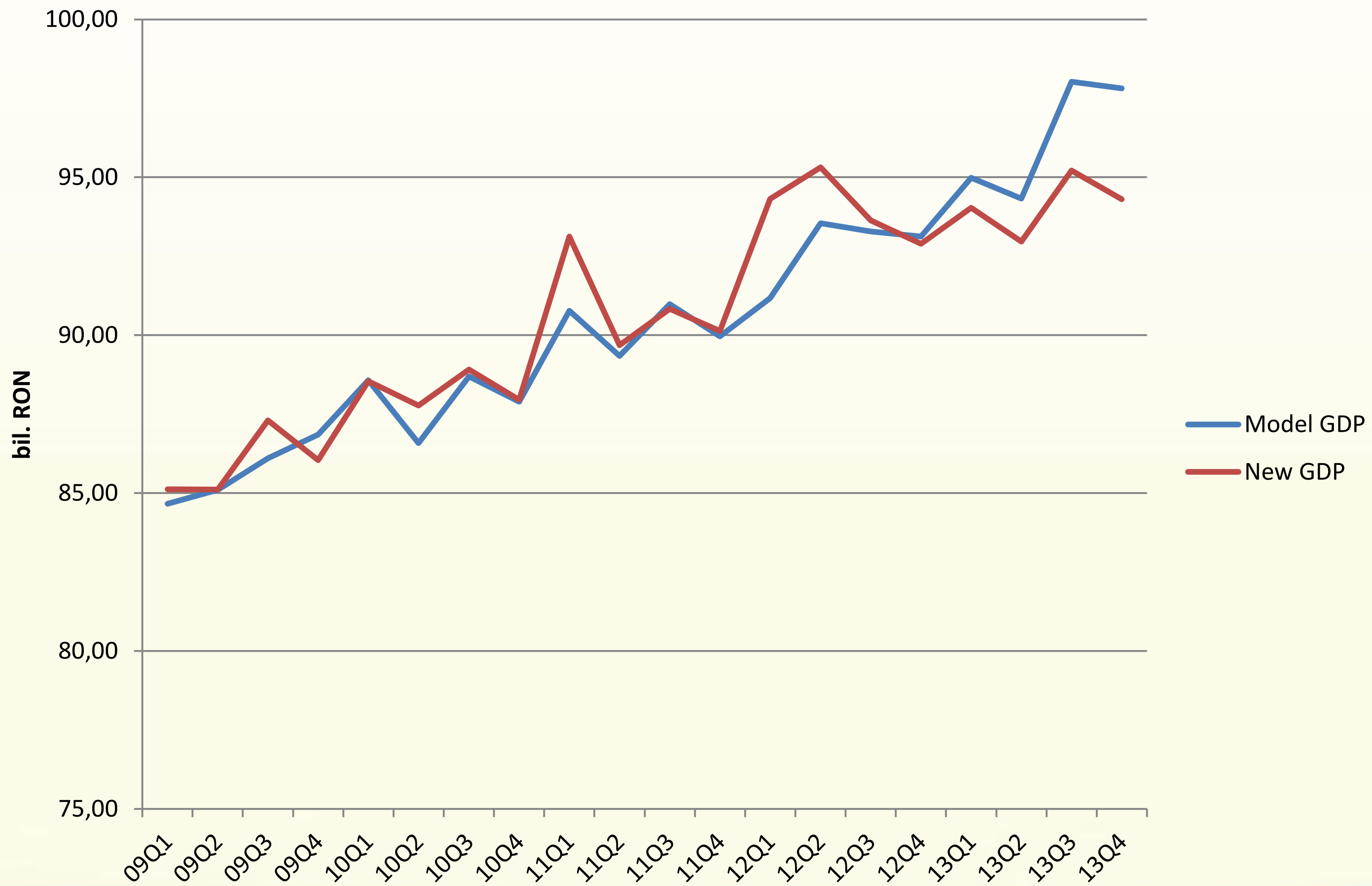
Results

- what if the central bank began decreasing the interest rate 1Y sooner ?



