The GPM Team

- Produces quarterly projections before each WEO
  - WEO numbers are produced by the country experts in the area departments
  - Models used to help impose macro consistency in the WEO (United States, Euro Area, Japan, Emerging Asia, Latin America and Remaining Countries)
  - Models used to produce risk assessments
- Produces monthly updates for GDP growth 1 year ahead
- Produces weekly note on recent economic developments
Key Models used for Production

- The Global Integrated Monetary and Fiscal Model (GIMF)
- The Global Economy Model (GEM)
- The Global Projection Model (GPM)
- The Flexible System of Global Models (FSGM) comprised of three modules (G2oMOD, EUROMOD, EMERGMOD)
The Global Projection Model (GPM)

- GPM is primarily a forecasting model whereas GIMF, GEM and FSGM are used for scenarios and policy analysis.
- GPM is the simplest model in terms of structure.
- It is a reduced-form model with only a handful of key behavioral equations.
- Smaller size makes system estimation of model parameters feasible.
- The main production version contains six regions: the United States, the euro area, Japan, Emerging Asia, Latin America, and the rest of the world.
The Global Projection Model (GPM)

- Several other versions of GPM have been developed
  - A euro area version has been built for the European Department which models individually Germany, France, Italy and Spain
  - A seven region version has been built that includes China individually.
  - An eleven region one is being developed that includes more individual Asian economies
The Global Projection Model: An Overview

Douglas Laxton and GPM team

Economic Modeling Division, Research Department, IMF

January 31, 2014
Roadmap

- Background and Motivation
- Stages in model building
- Structure of the model
- Confronting model with data
- Applications
- Ongoing Work
Background and Motivation

Two types of models developed by the IMF in recent years and used in central banks and by country desks

- A small quarterly projection model (QPM) with 4 or 5 key equations (Berg, Karam, and Laxton)
- DSGE models – usually based on stronger choice-theoretic foundations
To develop a series of country or regional small macro models incorporating real and financial linkages.

Use these models to assess global outlook and conduct risk scenarios.
GPM aims at providing consistent international forecasts

At present, projections of the external outlook at policymaking institutions usually take the following approaches:

- Use forecasts from commercial sources, including from think tanks and global banks
- Use forecasts prepared by international organizations
- Build internal models

Potential problems with these approaches

- Consistency
- Timing and frequency of forecast updates
- Resource constraints to develop macro models
- How to implement risk analysis
<table>
<thead>
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<th>Stages in GPM Model Development</th>
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<td>WP/05/278 &amp; 279</td>
</tr>
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</table>
GPM Coverage by Regions

Coverage 85.6% of World

- USA (20%)
- Euro Area (15.1%)
- Japan (6.2%)
- EA (23.4%)
- LA5 (6.1%)
- RC8 (14.8%)
GPM shocks

- GPM allows for various shocks to explain unanticipated movements in the data and to account for revisions in the underlying forecast. For GDP, these revisions can result in transitory changes, temporary but persistent changes, permanent changes and persistent changes in the growth rate.

- Examples of simple stochastic process to explain forecasts revisions to potential output and the NAIRU.
- **Potential Output**

\[
\bar{Y}_{i,t} = \bar{Y}_{i,t-1} + g_i/4 - \sigma_{1,i} \dot{RPOIL}_t^w + \varepsilon_{i,t} 
\]  
\[
g_{i,t} = \tau_i \bar{Y}_{i,ss} + (1 - \tau_i)\bar{Y}_{i,t-1} + \varepsilon_{g_i,t} \]  

- **NAIRU**

\[
\bar{U}_{i,t} = \bar{U}_{i,t-1} + g_{i,t} + \varepsilon_{i,t} 
\]  
\[
g_{i,t} = (1 - \alpha_{i,3})g_{i,t-1} + \varepsilon_{g_i,t} \]
Real GDP in steady state

\[
\overline{Y}_{i,t} = \overline{Y}_{i,t-1} + g_i/4 + \ldots + \varepsilon_{i,t}
\]

\[
g_{i,t} = \tau_i g_{i,ss} + (1 - \tau_i)g_{i,t-1} + \varepsilon_{g_{i,t}}
\]
Shock to the Level of GDP

\[ \bar{Y}_{i,t} = \bar{Y}_{i,t-1} + g_{i}/4 + \ldots + \varepsilon_{i,t} \]

\[ g_{i,t} = \tau_{i}\bar{Y}^{ss}_{i} + (1 - \tau_{i})g_{i,t-1} + \varepsilon_{i,t} \]
Shock to the level and the growth rate of GDP

\[
\bar{Y}_{i,t} = \bar{Y}_{i,t-1} + g_i/4 + \ldots + \varepsilon_{i,t}
\]

\[
g_{i,t} = \tau_i g_{i,ss} + (1 - \tau_i)g_{i,t-1} + \varepsilon_{i,t} g_{i,ss}
\]
BLT shock
Stochastic processes for the real interest rate and the real exchange rate

