Assessing the Economic Impacts of Weather and Value of Weather Forecasts

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Some Things to Mention

• A note of thanks … Caio, Barb, Manifred, others
• Talk on Monday focuses on the *Weather Information Value Chain* and includes some different examples of economics than this talk does
• A note on color blindness … apologies

• Meteorologist verification economics
Meteorologist relevant economics

Please raise your hand if you work for a *private* sector company that makes its money by *selling* products and services (i.e., you *do not* work for the government, a university or research institute, or non-profit organization).

Please raise your hand if you work for a *public* enterprise that gets its funding mainly from the government or other public source (i.e., you do work for the government, a university or research institute, or non-profit organization).
Meteorologist relevant economics

Scenario ... The Minister of Finance of the Country of Hypothetica is deciding how to allocate the 2018 Budget across all agencies ...

By some weird accident of history there are two agencies in Hypothetica providing technically identical hydro-met information ...

The Minister of Finance has indicated this will stop and he will only fund one agency heretofore, forthwith, and from now on and on ...

He calls the Directors in to make their case!
The Director of Popular National Hydrological and Meteorological Services of Hypothetica makes his case (we will call him Director A)

“Our new models have 3 KM grid resolution with 17 vertical layers at 15 second time steps. We have new D-band radar, verify at 23.5% at the 500mb level, and have a lead time for barometric pressure of 13.2 minutes ... We are the best!”
The Director of Peoples National Hydrological and Meteorological Services of Hypothetica makes his case (we will call him Director B)

“Using our new models led to warnings that saved 152 lives during last month’s floods. Forecasts save the airline industry $20 million a month on fuel costs and helped reduce drought impacts in Southern Hypothetica preventing 1,251 farmers from loosing their crops and livestock … We are the best!”
Who makes the better argument as far the Minister of Finance is concerned?
Did I mention he has a bachelor’s degree in the Fine Arts?
Did I mention your job depends this?

A. Director A (500 MB skill score)

B. Director B (152 lives saved)
Objectives

• Why should weather people care about economics?
• Cost-Loss Modeling
• What is economics? What is “value” (in economics)?
• Relationship of economics to verification and the Weather Information Value Chain
• Examples of economics and weather
• Some final thoughts …
Why Economics and Weather?

US National Weather Service

- Mission: Provide weather, water, and climate data, forecasts and warnings for the protection of life and property and enhancement of the national economy
- Goals that focus on critical weather-dependent issues:
  - Improve sector-relevant information in support of economic productivity;
    (http://www.nws.noaa.gov/com/weatherreadynation/files,strategic_plan.pdf)

World Meteorological Organization

- The vision of WMO is to provide world leadership in expertise and international cooperation in weather, climate, hydrology and water resources and related environmental issues and thereby contribute to the safety and well-being of people throughout all nations
  (http://www.wmo.int/pages/about/mission_en.html)

Lesotho Meteorological Services

- Mission Statement: To improve the livelihood of Basotho through effective application of the science of Meteorology and harmonization of their socio-economic activities with weather and climate
  (http://www.lesmet.org.ls/about-us.htm)

Do weather agencies “verify” their mission?
Cost-Loss Model

Model used extensively in the meteorology literature to explain the value of a forecast

In the simplest version - decision framework where there are:

- Two possible weather outcomes
  - Adverse weather - with probability $p$
  - No adverse weather - with probability $(1-p)$
  - $P$ - initially based on climatology, persistence, or ...

- Two available decision actions
  - Protect at cost = $C$
  - Do not protect at cost = 0

- If adverse weather and not protected there is a loss = $L$
Decision is to protect or not protect based on maximizing the expected value (or minimizing the expected cost) of the decision.

- If Protect the “expected value” is simply the cost $= C$
- If Do Not Protect the “expected value” is the probability of a loss times the loss $= p*L + (1-p)*0 = p*L$
- “expected value” over a large number of realizations – ex ante decision (not necessarily repeated decision)

<table>
<thead>
<tr>
<th>Action</th>
<th>Adverse Wx</th>
<th>No Adverse Wx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protect</td>
<td>$C$</td>
<td>$C$</td>
</tr>
<tr>
<td>Do Not Protect</td>
<td>$L$</td>
<td>$0$</td>
</tr>
</tbody>
</table>
Cost-Loss Model

<table>
<thead>
<tr>
<th>Action</th>
<th>Weather Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adverse Wx</td>
</tr>
<tr>
<td>Protect</td>
<td>C</td>
</tr>
<tr>
<td>Do Not Protect</td>
<td>L</td>
</tr>
</tbody>
</table>

