NEXT-GENERATION AGENT-BASED MODEL OF CANADA (CAN-ABM)

2021 Bank of Canada Annual Economic Conference (Behavioral Macroeconomics and Finance: Implications for Central Bankers)

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Cars Hommes*, Sebastian Poledna✦ & Yang Zhang*

* Bank of Canada

✦ International Institute for Applied Systems Analysis (IIASA)

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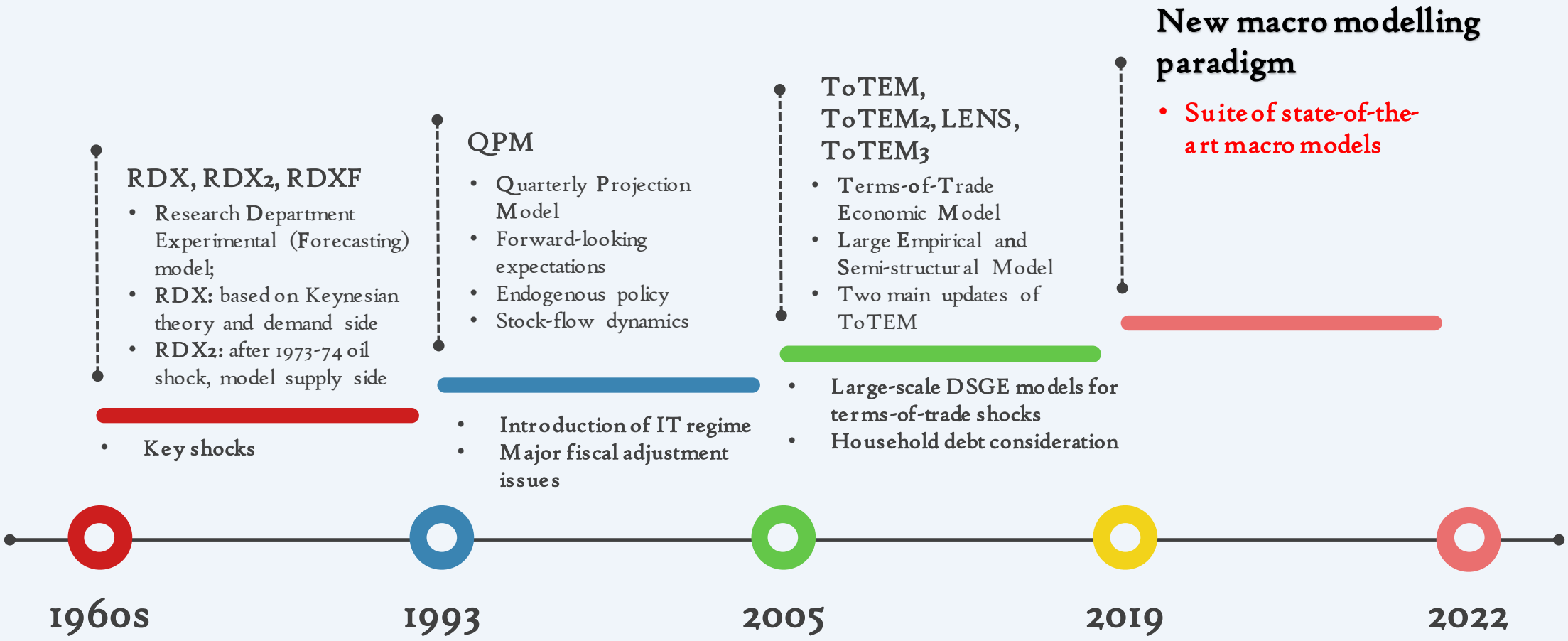
Models are Built to Adapt to Economic Context



Source: https://www.bankofcanada.ca/2017/01/models-art-science-making-monetary-policy/

Some Progress Made within DSGE framework

DSGE	Enhanced DSGE (Next Generation)
Representative agents	**TANK, HANK**
Solved at the aggregate level	———
Rational or model-consistent expectations	**Bounded rationality through myopia or limited foresight**
Agents optimize given expectations	———
Match the historical evolution of variables	———

Research from Het-Lab & Inflation-Target Renewal

Optimal policy under HANK

- **Optimal monetary policy** and inequality. - Acharya, Challe and Droga (2020)

Distributional impact of monetary policy

- **Labor heterogeneity**. -Kuncl and Ueberfeldt (2021)
- **Cost of inflation** - Cao, Meh, Rios-Rull, Terajima (2021)

Alternative expectation

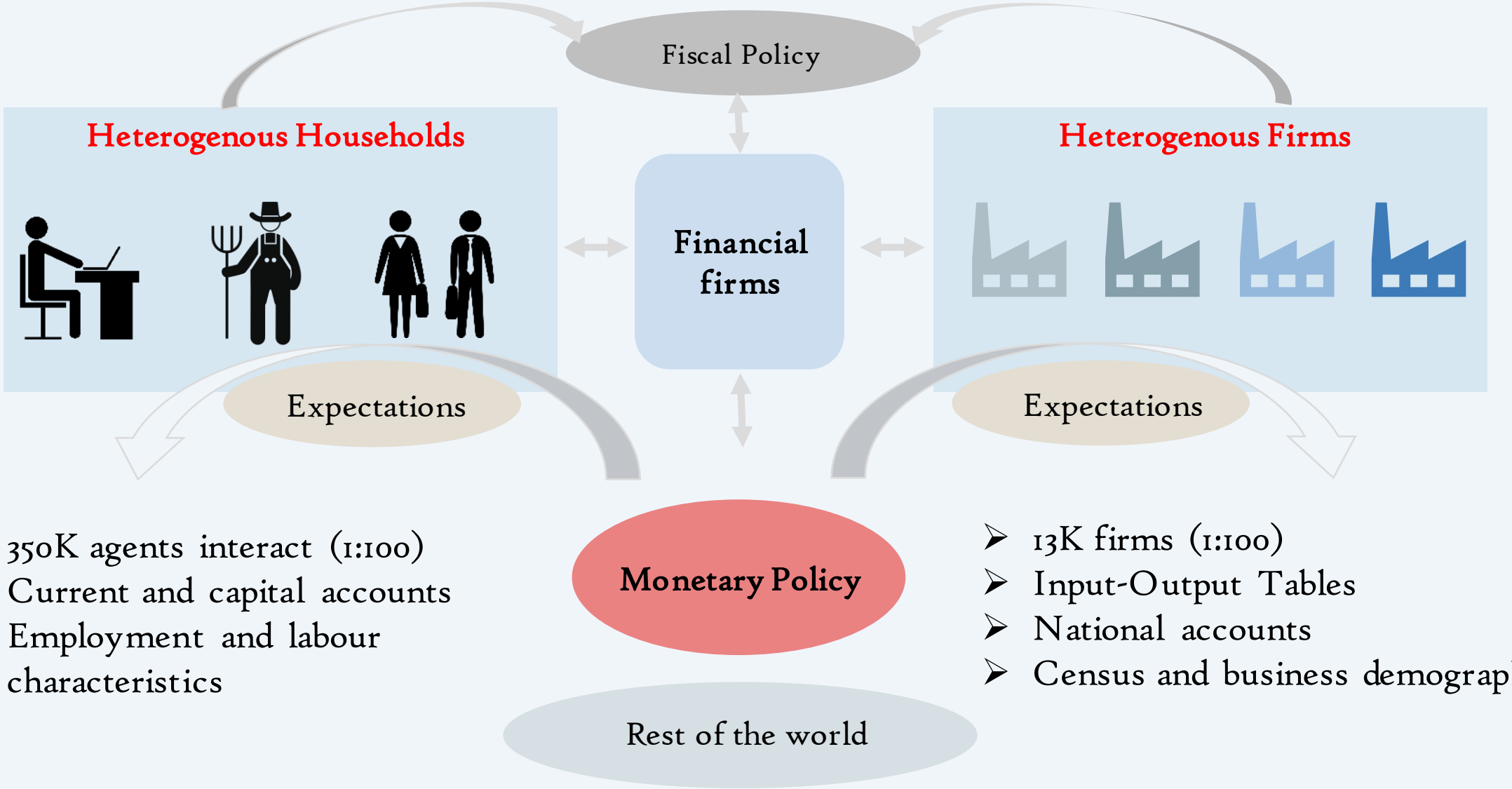
- **Limited foresight** and optimal stabilization policies - Woodford and Xie (2021)
- **Horse Race of history-dependent policies** under bounded rationality – Wagner, Schlanger and Zhang (2021)

