Modeling Data Revisions:
Measurement Error and the Dynamics of “True” Values

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Paper at www.eco.rug.nl/~jacobs
Motivation

**Monetary and fiscal policy**: Optimal forecasts and current estimates of economic conditions require a model of the data revision process.

**Productivity Growth**: Testing for trend breaks is complicated by data revisions.

**Garratt, Lee, Mise and Shields**: Multiple vintages aid in estimation of cycles.

**Aruoba**: *Data Revisions are Not Well-Behaved*
Figure 7A - End of Sample Breakpoint Tests
RealTime - US Output per Hour - Non Farm Business

p-Value

1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0.05
0

Break-Point

End of Sample
Reasons for revisions of official statistics

1. Incorporation of source data with more complete or otherwise better reporting (e.g. including late respondents) in subsequent estimates.

2. Correction of errors in source data (e.g. from editing) and computations (e.g. revised imputation).

3. Replacement of first estimates derived from incomplete samples (e.g. sub-samples) judgmental or statistical techniques when firmer data become available.

4. Incorporation of source data that more closely match the concepts and/or benchmarking to conceptually more accurate but less frequent statistics.

5. Incorporation of updated seasonal factors.

6. Updating of the base period of constant price estimates.

7. Changes in statistical methodology (such as the introduction of chain-linked volume estimates), concepts, definitions, and classifications.

8. Revisions to national accounts statistics arising from the confrontation of data in supply and use tables.
Structure

1. Some Notation and Some of the Literature
2. A State-Space Model
3. A Rudimentary Application
4. Conclusion
The Revision Triangle

\[
\begin{bmatrix}
y_1^1 & \cdots & y^{t-l}_1 & \cdots & y_t^t \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
y_{t-l}^t & \cdots & y_{t-l}^t & \cdots & y_t^t
\end{bmatrix}
\]
Modeling Data Revisions

Observed Values \( y^t = [y^t, \ldots, y^t_{t-l+1}, y^t_{t-l}]' \)

“True” Values \( \tilde{y} = [\tilde{y}_t, \ldots, \tilde{y}_t_{t-l+1}, \tilde{y}_t_{t-l}]' \)

Measurement Errors \( u^t \equiv y^t - \tilde{y} = [u^t, \ldots, u^t_{t-l+1}, 0]' \)

For i.i.d. measurement errors, the state-space model is

Measurement Equation \( y^t = Z\tilde{y} + \varepsilon_t \)

Transition Equation \( \tilde{y}_{t+1} = T\tilde{y} + \eta_t \)

\( \varepsilon_t \sim N(0, H); \eta_t \sim N(0, Q); \) and \( E(\varepsilon_t, \eta_{t+j}) = 0 \) for all \( j \).

Can use Kalman filter to form optimal estimates of \( \tilde{y}, y^{t+j}, \ldots \)

\( \Rightarrow \) But measurement errors are Not Well-Behaved.
Measurement Errors: “News” or “Noise”?

Noise

\[ y_t^i = \tilde{y}_t + \epsilon_t^i, \quad \text{cov}(\tilde{y}_t, \epsilon_t^i) = 0. \]  \hspace{1cm} (1)

- Simplest Case: \( \epsilon_i \sim i.i.d. \).
- Consistent with the above state-space model.
- Should filter multiple vintages to estimate \( \tilde{y} \).
- Revisions can be forecast.
- To test, just regress

\[ y_t^i - \tilde{y}_t = \alpha_1 + \beta_1 \tilde{y}_t + \varepsilon_t, \]  \hspace{1cm} (2)

and test \( \alpha_1 = 0, \beta_1 = 0. \)
Measurement Errors: “News” or “Noise”? 

**News**

\[ \tilde{y}_t = y^i_t + \nu^i_t, \quad \text{cov}(y^i_t, \nu^i_t) = 0. \]  

(3)

- Linked to rational forecast (De Jong 1987) and rational statistical agency (Sargent 1989).

- Revisions cannot be forecast.

- *Inconsistent* with the above state-space model.

- To test, just regress

\[ y^i_t - \tilde{y}_t = \alpha_2 + \beta_2 y^i_t + \varepsilon_t, \]  

(4)

and test \( \alpha_2 = 0, \beta_2 = 0 \).
dY: News or Noise?

Correlation with Revisions

Revision Vintage

- 0.4
- 0.3
- 0.2
- 0.1
- 0.0

with 1st Estimate

with Final Estimate
Measurement Errors: Spillovers

Spillovers: News and Noise only consider behaviour of $u^i_t$ for a given $t$. 

$$E(u^i_t, u^i_{t+j}) \neq 0.$$ (See Howrey 1978.)