- Equilibrium real interest rate
  \[
  \bar{RR}_{i,t} = \rho_i \bar{RR}_{i,SS} + (1 - \rho_i) \bar{RR}_{i,t-1} + \varepsilon_{i,t}
  \]  
  (5)

- Equilibrium real exchange rate
  \[
  LZ_{i,t} = 100 \times \log \left( S_{i,t} P_{us,t} / P_{i,t} \right)
  \]  
  (6)

  \[
  \Delta LZ_{i,t} = 100 \Delta \log \left( S_{i,t} \right) - \left( \pi_{i,t} - \pi_{us,t} \right) / 4
  \]  
  (7)

  \[
  \bar{LZ}_{i,t} = \bar{LZ}_{i,t-1} + \varepsilon_{i,t}
  \]  
  (8)
We introduce three types of effects to the traditional open economy output-gap equation

- Real-financial linkages
- Real-international spillovers
- Spillovers from commodity prices

\[ y = y(\text{lead, lag, interest-rate gap, real exchange-rate gap, } y^* ; \text{financial linkages, real spillovers, commodity prices}) \]
Real-Financial linkages
The model exploits information from the FED’s Senior-Loan officers survey.

Figure 2: U.S. Output Gap (Negative) and Lagged Bank Lending Tightening
(In percent)
Real-financial Linkages

- Introduction of Bank Lending Tightening variable for the US

\[ y_{US,t} = \beta_{US,1} y_{US,t+1} + \beta_{US,2} y_{US,t-1} - \beta_{US,3} mrr_{US,t-1} + \beta_{US,4} reer_{US,t-1} + \theta_{US} \eta_{US,t} + \ldots + \varepsilon_{US,t} \]
The term 

\[ \theta_{US} \eta_{US,t} \]

captures financial surprises that provide signals on expected real activity. We isolate the expected activity variable from the observed measure of BLT.

\[ BLT_{US,t} = \overline{BLT}_{US,t} - \kappa_{US} \eta_{US,t+4} - \varepsilon_{US,t} \]

The trend in BLT follows a simple stochastic process.

\[ \overline{BLT}_{US} = \overline{BLT}_{US,t-1} + \varepsilon_{US,t} \]

For the US, we found the persistency of BLT shocks to last 8 quarters.

\[ \eta_{US,t} = 0.04 \varepsilon_{BLT_{US,t-1}} + 0.08 \varepsilon_{BLT_{US,t-2}} + 0.12 \varepsilon_{BLT_{US,t-3}} + 0.16 \varepsilon_{BLT_{US,t-4}} + 0.20 \varepsilon_{BLT_{US,t-5}} + 0.16 \varepsilon_{BLT_{US,t-6}} + 0.12 \varepsilon_{BLT_{US,t-7}} + 0.08 \varepsilon_{BLT_{US,t-8}} + 0.04 \varepsilon_{BLT_{US,t-9}} \]
Spillover Channels

- Direct: foreign demand shocks
  \[ \sum_j \omega_{i,j,5} \nu_j \]

- Indirect: foreign output gaps, \( y^* \)

- Effect of commodity prices on income and wealth
  \[ \beta_{i,6} q_{i,t} \]
• Output-Gap equation

\[ y_{i,t} = \beta_{i,1} y_{i,t+1} + \beta_{i,2} y_{i,t-1} - \beta_{i,3} mrr_{i,t-1} + \beta_{i,4} \text{reer}_{i,t-1} - \{\theta_i \eta_i, t\} + \sum_j \omega_i,j,5 \nu_j + \beta_{i,5} \sum_{j \neq i} \omega_i,j,5 y_{j,t-1} + \beta_{i,6} q_{i,t} + \varepsilon^y_{i,t} \] (9)
Inflation Block

- Core inflation excludes food and energy prices. Model includes leads, lags, output gap, changes in exchange-rate gaps and past differences between headline and core. The later term reflects the fact that food and energy prices are inputs into the production process of other goods and may also reflect the fact that workers may bargain on the basis of headline inflation.

- Domestic gasoline prices depend on crude oil costs, taxes other factor input costs as well as markups. The parameters are calibrated based on available data on cost shares and the tax structure of each country.