Consider ABM into NextGen Model Suite

DSGE	Enhanced DSGE (Next Generation)	CAN-ABM* (Next Generation)
Representative agents	TANK, HANK	**Heterogeneous agents**
Solved at the aggregate level	_____	Solved **numerically** at the agent level
Rational or model-consistent expectations	Bounded rationality through myopia or limited foresight	**Bounded rationality** in expectations
Agents optimize given expectations	_____	Agents use **simple heuristics** calibrated to data
Match the historical evolution of variables	_____	Match historical evolution of macro variables and reproduce stylized facts

* Poledna, S., Miess, M.G., & Hommes, C.H. (2020). *Economic Forecasting with an Agent-Based Model*. IIASA Working Paper. Laxenburg, Austria: WP-20-001

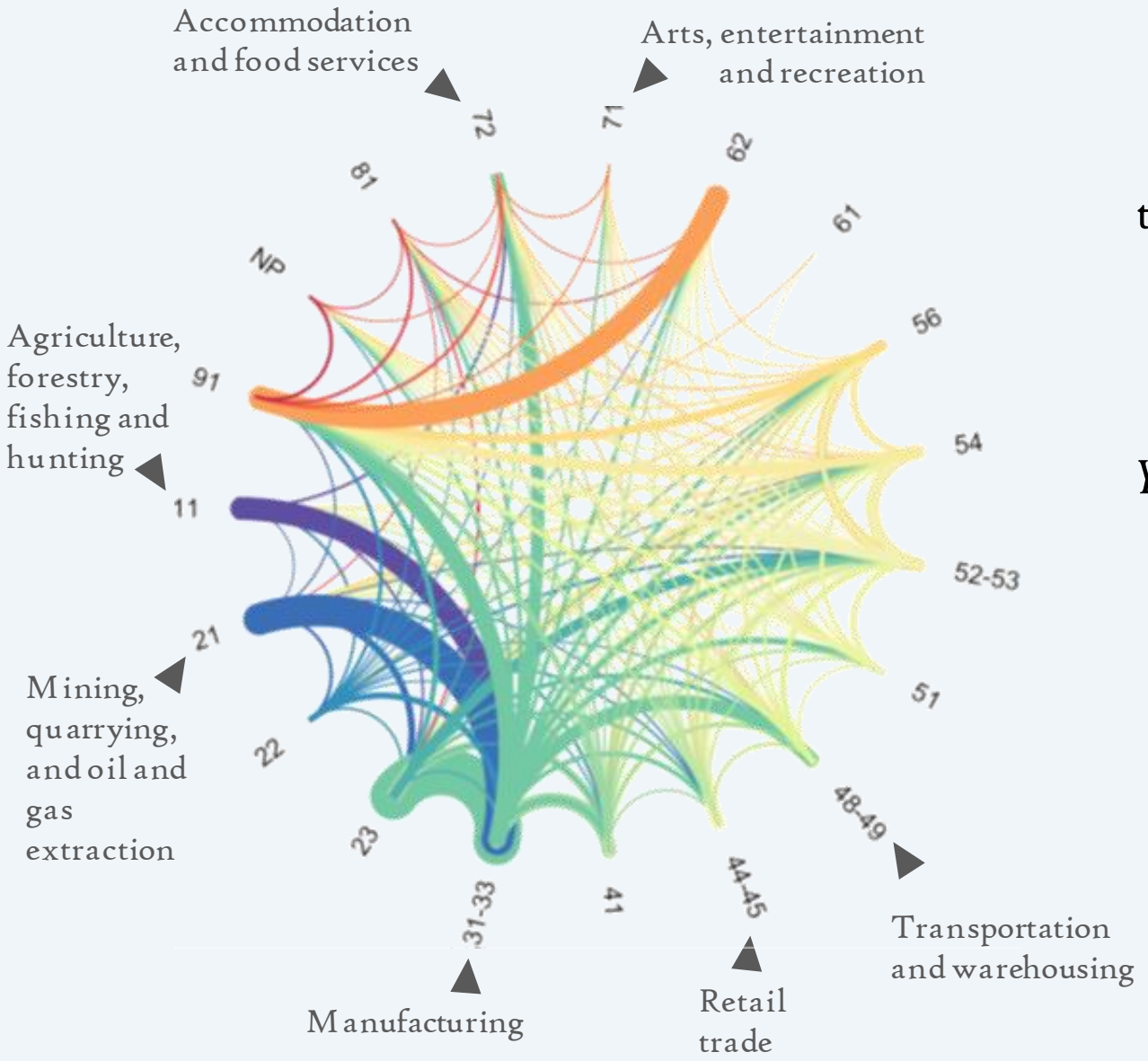
Agents & Markets in CAN-ABM



- 350K agents interact (1:100)
- Current and capital accounts
- Employment and labour characteristics

- 13K firms (1:100)
- Input-Output Tables
- National accounts
- Census and business demography