- Decision Context: Maximize Expected Value
- Decision Context: Minimize Expected Loss
- Chose Action = \(\min(C, p \times L)\)
- Protect if \(C < p \times L\)
  
  rearranging \(\frac{C}{L} < p\)
Example

- Decision context: whether to de-ice airplanes at the airport in the event of freezing weather (T<32F)
- It costs $10,000 per plane to de-ice and 100 planes a day –
  \[ C = \$10,000 \times 100 = \$1,000,000 \]
- If you don’t de-ice and (T>32F) then no freezing – no cost and no loss
- If you don’t de-ice and (T<32F) then freezing – 1 out every 100 planes crashes (one a day) – 200 people on board - $6M/person VSL – Loss = $1.2 B
- Climatology: (T<32F) on 36.5 days/yr … \( p = \frac{36.5}{365} = 0.10 \)
- Decision Rule: Protect if \( C < p \times L \) or if \( \frac{C}{L} < p \)
- Protect if \$1 \text{M} < 0.10 \times \$1.2 \text{B} \quad \text{... Protect if \$1 \text{M} < \$120 \text{M}} \)
- or if \$1M/$1.2 \text{B} < 0.10 \quad \text{... Protect if 0.0008333 < 0.10} \)
- Total Cost of Decision = 365 days * \$1\text{M/day} = \$365 \text{M/yr}

<table>
<thead>
<tr>
<th>Action</th>
<th>Weather Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T&lt;32F</td>
</tr>
<tr>
<td>De-Ice</td>
<td>$1 \text{M}</td>
</tr>
<tr>
<td>Don’t De-Ice</td>
<td>$1.2 \text{B}</td>
</tr>
</tbody>
</table>

Example

Weather Outcomes

<table>
<thead>
<tr>
<th>T&lt;32F</th>
<th>T&gt;32F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \text{M}$</td>
<td>$1 \text{M}$</td>
</tr>
<tr>
<td>$1.2 \text{B}$</td>
<td>$0$</td>
</tr>
</tbody>
</table>
Example – Perfect Forecast

- Decision Rule: Protect if Forecast (T<32) – so protect 36.5 days a year
- Perfect Forecast (T>32F) – no de-icing – no cost and no loss
- Perfect Forecast: (T<32) on 36.5 days/yr
- Total Cost of Decision = 36.5 days * $1M/day = $36.5 M/yr

<table>
<thead>
<tr>
<th>Annual Cost (Climatology)</th>
<th>$365.0 M/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Cost (Perfect Forecast)</td>
<td>$ 36.5 M/yr</td>
</tr>
</tbody>
</table>

Value of Perfect Forecast $ 328.5 M/yr

<table>
<thead>
<tr>
<th>Action</th>
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<tbody>
<tr>
<td></td>
<td>T&lt;32F</td>
</tr>
<tr>
<td>De-Ice</td>
<td></td>
</tr>
<tr>
<td>Don’t De-Ice</td>
<td>NA</td>
</tr>
</tbody>
</table>
### Cost-Loss Model

<table>
<thead>
<tr>
<th>Action</th>
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<tr>
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<td>L</td>
</tr>
</tbody>
</table>

- **Value of forecast**
- **Improvement over “counterfactual”**
  - Climatology
  - Persistence
  - Existing forecast system
- **Add information on forecast probabilities on the weather outcomes**
Cost-Loss Model

<table>
<thead>
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<td></td>
</tr>
<tr>
<td>Do Not Protect</td>
<td>L</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

- Extensions
  - Risk aversion
  - Probabilistic information
  - Various distributions of forecast information
  - Various measures of forecast quality
  - Repeated decision making – dynamic
  - Many extensions ...

Cost-Loss Model

- Cost
- Loss

Weather Outcomes

- Adverse Wx
- No Adverse Wx

Cost-Loss Table:

<table>
<thead>
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<th>Action</th>
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<td>C</td>
</tr>
<tr>
<td>Do Not Protect</td>
<td>L</td>
<td>0</td>
</tr>
</tbody>
</table>
• **Cost-Loss Model**
  • Related more to decision analysis than “economics”

• **Limitations of the Cost-Loss Model**
  • Realism of decision context?
  • Decisions are not categorical
  • Forecasts are not categorical
  • What are the costs? Where does that info come from?
  • What are the losses? Where does that info come from?
  • Lazo WCAS editorial

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<td></td>
</tr>
<tr>
<td>Do Not Protect</td>
<td>L</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