- Domestic food inflation: similar methodology as gasoline prices in the sense they are affected by international prices and other prices, "costs".
Inflation Block

\[ \pi_{i,t} = \lambda_{i,1} \pi_{i,t}^x + \lambda_{i,2} \pi_{i,t}^{\text{gas}} + (1 - \lambda_{i,1} - \lambda_{i,2}) \pi_{i,t}^{\text{food}} \]

Core inflation (excludes energy and food items)

\[ \pi_{i,t}^x = \lambda_{i,1}^x \pi_{i,t+4}^x + (1 - \lambda_{i,1}^x) \pi_{i,t-1}^x + \lambda_{i,2}^x \gamma_{i,t-1}^x \]
\[ + \lambda_{i,3}^x \sum_j \omega_{i,j,3}(z_{i,j,t} - z_{i,j,t-4})/4 + \lambda_{i,4}^x \mathcal{W}_{i,t-1} - \varepsilon_{i,t}^x \]

Domestic gasoline inflation

\[ \pi_{i,t}^{\text{gas}} = \iota_{i,1}^{\text{gas}} \pi_{i,t-1}^{\text{gas}} + (1 - \iota_{i,1}^{\text{gas}}) \left\{ \iota_{i,2}^{\text{gas}} \pi_{i,t}^{\text{oil}} + \left(1 - \iota_{i,2}^{\text{gas}}\right) \pi_{i,t}^T \right\} - \varepsilon_{i,t}^{\text{gas}} \]

Food inflation

\[ \pi_{i,t}^{\text{food}} = \iota_{i,1}^{\text{food}} \pi_{i,t-1}^{\text{food}} + (1 - \iota_{i,1}^{\text{food}}) \left\{ \iota_{i,2}^{\text{food}} \pi_{i,t}^{\text{food}_W} + \left(1 - \iota_{i,2}^{\text{food}}\right) \pi_{i,t}^T \right\} - \varepsilon_{i,t}^{\text{food}} \]
Policy Interest Rate, \textit{inflation-forecast based rule}

\[ l_{i,t} = \gamma_{i,1} l_{i,t-1} + \]
\[ (1 - \gamma_{i,1}) \left\{ \overline{RR}_{i,t} + \pi_{i,t+3}^4 + \gamma_{i,2} \left( \pi_{i,t+3}^4 - \pi_{i,\text{tar}}^4 \right) + \gamma_{i,4} y_{i,t} \right\} + \varepsilon_{i,t} \]

- The term

\[ \pi_{i,t+3}^4 = \pi_{i,t+3}^4 + \pi_{i,t+2}^4 + \pi_{i,t+1}^4 + \pi_{i,t}^4 \]

is used because it allows monetary policy to react to current period quarterly inflation rate

\[ \pi_{i,t}^4 = 100 \times \log \left( P_{i,t}^4 / P_{i,t-1}^4 \right) \]

in addition to forecasts of inflation

\[ \pi_{i,t+1}^4, \pi_{i,t+2}^4, \pi_{i,t+3}^4 \]
Uncovered Interest Rate Parity, risk-adjusted

\[(RR_{i,t} - RR_{us,t}) = 4(LZ_{i,t+1}^e - LZ_{i,t}) + (\overline{RR}_{i,t} - \overline{RR}_{us,t}) + \varepsilon_{i,t}^{RR - RR_{us}}\] (10)

\[LZ_{i,t+1}^e = \phi_i LZ_{i,t+1} + (1 - \phi_i) LZ_{i,t-1}\] (11)

Unemployment Rate

\[u_{i,t} = \alpha_{i,1} u_{i,t-1} + \alpha_{i,2} y_{i,t} + \varepsilon_{i,t}^u\] (12)
World Commodity Prices

- Oil and food prices are affected by global activity.
- For oil, we use a short-run price elasticity w.r.t. world income equal to 9.
- For food, we use a short-run price elasticity w.r.t. world income equal to 0.8.
- Flexible process for the trends in prices. The oil price the trend is consistent with recent empirical studies analyzing supply and demand conditions, see Benes and others (2013),
The block of **commodity prices** is defined as

\[
Q_t^w = \bar{Q}_t^w + q_t^w
\]

\[
\bar{Q}_t^w = \bar{Q}_{t-1}^w + g_t \bar{Q}_t^w + \varepsilon_t \bar{Q}_t^w
\]

\[
g_t \bar{Q}_t^w = \left(1 - \iota Q^3\right) g_{t-1} \bar{Q}_t^w + \varepsilon_t \bar{Q}_t^w
\]

\[
q_t^w = \iota_1 q_{t-1}^w + \iota_2 y_t^w + \varepsilon_t^w
\]

For \( Q = \{OIL, FOOD\} \), which denotes world’s oil and food real price levels, and \( q = \{oil, food\} \), which denotes their cyclical component
Advantages of Bayesian Methods

- Puts some weight on priors and some weight on the data.
- Incorporates theoretical insights to prevent incorrect empirical results, such as interest-rate movements having perverse effects on inflation, but also confronts model with the data to some extent.
- Allows use of small samples without concern for incorrect estimated results.
- Allows estimation of many coefficients and latent variables (e.g., output gap, NAIRU, equilibrium real interest rate) even in small samples.