Multi-sector Production Network

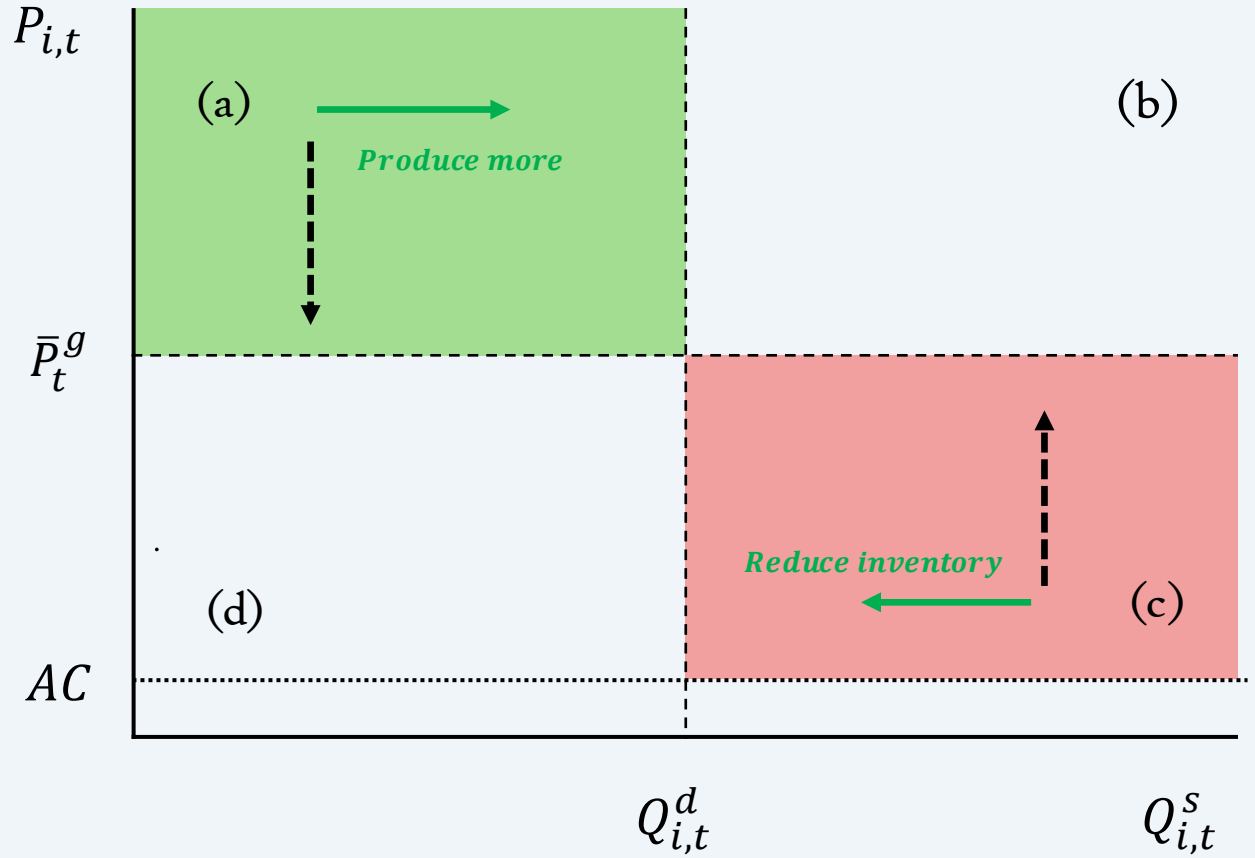


Firm i produces $Y_{i,t}$ with Leontief technology using labour $N_{i,t}$, intermediate inputs $M_{i,t}$ and capital stock $K_{i,t-1}$:

$$Y_{i,t} = min\left(Q^{S}_{i,t},\ \alpha_{i,t} N_{i,t}, \beta_{i,t} M_{i,t}, \kappa_{i,t} K_{i,t-1}\right)$$

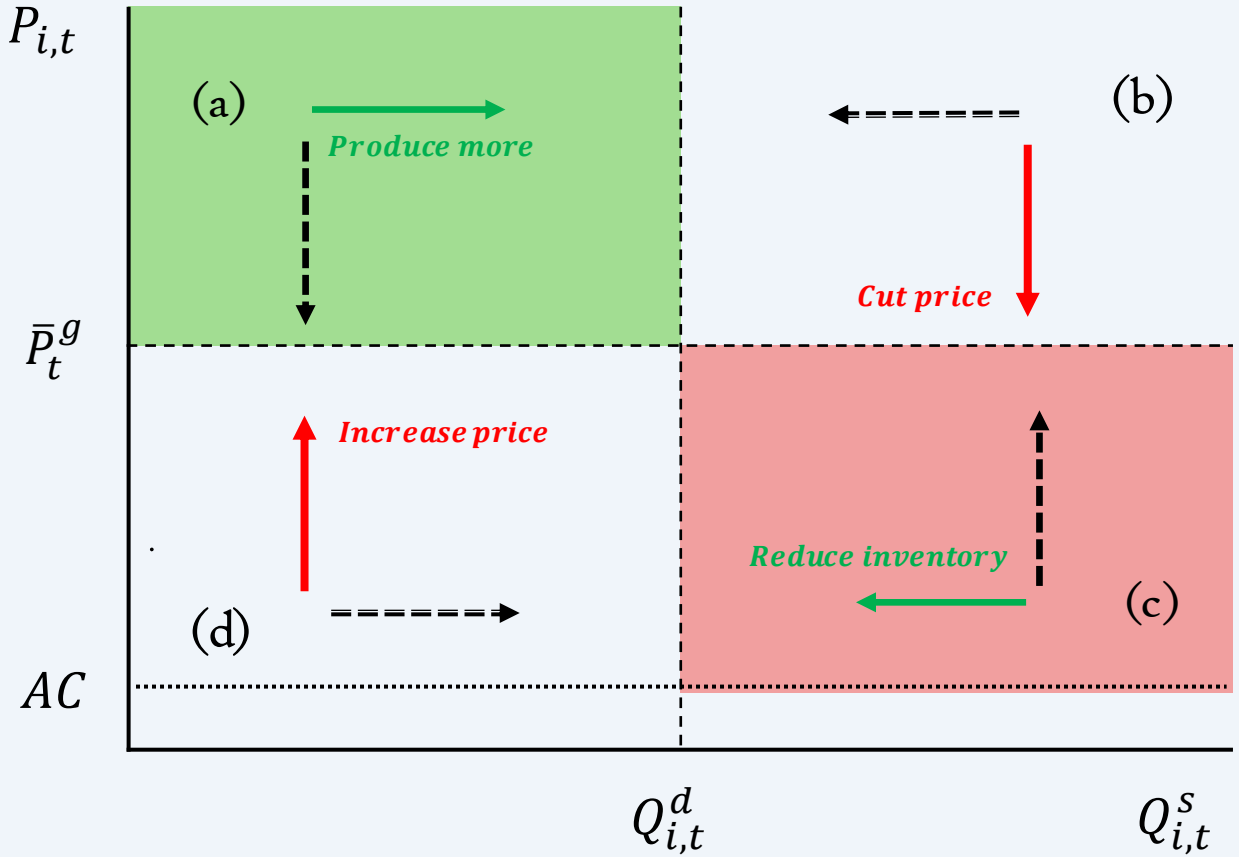
$$\pi^{c}_{i,t} = \underbrace{\frac{\left(1+\tau^{SIF}\right)\bar{w}_i}{\bar{\alpha}_i}\left(\frac{\bar{P}^{HH}_{t-1}}{P_{i,t-1}}-1\right)}_{\textbf{Wage}} + \underbrace{\frac{1}{\beta_i}\left(\frac{\sum_g \boldsymbol{\alpha_{sg}} \bar{P}^{g}_{t-1}}{P_{i,t-1}}-1\right)}_{\textbf{Production Inputs}} + \underbrace{\frac{\delta_i}{\kappa_i}\left(\frac{\bar{P}^{CF}_{t-1}}{P_{i,t-1}}-1\right)}_{\textbf{Financing Cost}}$$