<table>
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<tr>
<th>Autocorrelation</th>
<th>$y_{t}^{t+2} - y_{t}^{t+1}$</th>
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<td>-0.09</td>
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<td>3</td>
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<td>8</td>
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</table>
Measurement Errors: Summary

Realistically, we may have to model

1. Noise revisions
2. News revisions
3. Spillovers

How?
## Literature Review

<table>
<thead>
<tr>
<th>Author</th>
<th>Noise</th>
<th>News</th>
<th>Spillover</th>
</tr>
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<tbody>
<tr>
<td>Howrey (1978)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Conrad and Corrado (1979)</td>
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<td>No</td>
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<tr>
<td>Harvey et al. (1983)</td>
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<td>Trivellato and Rettore (1986)</td>
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<td>Patterson (1994)</td>
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<td>Kapetanios and Yates (2004)</td>
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<td>De Antonio Liedo and Carstensten (2005)</td>
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<td>Kishor and Koenig (2005)</td>
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<tr>
<td>Harrison, Kapetanios and Yates (2005)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Busetti (2006)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
A State-Space Model

Notation and Structure

\[ y_t = Z \alpha_t + \varepsilon_t \]  \hspace{1cm} (5)

\[ \alpha_{t+1} = T \alpha_t + R \eta_t \]  \hspace{1cm} (6)

\( y_t \) is \( l \times 1 \), \( \alpha_t \) is \( m \times 1 \), \( \eta_t \) is \( r \times 1 \) and \( \sim \) i.i.d. \( N(0, I_r) \).

\( \varepsilon_t = 0 \) (Ignore it.) We’ll ignore constants too.

\[ y_t = [y_t^{t+1}, y_t^{t+2}, \ldots, y_t^{t+l}]' \]

Unlike our earlier model, this vector groups data by date rather than vintage.
A State-Space Model

Partitioning: Measurement Equation

\[ y_t = Z \alpha_t \]

\[ \alpha_t = [\tilde{y}_t, \phi'_t, \nu'_t, \varepsilon'_t]' \]

\[ Z = [Z_1, Z_2, Z_3, Z_4] = [\iota_l, 0_{l \times b}, I_l, I_l] \]

where

- \( \iota_p \) is a \( l \times 1 \) vector of 1’s
- \( I_n \) is a \( n \times n \) identity matrix.

This means that \( Z\alpha_t = \tilde{y}_t + \nu_t + \varepsilon_t = \text{“Truth” + “News” + “Noise”} \)

Note: Resembles a factor model.
A State-Space Model

Partitioning: Transition Equation

\[ \alpha_{t+1} = T\alpha_t + R\eta_t \]

\[ \alpha_t = [\tilde{y}_t, \phi'_t, \nu'_t, \varepsilon'_t]' \]

\[ \eta_t = [\eta'_{1t}, \eta'_{2t}, \eta'_{3t}]' \]

\[ T = \begin{bmatrix} T_{11} & T_{12} & 0 & 0 \\ T_{21} & T_{22} & 0 & 0 \\ 0 & 0 & T_3 & 0 \\ 0 & 0 & 0 & T_4 \end{bmatrix} \]

\[ R = \begin{bmatrix} R_1 & R_3 & 0 \\ R_2 & 0 & 0 \\ 0 & -U_1 \cdot \text{diag}(R_3) & 0 \\ 0 & 0 & R_4 \end{bmatrix} \]

- \( U_l \) is a \( l \times l \) matrix with zeros below the main diagonal and ones everywhere else.

- \( R_3 = [\sigma_{\nu 1}, \sigma_{\nu 2}, \ldots, \sigma_{\nu l}] \) and \( \text{diag}(R_3) \) is a \( l \times l \) matrix with elements of \( R_3 \) on its main diagonal.
A State-Space Model

Notes

- We do not assume that the last available estimate has no measurement error (i.e. that $y_{t+l} = \tilde{y}_t$.) Instead, $[\tilde{y}_t, \phi_t]$ and $(T_{11}, T_{21}, T_{12}, T_{22}, R_1, R_2, R_3)$ define dynamics of latent "true" values.

- Dynamics sufficiently general to handle any ARIMA or structural time-series model.
  Example in paper shows a local linear trend with stochastic cyclic dynamics (e.g. Harvey-Jaeger.)

Let’s consider some special cases to understand how this structure works
**Measurement Errors: Pure Noise**

\[ \alpha_t = \begin{bmatrix} \tilde{y}_t \\ \phi_t \\ \epsilon_t \end{bmatrix} \quad T = \begin{bmatrix} T_{11} & T_{12} & 0 \\ T_{21} & T_{22} & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad R = \begin{bmatrix} R_1 & 0 \\ R_2 & 0 \\ 0 & R_4 \end{bmatrix} \]

Pure Noise implies that measurement errors are independent of those in neighbouring vintages, so \( \mathbb{E}(u_t u'_t) \) is a diagonal matrix. This means

\[ R_4 \equiv \begin{bmatrix} \sigma_{\epsilon 1} & 0 & \cdots & 0 \\ 0 & \sigma_{\epsilon 2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_{\epsilon l} \end{bmatrix} \]

Estimates become more precise over time \( \iff \sigma_{\epsilon l} < \sigma_{\epsilon, l-1} < \ldots < \sigma_{\epsilon 1} \).
Measurement Errors: Pure News

Pure News requires

1. revisions \((y^{t+j}_t - y^{t+j+k}_t)\) are unpredictable given \(\Omega_{t+j}\)

2. \(V(u^j_t)\) nonincreasing as we increase \(j\).