- **Cost-Loss Model**
- **Limitations of the Cost-Loss Model**
- **Weather Outcomes**
- **Decision Context**
- **Costs and Losses**
- **Information Sources**
- **Lazo WCAS editorial**
Verification Analysis of Cost-Loss Model

References

<table>
<thead>
<tr>
<th>References</th>
<th>Economics</th>
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<tbody>
<tr>
<td>21</td>
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<tr>
<td>9</td>
<td>0</td>
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<tr>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>2</td>
</tr>
<tr>
<td><strong>111</strong></td>
<td><strong>4</strong></td>
</tr>
</tbody>
</table>

  - 9 references
  - 20 references
  - 20 references
  - 5 references
  - 21 references
  - 36 references – 2 economics
  - Econ references are from econometric journal on a type of regression analysis – not really on economics
Relationship of economics to verification

• User relevant verification
  – Who are the users
  – What is relevant to them
  – How do we measure that
  – How do we use user-relevant verification to improve forecasting?
Relationship of economics to verification

- **Impact based warning**
  - Forecast - severe weather and 10 people will die in the storm tomorrow.
  - Impacts Forecast A - 10 die
  - Impacts Forecast B - 0 die
  - Which forecast “verifies”?
  - Which is the better forecast?
Good forecast or bad forecast?
Valuable forecast or valueless forecast?

Is there a relationship between “Good Forecast” and “Valuable forecast”? What is the relationship between “Good Forecast” and “Valuable forecast”?
Valuable forecast or valueless forecast?

If I’m a water manager for this watershed, it’s a **valueless** forecast...

If I’m a water manager for this watershed, it may be an **expensive** forecast...
Valuable forecast or valueless forecast?

If I’m an aviation traffic strategic planner...

It might be a **valuable** forecast
Valuable forecast or valueless forecast?
Barb Brown Corollary

- Brown Corollary 1: If it is worth forecasting it is worth verifying

- Corollary 1b: If it is worth verifying ... what is it worth?
What is the weather information value chain?

- Conceptual model of the value creation process
- Emphasize this is *not* linear in the real world!
- End-to-end-to-end
  - This doesn’t show feedbacks, loops, discontinuities ...
What is economics?

Economics is ...

... a science
  – theory based
  – diverse methodologies
  – focus on empirical analysis

... a social science
  – a study of human behavior
  – a theory of value
  – focus on understanding choices between options
What does economic value mean?

Economic welfare is measured by individual utility.

The “consumer problem:”

\[ \max U(\bar{X}) \text{ subject to } \bar{P}'\bar{X} \leq Y \]

- \( U \) is the utility function
- \( \bar{P} \) is the vector of prices
- \( \bar{X} \) is a vector of goods and services
- \( Y \) is income

By substituting the utility maximizing demands for \( \bar{x} \) into \( U \) (the “direct utility function”) we can derive the “indirect” utility function:

\[ U = V(\bar{P}, Y) \]

Maximum utility attainable at given prices, \( \bar{P} \), and income, \( Y \).
What does economic value mean?

\[ U = V(\bar{P}, Y) \]

Indirect utility function has arguments in prices, \( \bar{P} \), and income, \( Y \). Can add "W" as weather - taken as an exogenous "given" argument in \( V \).

\[ U = V(\bar{P}, Y | W) \]

Maximum utility attainable at given prices, \( \bar{P} \), income, \( Y \), and weather \( W \).

Given initial \( \bar{P}^0, Y^0 \), and \( W^0 \) achieve:

\[ U^0 = V(\bar{P}^0, Y^0 | W^0) \]

Suppose now weather changes from \( W^0 \) to \( W^1 \). What is the change in well-being?

- Measured by the change in income needed to leave the individual at the same level of utility prior to the change in weather.
- Willingness-to-Pay (WTP)

\[ U^0 = V(\bar{P}^0, Y^0 | W^0) = V(\bar{P}^0, Y^0 - WTP | W^1) \]

WTP is the maximum amount of income individual is willing to give up (can be negative) to get a good (or to avoid a bad).
What does economic value mean?

Decision making under uncertainty: Value of Information (VOI)

Suppose now weather forecast quality is at initial level: \( I^0 \).

\[
U^0 = V \left( \bar{P}^0, Y^0 \mid W^0, I^0 \right)
\]

Weather forecast quality changes from \( I^0 \) to \( I^1 \).

\[
U^1 = V \left( \bar{P}^0, Y^0 \mid W^0, I^1 \right)
\]

Weather doesn’t change just because forecast quality does \( (W^0) \).

What is the change in well-being?