Firm Quantity and Price Setting



Source: Delli Gatti, D., Desiderio, S., Gaffeo, E., Cirillo, P., & Gallegati, M. (2011). The Market for Consumption Goods. In Macroeconomics from the bottom-up (pp. 54–57). essay, Springer Milan.

Firm Quantity and Price Setting



$$\pi_{i,t}^d = \begin{cases} positive, & if \text{ optimistic about demand and price is competitive} \\ negative, & if \text{ positive inventory but charged higher price than average} \end{cases}$$

Adaptive Learning

- Behavioral learning equilibrium (BLE) (Hommes and Zhu [2014])
  - Actual law of motion of the economy high dimensional linear stochastic system
  - But agents don't fully recognize this structure
- **Expectations** on GDP growth and inflation are formed using AR(1):

$$1 + \pi_t^e = e^{\alpha_t^\pi \pi_{t-1} + \beta_t^\pi + \epsilon_t^\pi}$$

$$P_{i,t} = P_{i,t-1} \cdot \underbrace{(1 + \pi_{i,t}^c)}_{Supply\ channel} \cdot \underbrace{(1 + \pi_{i,t}^d)}_{Demand\ channel} \cdot \underbrace{(1 + \pi_t^e)}_{Inflation\ expectation}$$

"In principle it might even be possible to create an agent-based economic model capable of making useful forecasts of the real economy, although this is ambitious ... like climate modelling, [it's] a huge undertaking."

(Farmer & Foley, 2009)

Out-of-Sample Forecasts Outperform VAR(1)

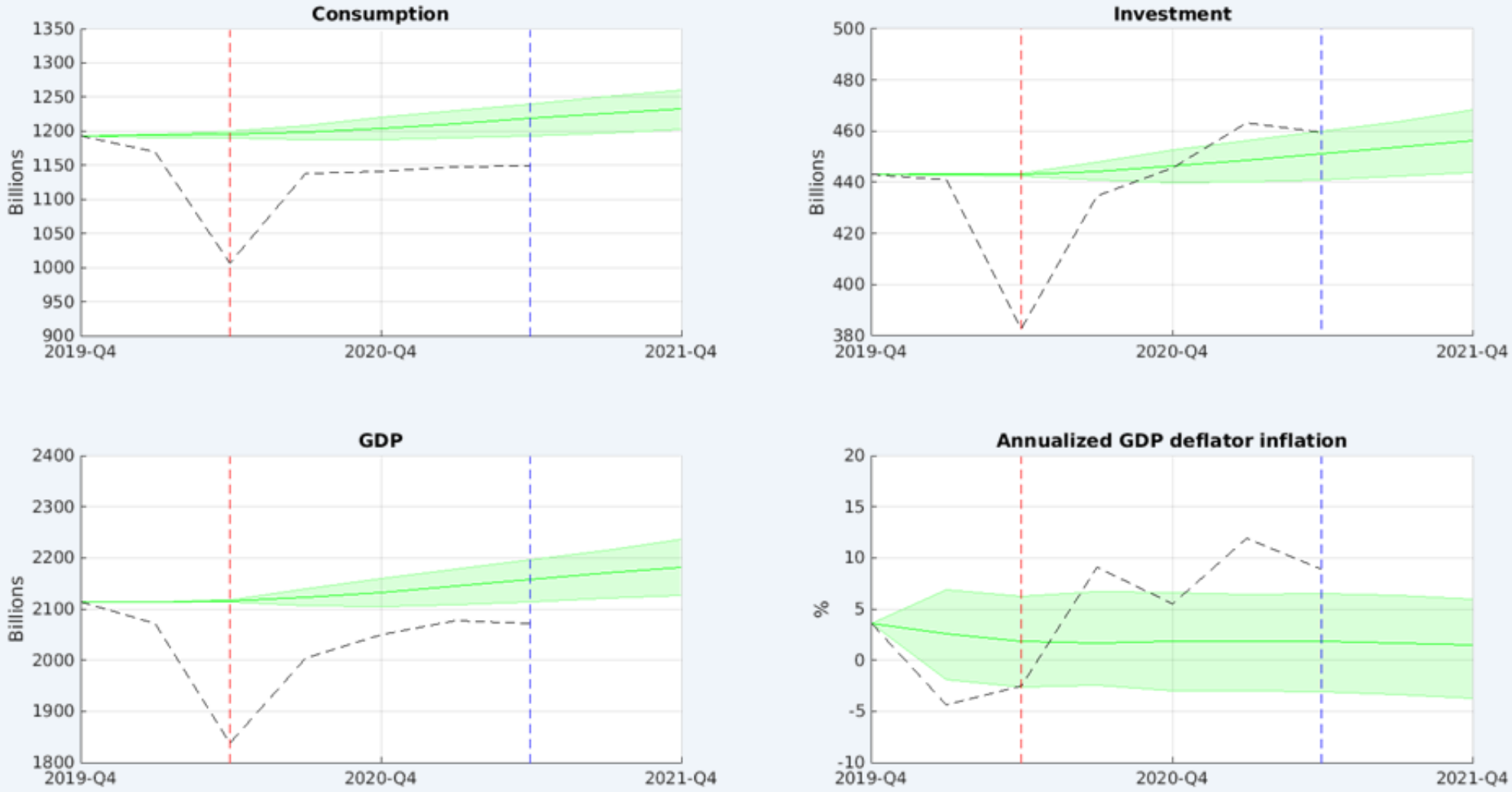
Table 1: Out-of-sample forecast performance