3. \(V(y^j_t)\) nondecreasing as we increase \(j\).
To impose these properties, we set

\[
\alpha_t = \begin{bmatrix} \tilde{y}_t \\ \phi_t \\ \nu_t \end{bmatrix}, \quad T = \begin{bmatrix} T_{11} & T_{12} & 0 \\ T_{21} & T_{22} & 0 \\ 0 & 0 & 0 \end{bmatrix}, \quad R = \begin{bmatrix} R_1 & R_3 \\ R_2 & 0 \\ 0 & -U_1 \cdot \text{diag}(R_3) \end{bmatrix}
\]

This means

\[
\tilde{y}_t = T_{11} \cdot \tilde{y}_{t-1} + T_{12} \cdot \phi_{t-1} + R_1 \eta_{1t} + R_3 \eta_{2t}
\]

and

\[
\nu_t = -U_1 \cdot \text{diag}(R_3) \cdot \eta_{2t} \equiv -\begin{bmatrix} \sigma_{\nu_1} & \sigma_{\nu_2} & \cdots & \sigma_{\nu_l} \\ 0 & \sigma_{\nu_2} & \cdots & \cdots \\ \vdots & \cdots & \cdots & \sigma_{\nu_l} \\ 0 & \cdots & 0 & \sigma_{\nu_l} \end{bmatrix} \cdot \eta_{2t}
\]
Measurement Errors: Spillovers

Spillovers are independent of news or noise.

Accordingly, spillovers have no implications for the form of $R_3$ or $R_4$. Captured instead via $T_3$ or $T_4$.

**Simplest case:** $T_4 = \rho I_l$ where $\rho$ is the correlation $(u_t, u_{t-1})$.

Can model higher-order effects by stacking successive values of $u_t$ into the state vector.
Measurement Errors: General Cases

- We can have any arbitrary combination of spillover, noise and news effects.
- Spillovers may differ for news and for noise.
- Noise need not be i.i.d. across vintages – could allow $R_4$ to be an unrestricted matrix.
Application

• Real output series of the Philadelphia Federal Reserve Board
• Growth rates (first difference of logs)
• 153 observations, variable number of vintages
• Dynamics of true values: AR process
• Noise + News model
• No spillovers (yet)
### AR(2) model with noise; 4 vintages

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>T[1,1]</td>
<td>0.4103</td>
<td>0.0819</td>
<td>0.2484</td>
<td>0.5721</td>
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<tr>
<td>T[1,2]</td>
<td>0.0426</td>
<td>0.0823</td>
<td>-0.1200</td>
<td>0.2052</td>
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<tr>
<td>ARSigma</td>
<td>0.9074</td>
<td>0.0523</td>
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<tr>
<td>RNoise1</td>
<td>0.2387</td>
<td>0.0152</td>
<td>0.2087</td>
<td>0.2688</td>
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<tr>
<td>Rnoise2</td>
<td>0.1028</td>
<td>0.0097</td>
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<td>0.1219</td>
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<tr>
<td>Rnoise3</td>
<td>0.0726</td>
<td>0.0112</td>
<td>0.0506</td>
<td>0.0947</td>
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<tr>
<td>Rnoise4</td>
<td>0.1569</td>
<td>0.0105</td>
<td>0.1362</td>
<td>0.1776</td>
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</tbody>
</table>

Number of cases: 153
### AR(2) model with news; 4 vintages

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Standard Error</th>
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<tr>
<td>$T[1,1]$</td>
<td>0.2167</td>
<td>0.1657</td>
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<td>$T[1,2]$</td>
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<td>0.3466</td>
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<td>RNews1</td>
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<td>RNews2</td>
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<td>RNews3</td>
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Number of cases: 153
AR(2) model with news and noise; 4 vintages

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<th>Parameter</th>
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<tr>
<td>T[1,1]</td>
<td>0.3941</td>
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<td>T[1,2]</td>
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<td>RNoise3</td>
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Number of cases: 153
### AR(4) model with noise; 12 vintages

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<tr>
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<tbody>
<tr>
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Number of cases: 153
# AR(4) model with news; 12 vintages

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<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>T[1,1]</td>
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</tr>
<tr>
<td>T[1,3]</td>
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Number of cases: 153
AR(4) model with news and noise; 12 vintages
Conclusions and Tour d’Horizon

Integrated State-Space Framework allows for 3 important kinds of measurement errors.

Also allows for true values that are never observed.

Applications:
- Estimation and Testing of Revision Structures
- Optimal Estimation (and Forecasting) of Recent Trends and Cycles
- More Robust Confidence Intervals
- Pursuing applications to Business Cycles and Productivity Growth Trends
The Society for Computational Economics announces

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