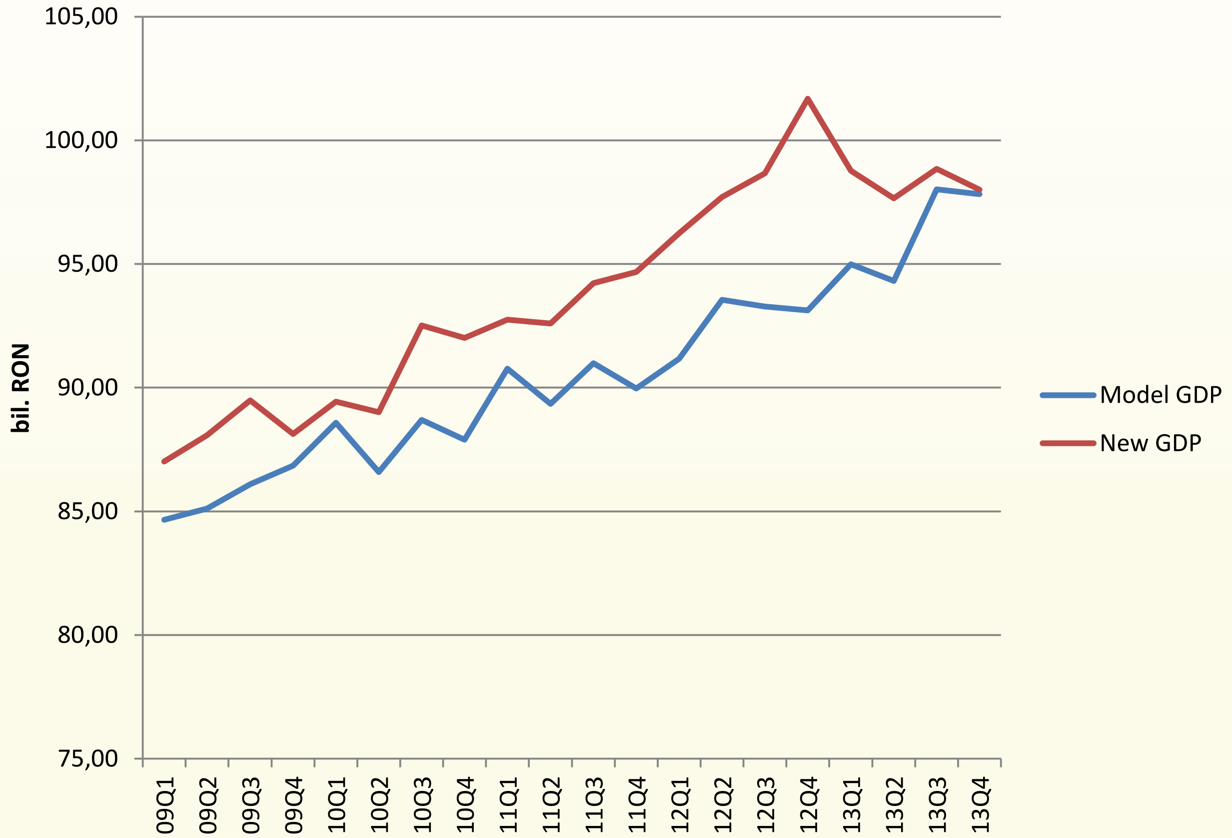
Results

- what if the wage indexation coeff. were 10% higher?