	GDP	Inflation	Consumption	Investment	Exports	Imports
VAR(1)	*RMSE-statistic for different forecast horizons*					
1q	0.55	0.67	0.34	1.43	2.34	1.6
2q	0.83	0.61	0.54	2.78	3.04	2.48
4q	1.37	0.61	0.99	5.56	3.81	4.72
8q	1.98	0.7	1.62	10.43	4.73	9.34
12q	2.21	0.72	1.98	15.21	4.72	13.83
AR(1)	*Percentage gains (+) or losses (-) relative to VAR(1) model*					
1q	2.6 (0.35)	15.6 (0.02)	17.7 (0.06)	-0.3 (0.51)	-1.6 (1.00)	12.5 (0.03)
2q	1.6 (0.40)	1.9 (0.33)	7.1 (0.23)	9.6 (0.19)	4.4 (0.99)	29.9 (0.05)
4q	11.2 (0.00)	0.7 (0.42)	10.9 (0.12)	18.6 (0.05)	1.6 (1.00)	47.3 (0.04)
8q	10.3 (0.00)	3.8 (0.15)	11.6 (0.24)	21.8 (0.01)	-6.3 (0.99)	61.8 (0.05)
12q	19.3 (0.03)	2.8 (0.12)	8.8 (0.36)	26 (0.00)	-14.1 (0.99)	68.6 (0.28)
ABM	*Percentage gains (+) or losses (-) relative to VAR(1) model*					
1q	3 (0.32)	13.5 (0.06)	-19 (0.87)	-4.7 (0.83)	5.6 (0.15)	14 (0.12)
2q	2.9 (0.29)	-2.6 (0.66)	-17.4 (0.83)	11 (0.02)	11.1 (0.06)	33.6 (0.03)
4q	12 (0.06)	-4.8 (0.77)	12.4 (0.29)	23.1 (0.05)	7.4 (0.09)	49.5 (0.01)
8q	17.3 (0.02)	9.3 (0.06)	19.3 (0.34)	33 (0.04)	2.8 (0.38)	65.6 (0.01)
12q	27.1 (0.00)	3.1 (0.36)	33.4 (0.32)	43.2 (0.00)	2.7 (0.41)	77.7 (0.03)

Note: RMSE-statistic for main aggregates from ABM simulations in comparison to VAR(1) and AR(1) models for the forecast period from 2010:Q2-2019:Q4 for Canada.

Source: Model simulations, Statistics Canada

Useful Tool For Developing Macro Scenarios



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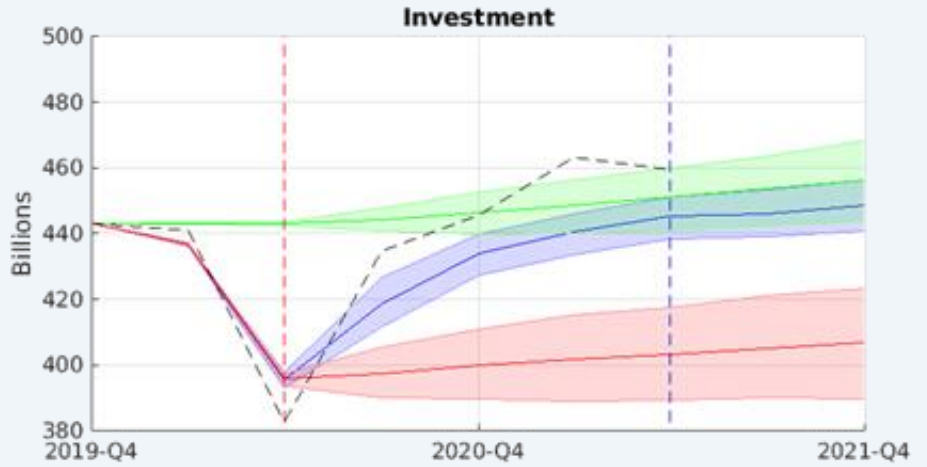
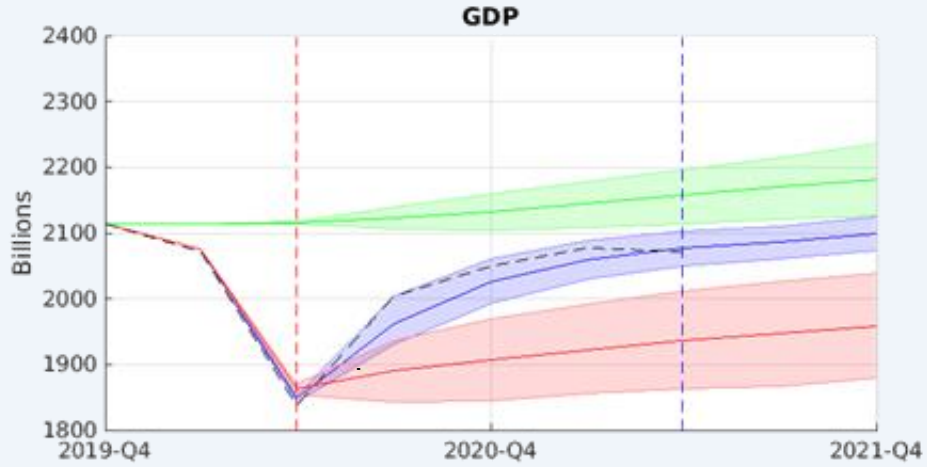
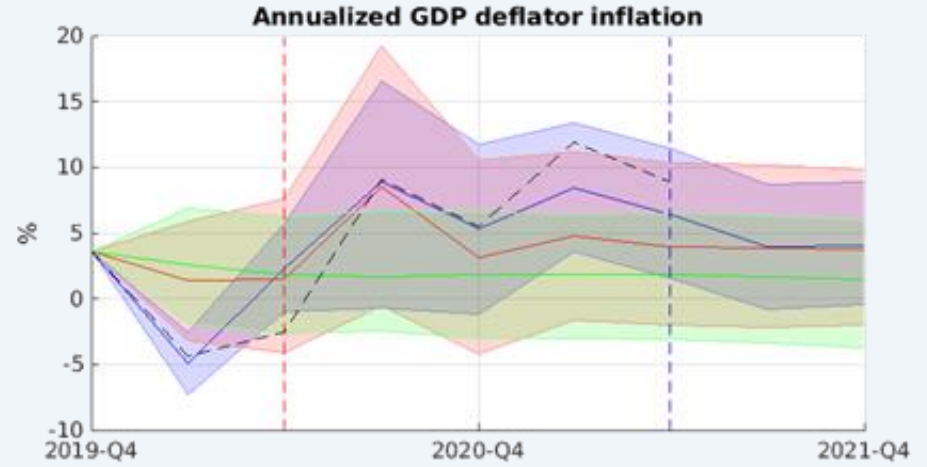
Useful Tool For Developing Macro Scenarios