*By specifying tightness of distribution on priors, researcher can change relative weights on priors and data in determining posterior distribution for parameters.*
Full estimation is infeasible and we proceeded in stages:

- Previous GPM work, particularly GPM6
- Strong priors e.g., spillovers formulation, commodities block
US response to: RES_YY_US = 1; 1-period shock

- Output Gap
- Headline Inflation (q/q)
- Policy Rate
- Nominal Oil Price
- BLT
- Core Inflation (q/q)
- Real Interest Rate
- Real Oil Price
- Gasoline Inflation (q/q)
- Nominal Food Price
- GDP Level
- Cons. Food Inflation (q/q)
- REER Gap
- Real Food Price
- World Output Gap
- Foreign Activity
- World Oil Price Gap
- RES_YY_US
Cumulative 2-year Real GDP Growth Spillovers from a Demand Shock 1/
-Deviations from steady-state, in percent-

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>EU</th>
<th>JA</th>
<th>EA6</th>
<th>LA6</th>
<th>RC6</th>
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1/ Shock emitters in rows
Effect on the level of real GDP of a permanent 10% oil price shock
- Deviations from steady-state, in percent-
Effect on the level of real GDP of a transitory 10% oil price shock
- Deviations from steady-state, in percent-
### RMSEs G3

#### GPM6 Commodity Data

**United States RMSEs (1999Q1:2007Q4)**

<table>
<thead>
<tr>
<th>Commodity</th>
<th>1Q Ahead</th>
<th>4Q Ahead</th>
<th>8Q Ahead</th>
<th>12Q Ahead</th>
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<tbody>
<tr>
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<td>1.43</td>
<td>1.62</td>
<td>1.60</td>
<td>1.61</td>
</tr>
<tr>
<td>GROWTH4</td>
<td>0.36</td>
<td>0.86</td>
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<tr>
<td>PIE</td>
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**Euro Area RMSEs (1999Q1:2007Q4)**

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<th>8Q Ahead</th>
<th>12Q Ahead</th>
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<tbody>
<tr>
<td>GROWTH</td>
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<td>1.06</td>
<td>1.54</td>
<td>1.32</td>
</tr>
<tr>
<td>GROWTH4</td>
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<td>0.91</td>
<td>1.16</td>
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<td>1.01</td>
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<td>19.43</td>
<td>24.86</td>
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**Japan RMSEs (1999Q1:2007Q4)**

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<tr>
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<td>2.31</td>
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<tr>
<td>GROWTH4</td>
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<td>2.03</td>
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### RMSEs non-G3

#### GPM6 Commodities

**Emerging Asia RMSEs (1999Q1:2007Q4)**

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**Latin America RMSEs (1999Q1:2007Q4)**

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#### GPM6 Commodities

**Remaining Countries RMSEs (1999Q1:2007Q4)**

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<td>LS</td>
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</table>
- Construction of model-based global projections to help coordinate the WEO
- Creation of risk scenarios for multilateral surveillance
- Collaboration with Central Banks
• For WEO exercise, GPM-based forecast is a key ingredient
• GPM-based forecast is augmented by near-term monitoring, conducted by GPM-team country experts at the IMF
• For simulation purposes, GPM considers two important non-linearities: zero interest floor and convex Phillips curve
Convexity in the Phillips Curve

\[ \alpha_{y\text{gap}} \left( \frac{y_{\text{gap}, t}}{y_{\text{max}} - y_{\text{gap}, t}} y_{\text{max}} \right) \]

Inflation

In this region, slope isn’t different from the linear model

y_{\text{max}} (calibrated at 5%)
Since the model is non-linear, we have to conduct many draws of simulations to get estimates of the confidence bands.

- Probability of shocks being drawn corresponds to historical estimates.

- Monte Carlo simulation breaks because of the high dimensionality of the problem (number of shocks, number of periods and number of state variables).
Ongoing work

- Develop the next production version of the model (China)