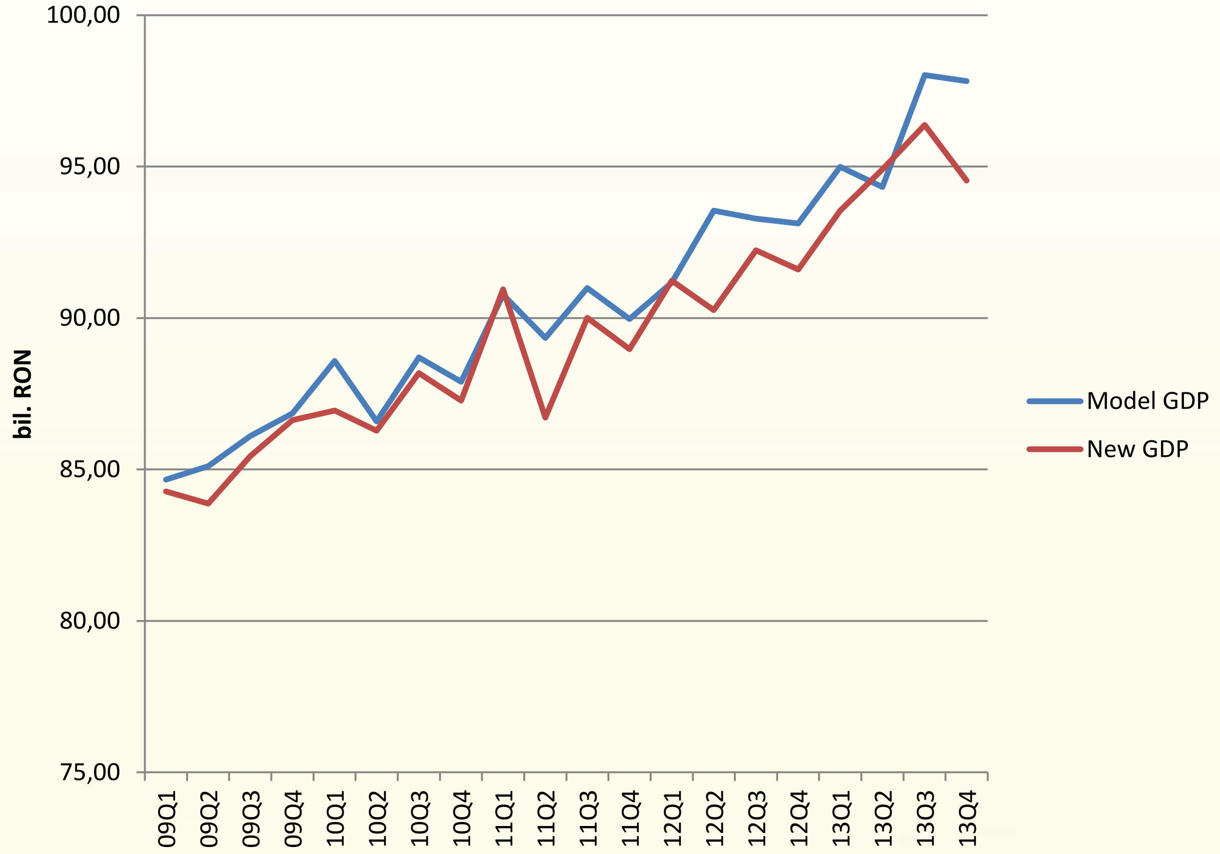
Results

- what if the wage indexation coeff. were 12.5% higher?