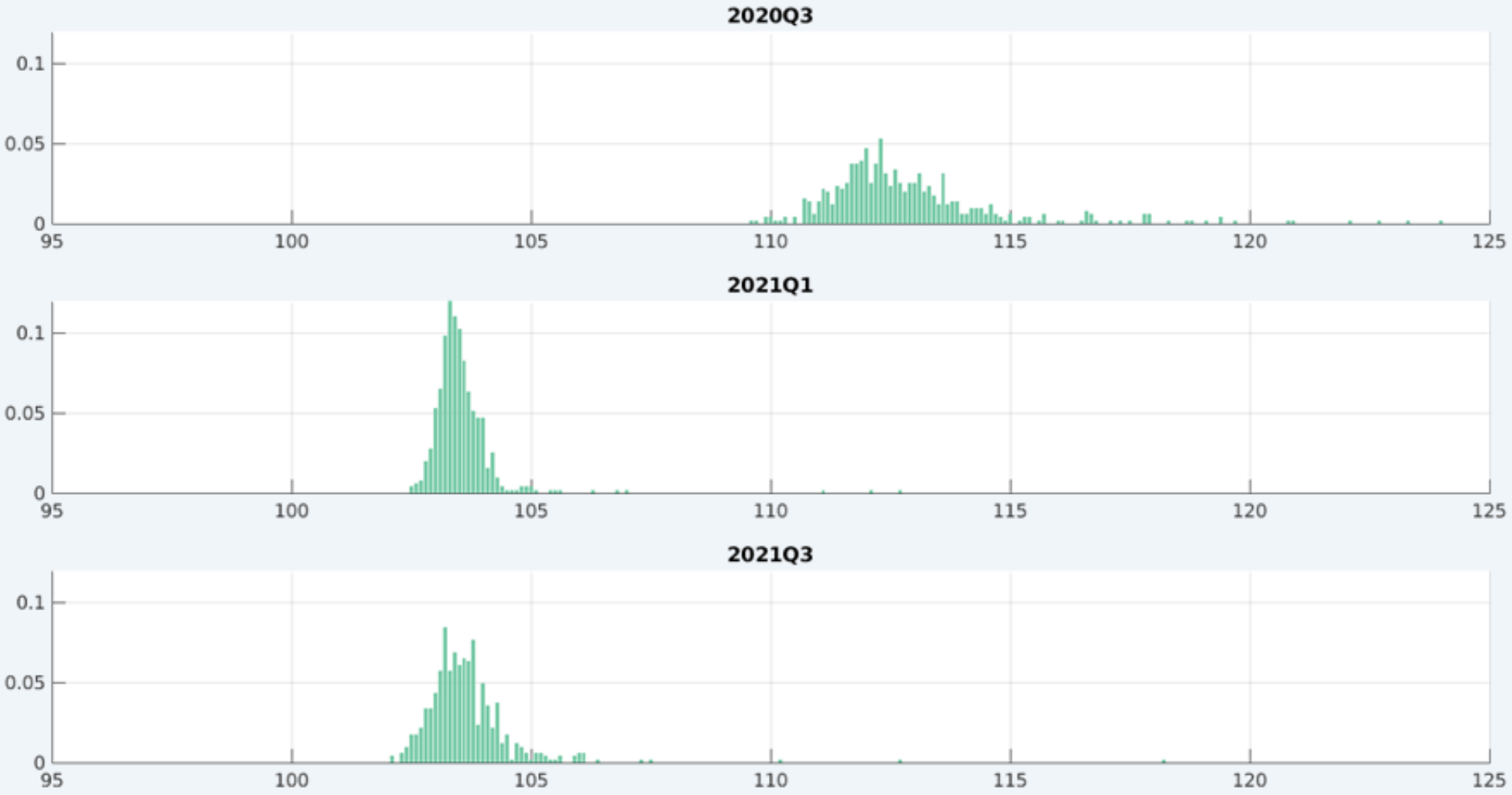




Data
Baseline
Demand shock
Demand shock & Trade shock

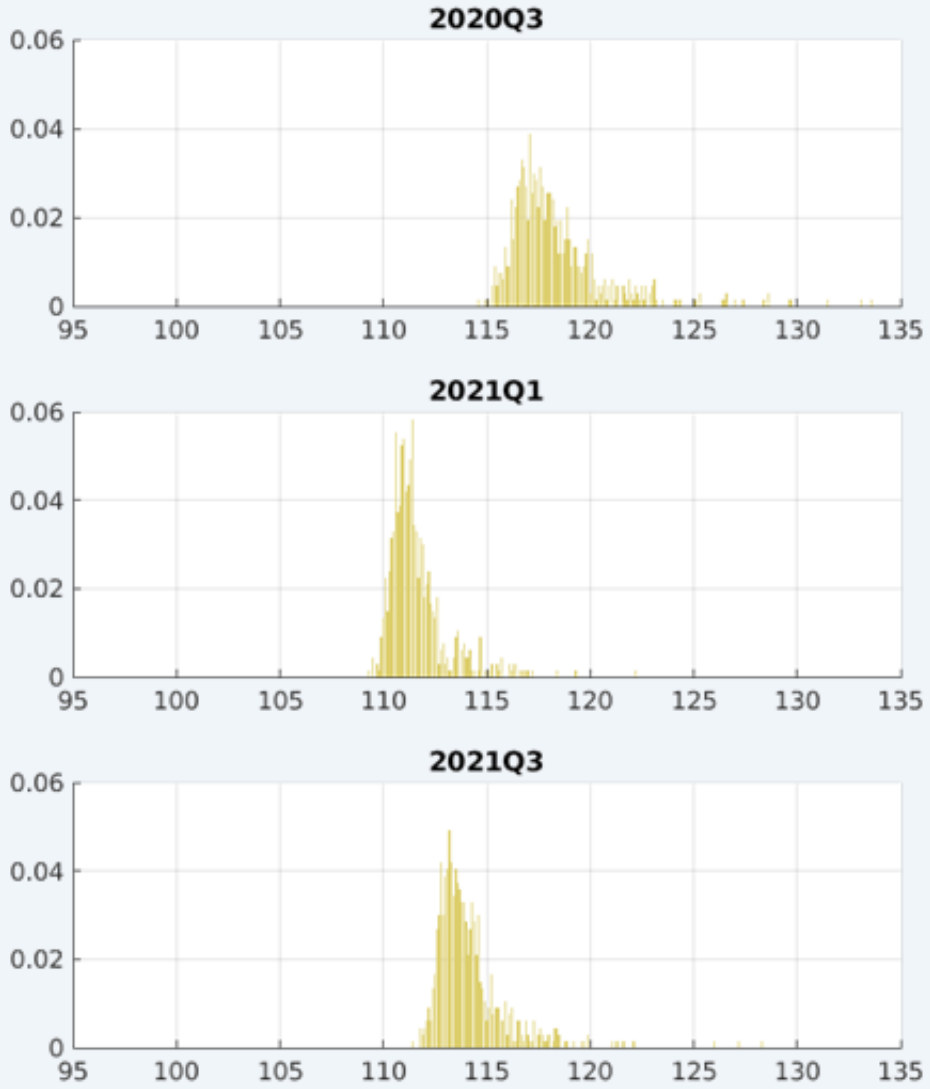
Source: Model simulations, Statistics Canada