• Measured by the change in income needed to leave the individual at the same level of utility prior to the change in weather

• Willingness-to-Pay (WTP) for improved weather forecast accuracy:

\[
U^0 = V \left( \bar{P}^0, Y^0 \mid W^0, I^0 \right) = V \left( \bar{P}^0, Y^0 - WTP \mid W^0, I^1 \right)
\]

• “Better” information factors into ability to make better informed decisions

• Decision theory or more specific models can develop the “how” better information improves decisions to generate value.
What sorts of economic questions can be asked (and hopefully answered) about weather and weather forecasts?

1. What is the economic impact of weather?
2. What is the value to the general public of current weather forecasts?
3. What is the value of improving the accuracy of hurricane forecasts?
4. What is the benefit of investment in research to improve forecasts?
1. ECONOMIC IMPACT OF WEATHER

Dutton (BAMS 2002)

“... the third column lists the contribution to the GDP of industries with a (subjectively determined) weather sensitivity on operations, demand, or price.”

<table>
<thead>
<tr>
<th>Industries (1987 standard industrial classification)</th>
<th>GDP components ($ billion)</th>
<th>Weather sensitive components ($ billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture, forestry, and fishing</td>
<td>135.8</td>
<td>135.8</td>
</tr>
<tr>
<td>Farms</td>
<td>79.0</td>
<td>79.0</td>
</tr>
<tr>
<td>Agricultural services, forestry, and fishing</td>
<td>56.7</td>
<td>56.7</td>
</tr>
<tr>
<td>Mining</td>
<td>127.1</td>
<td>109.6</td>
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<tr>
<td>Coal mining</td>
<td>10.1</td>
<td>10.1</td>
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<tr>
<td>Oil and gas extraction</td>
<td>99.5</td>
<td>99.5</td>
</tr>
<tr>
<td>Other mining</td>
<td>17.5</td>
<td>0.0</td>
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<tr>
<td>Construction</td>
<td>463.6</td>
<td>463.6</td>
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<tr>
<td>Manufacturing</td>
<td>1,566.6</td>
<td>—</td>
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<tr>
<td>Transportation and public utilities</td>
<td>825.0</td>
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<tr>
<td>Transportation</td>
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<tr>
<td>Railroad transportation</td>
<td>22.9</td>
<td>22.9</td>
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<tr>
<td>Local and interurban passenger transit</td>
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<td>18.7</td>
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<tr>
<td>Trucking and warehousing</td>
<td>126.0</td>
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<tr>
<td>Water transportation</td>
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<td>14.8</td>
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<td>Transportation by air</td>
<td>93.0</td>
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<tr>
<td>Other transportation</td>
<td>38.5</td>
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<tr>
<td>Communications</td>
<td>261.1</td>
<td>281.1</td>
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<tr>
<td>Electric, gas, and sanitary services</td>
<td>230.0</td>
<td>230.0</td>
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<tr>
<td>Wholesale trade</td>
<td>674.1</td>
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<tr>
<td>Retail trade</td>
<td>893.9</td>
<td>893.9</td>
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<td>Finance, insurance, and real estate</td>
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<td>Security and commodity brokers</td>
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<tr>
<td>Insurance carriers</td>
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<td>Other finance, insurance, real estate</td>
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<td>Services</td>
<td>2,144.6</td>
<td>261.2</td>
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<tr>
<td>Hotels and other lodging places</td>
<td>96.5</td>
<td>96.5</td>
</tr>
<tr>
<td>Auto repair, services, and parking</td>
<td>93.9</td>
<td>93.9</td>
</tr>
<tr>
<td>TOTAL GROSS DOMESTIC PRODUCT</td>
<td>9,872.9</td>
<td>3,859.1</td>
</tr>
</tbody>
</table>
What is Weather Sensitivity?

\[ S(K^0, L^0, E^0; W^0) \]

\[ S(K^0, L^0, E^0; W^1) \]

\[ D(W^1) \]

\[ D(W^0) \]

\[ \text{Change in GSP} \]

\[ \text{GSP} \]

\[ Q^* \]

\[ Q^1 \]
transcendental logarithmic (translog) functional form

\[
\ln GSP_{it} = \alpha_i + \beta + \sum_{k=1}^{N} \ln X_{kit} + \frac{1}{2} \sum_{k=1}^{N} \sum_{l=1}^{N} \gamma_{k1} \ln X_{kit} \ln X_{lit} + \epsilon_{it}
\]

**GSP** – Gross State Product

**X** – economic & weather inputs (K, L, E, Temp, Precip) (indexed with \( k \))

\( i \) – state

\( t \) – year

\( \alpha \) – state specific fixed effects

\( \delta \) – “technological change”