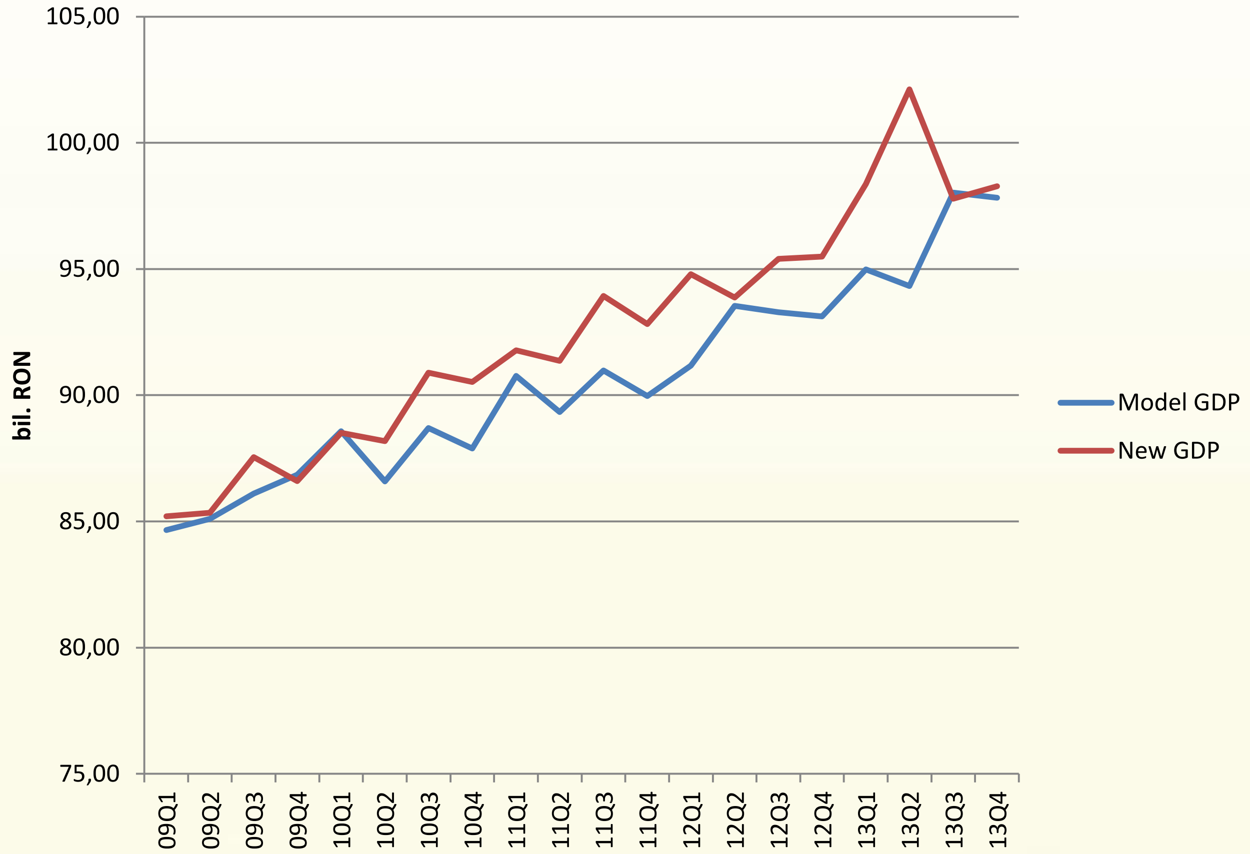
Results

- what if the required reserve ratio was 0.18 instead of 0.15?



Results

- what if the required reserve ratio was 0.12 instead of 0.15?



Results

Policy parameters		GDP statistics	
		Average GDP	Standard dev
Tax rate	0.2	89.6011	3.4683
	0.16	90.5890	3.9464
	0.12	92.3405	3.2782
Unemployment subsidy rate	0.8	89.9776	2.9746
	0.75	90.5890	3.9464
	0.7	91.7442	3.3280
Policy rate	r	90.5890	3.9464
	r(t-3M)	91.4862	3.2513
	r(t-1Y)	91.9937	3.6275
Wage indexation	0.1	90.5890	3.9464
	0.11	90.6605	3.4346
	0.115	93.2993	3.6917
Required reserve ratio	0.18	89.5095	3.6367
	0.15	90.5890	3.9464
	0.12	92.4400	4.7109

Conclusion:

- *ABMs as a more transparent and realistic representation of real-world systems*
- *ABMs as an environment to test and comment on monetary and fiscal policy*

- *Original contributions: Successful calibration and incorporation of real – world data*

- *Possible extensions of the model:*
  - *Inflation targeting rule*
  - *Heterogeneous banks*
  - *Varying no. of firms*
  - *Replace mark-up pricing rule*
  - *Workers save & get credit*

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