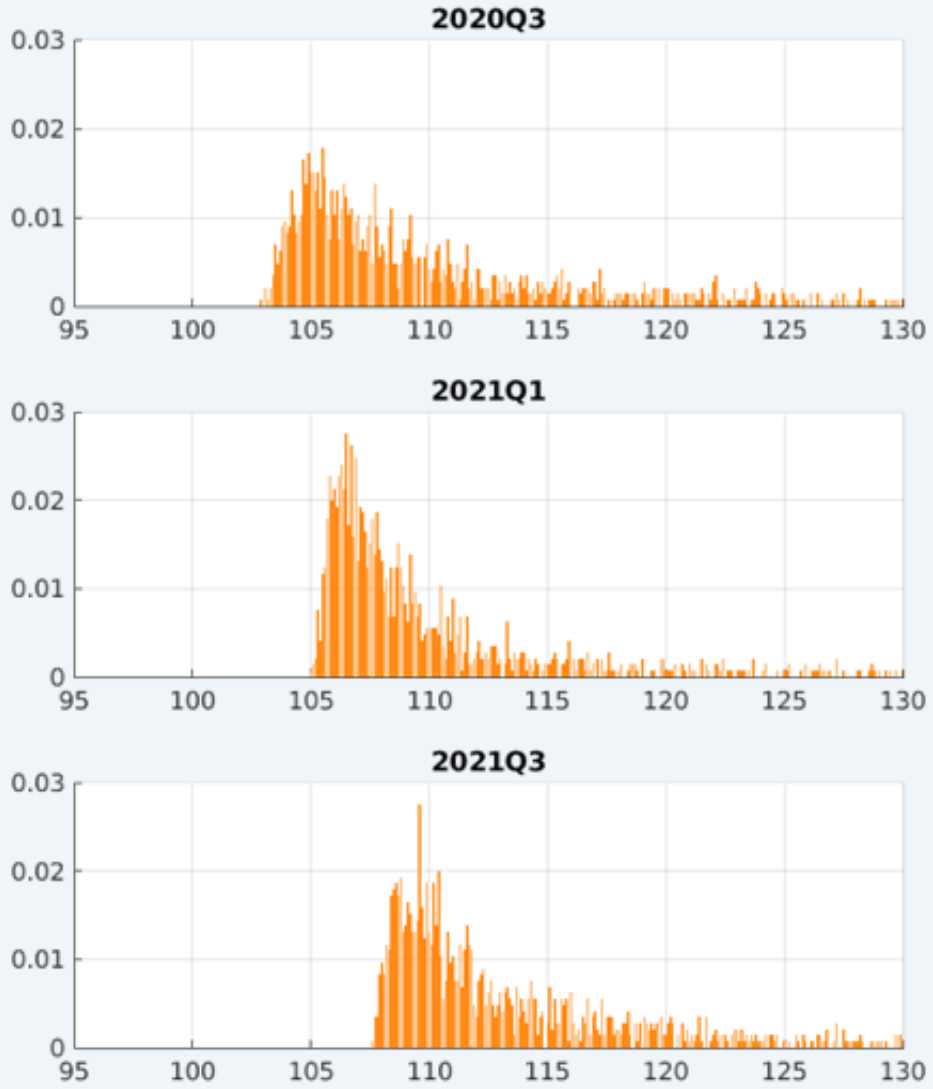
Simulated Price Distribution (2019Q4 = 100)



Source: Model simulations

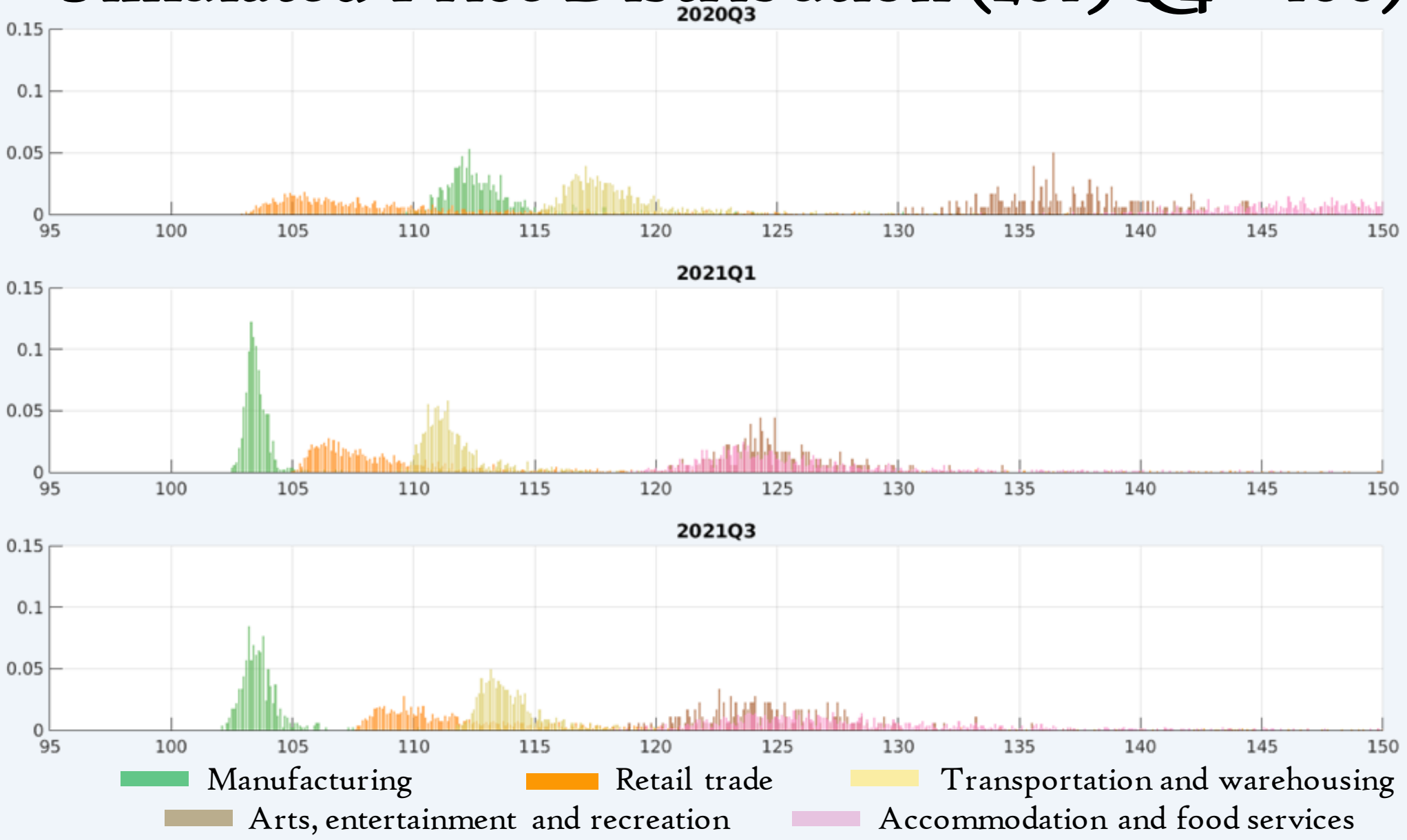
Simulated Price Distribution (2019Q4 = 100)





