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

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The views expressed in this presentation are solely those of the authors and may differ from official Bank of Canada views. No responsibility for them should be attributed to the Bank of Canada.
Models are Built to Adapt to Economic Context

- **RDX, RDX₂, RDXF**
  - Research Department Experimental (Forecasting) model;
  - RDX: based on Keynesian theory and demand side
  - RDX₂: after 1973-74 oil shock, model supply side

- **QPM**
  - Quarterly Projection Model
  - Forward-looking expectations
  - Endogenous policy
  - Stock-flow dynamics

- **Introduction of IT regime**
  - Major fiscal adjustment issues

- **ToTEM, ToTEM₂, LENS, ToTEM₃**
  - Terms-of-Trade Economic Model
  - Large Empirical and Semi-structural Model
  - Two main updates of ToTEM

- **Large-scale DSGE models for terms-of-trade shocks**
  - Household debt consideration

- **New macro modelling paradigm**
  - Suite of state-of-the-art macro models

Source: [https://www.bankofcanada.ca/2017/01/models-art-science-making-monetary-policy/](https://www.bankofcanada.ca/2017/01/models-art-science-making-monetary-policy/)
Some Progress Made within DSGE framework

<table>
<thead>
<tr>
<th>DSGE</th>
<th>Enhanced DSGE (Next Generation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representative agents</td>
<td>TANK, HANK</td>
</tr>
<tr>
<td>Solved at the aggregate level</td>
<td></td>
</tr>
<tr>
<td>Rational or model-consistent</td>
<td>Bounded rationality through</td>
</tr>
<tr>
<td>expectations</td>
<td>myopia or limited foresight</td>
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<tr>
<td>Agents optimize given expectations</td>
<td></td>
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<tr>
<td>Match the historical evolution of</td>
<td></td>
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<tr>
<td>variables</td>
<td></td>
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</tbody>
</table>
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

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

Agents & Markets in CAN-ABM

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

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

- **Financial firms**

- **Monetary Policy**

- **Fiscal Policy**

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

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

$$\pi_{i,t}^c = \left( \frac{1 + \tau_{SIF}^S}{\bar{\alpha}_i} \right) \left( \frac{\bar{P}_{t-1}^{HH} - 1}{P_{i,t-1}} \right)$$

$$+ \frac{1}{\beta_i} \left( \frac{\sum_g \alpha_{sg} \bar{P}_{t-1}^g}{P_{i,t-1}} - 1 \right)$$

$$\frac{\delta_i}{\kappa_i} \left( \frac{\bar{P}_{t-1}^{CF}}{P_{i,t-1}} - 1 \right)$$

Accommodation and food services
Arts, entertainment and recreation
Agriculture, forestry, fishing and hunting
Mining, quarrying, and oil and gas extraction
Manufacturing
Retail trade
Transportation and warehousing

Multi-sector Production Network
Firm Quantity and Price Setting

\[ P_{i,t} \]

\[ Q_{i,t}^d \]

\[ Q_{i,t}^s \]

(a) \( \rightarrow \) Produce more

(b) \( \downarrow \) Reduce inventory

Firm Quantity and Price Setting

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

• Behavioral learning equilibrium (BLE) (Hommes and Zhu [2014])
  o Actual law of motion of the economy high dimensional linear stochastic system
  o But agents don’t fully recognize this structure

• Expectations on GDP growth and inflation are formed using AR(1):

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

\[
P_{i,t} = P_{i,t-1} \cdot \frac{(1 + \pi_{i,t}^c)}{\text{Supply channel}} \cdot \frac{(1 + \pi_{i,t}^d)}{\text{Demand channel}} \cdot \frac{(1 + \pi_t^e)}{\text{Inflation expectation}}
\]
“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

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

**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

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

Chart 4: Measures of labour market inclusiveness

a. Unemployment rate

<table>
<thead>
<tr>
<th>Category</th>
<th>Crisis trough (%)</th>
<th>2019 monthly average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, 15-24</td>
<td>28.9</td>
<td>9.8</td>
</tr>
<tr>
<td>Short-term (&lt;= 27 weeks)</td>
<td>12.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Male, 15-24</td>
<td>29.4</td>
<td>13.2</td>
</tr>
<tr>
<td>University</td>
<td>8.9</td>
<td>5.0</td>
</tr>
<tr>
<td>Female, 25-54</td>
<td>11.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Non-university</td>
<td>15.2</td>
<td>8.1</td>
</tr>
<tr>
<td>Male, 25-54</td>
<td>11.5</td>
<td>6.2</td>
</tr>
<tr>
<td>Female, 55+</td>
<td>11.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Male, 55+</td>
<td>11.2</td>
<td>7.7</td>
</tr>
</tbody>
</table>

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
  o Rich household and firm heterogeneity
  o Nonlinear effects
  o Competitive out-of-sample forecasting performance

• Strength in realistic expectation formation and behavior modelling
  o Bounded rationality
  o Crucial for monetary policy transmission

• Great potential for policy analysis & scenario building
  o Climate scenario