Source: Model simulations

Simulated Price Distribution (2019Q4 = 100)

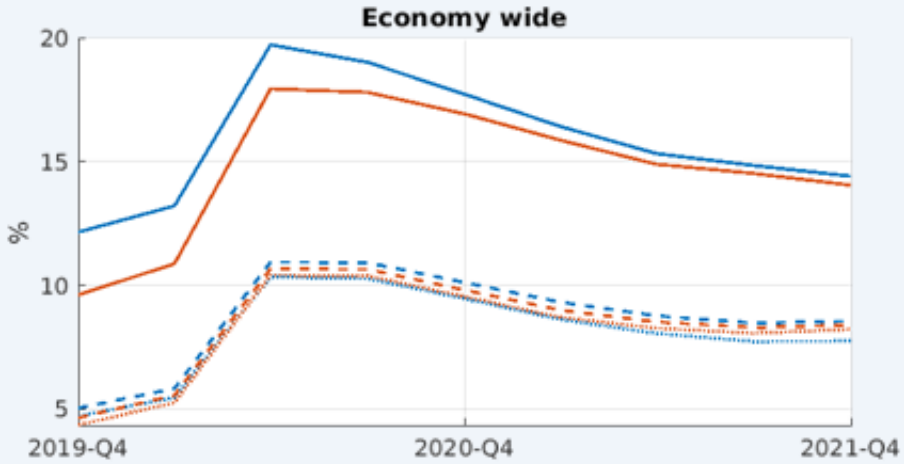


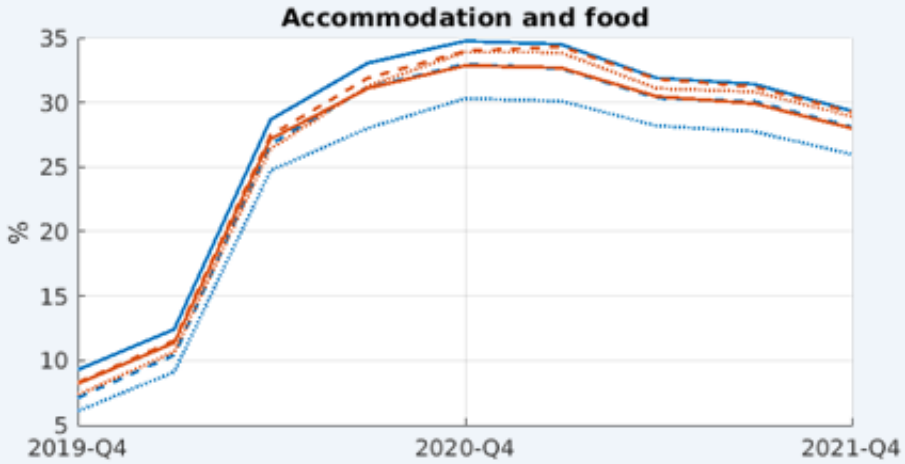
Source: Model simulations

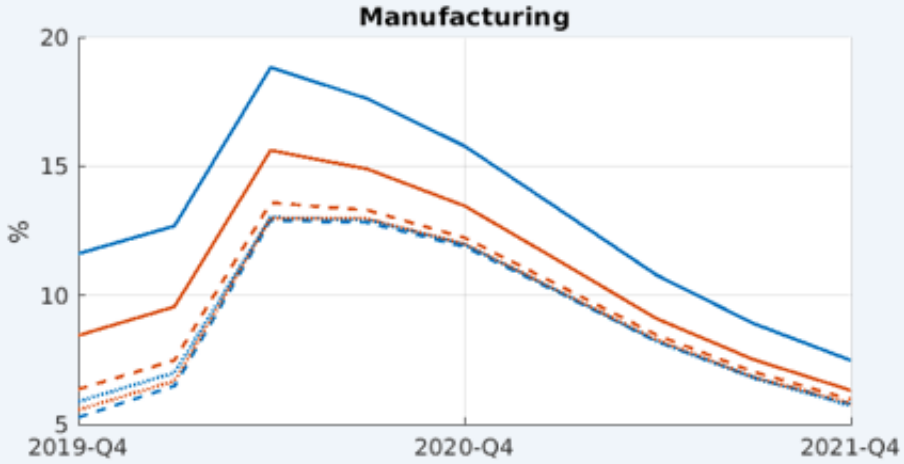
Measuring Labour Market Condition Essential for CBs

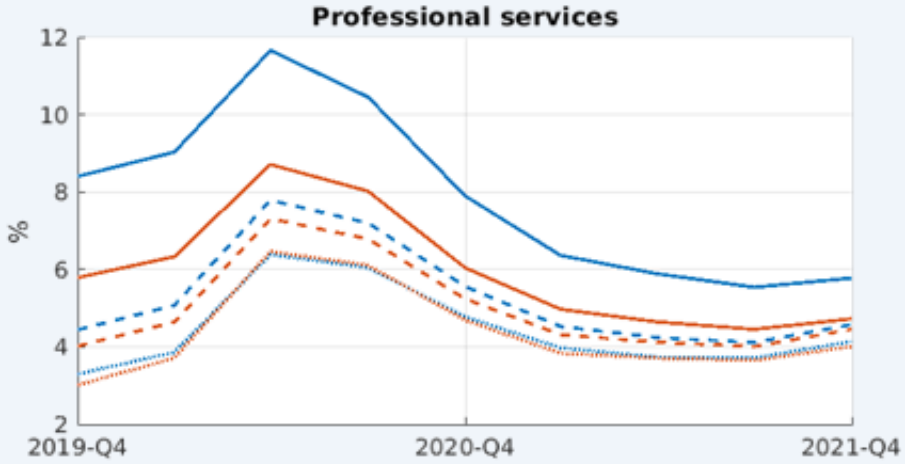
Source: Ens, Savoie-Chabot, See and Wee (2021), "Assessing Labour Market Slack for Monetary Policy"
Last observation: 2021 Q3

ABM Could Provide Some Insights for Inclusive Recovery









Sectoral Male unemployment rate (%): aged 15-24 aged 25-54 aged 55 and over

Sectoral female unemployment rate (%) : aged 15-24 aged 25-54 aged 55 and over

Source: Model simulations

Visions

- **CAN-ABM offers a complementary tool to DSGEs for central bank policy analysis**
  - Rich household and firm heterogeneity
  - Nonlinear effects
  - Competitive out-of-sample forecasting performance
- **Strength in realistic expectation formation and behavior modelling**
  - Bounded rationality
  - Crucial for monetary policy transmission
- **Great potential for policy analysis & scenario building**
  - Climate scenario