GSP: value added, is equal to its gross output (sales or receipts and other operating income, commodity taxes, and inventory change) minus its intermediate inputs (consumption of goods and services purchased from other U.S. industries or imported)
Economic Modeling

Output elasticity of a productive input or weather variable \( k \)

\[
\frac{\partial \ln GSP_{it}}{\partial \ln X_{kit}} = \beta_k + \sum_{l=1}^{N} \gamma_{kl} \ln X_{lit}
\]

Percent change in output due to percent change in input accounting for all main and cross effects (productive input or weather variable \( k \))

Calculated variance of estimated output elasticities to calculate t-stats

A statistically significant estimate will suggest that an input does have an effect on output ...
Data

**Economic Data** - state x year x sector

Gross State Product (dependent variable)

**Production Inputs**
- Capital (K) - dollars
- Labor (L) - hours
- Energy (E) – BTUs

**Weather Data** - state x year

**Temperature Variability**
- CDD : Cooling Degree Days: (T - 65) on a given day
- HDD : Heating Degree Days: (65 - T) on a given day

**Precipitation**
- P_Tot: Precipitation Total (per square mile)
- P_Std: Precipitation Standard Deviation

i = state 48
j = sector 11
t = year 1977-2000 = 24 years
48 x 11 x 24 = 12,672 “observations”
### Super Sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>2000 GDP (Billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>98</td>
</tr>
<tr>
<td>Communications</td>
<td>458</td>
</tr>
<tr>
<td>Construction</td>
<td>436</td>
</tr>
<tr>
<td>Finance-Insurance-Real Estate (FIRE)</td>
<td>1,931</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>1,426</td>
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<tr>
<td>Mining</td>
<td>121</td>
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<tr>
<td>Retail Trade</td>
<td>662</td>
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<tr>
<td>Services</td>
<td>2,399</td>
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<tr>
<td>Transportation</td>
<td>302</td>
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<tr>
<td>Utilities</td>
<td>189</td>
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<tr>
<td>Wholesale Trade</td>
<td>592</td>
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<tr>
<td>Total Private Sector</td>
<td>8,614</td>
</tr>
<tr>
<td>Government</td>
<td>1,135</td>
</tr>
<tr>
<td>Total GDP</td>
<td>9,749</td>
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</tbody>
</table>
Econometric Methods

\[
\ln GSP_{it} = \alpha_i + \beta + \sum_{k=1}^{N} k \ln \text{kit} + \frac{1}{2} \sum_{k=1}^{N} \sum_{l=1}^{N} \gamma_{k1} \ln X_{kit} \ln \text{lit} + \varepsilon_{it}
\]

• Heteroskedasticity – non-constant error term

• Serial correlation – panel data

• Fixed Effects – state level variation not accounted for in our explanatory variables (Hausman test)

FGLS – Feasible Generalized Least Squares – mixed mode (fixed effects and autoregressive (AR1)) corrected for heteroskedasticity
### “Economic Input” Elasticities

(Blue box indicates significant at 10%)

\( \frac{\partial \ln GSP}{\partial \ln X} \)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Capital</th>
<th>Labor</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>1.10</td>
<td>0.44</td>
<td>-0.01</td>
</tr>
<tr>
<td>Communications</td>
<td>1.12</td>
<td>0.31</td>
<td>-0.14</td>
</tr>
<tr>
<td>Construction</td>
<td>0.48</td>
<td>1.14</td>
<td>0.12</td>
</tr>
<tr>
<td>FIRE</td>
<td>0.98</td>
<td>0.39</td>
<td>-0.20</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.48</td>
<td>0.62</td>
<td>0.09</td>
</tr>
<tr>
<td>Mining</td>
<td>1.20</td>
<td>0.60</td>
<td>0.10</td>
</tr>
<tr>
<td>Retail Trade</td>
<td>0.91</td>
<td>0.54</td>
<td>-0.04</td>
</tr>
<tr>
<td>Services</td>
<td>0.94</td>
<td>0.64</td>
<td>-0.07</td>
</tr>
<tr>
<td>Transportation</td>
<td>0.94</td>
<td>0.33</td>
<td>0.07</td>
</tr>
<tr>
<td>Utilities</td>
<td>1.11</td>
<td>-0.31</td>
<td>-0.03</td>
</tr>
<tr>
<td>Wholesale</td>
<td>0.50</td>
<td>0.78</td>
<td>-0.02</td>
</tr>
</tbody>
</table>
## “Weather Input” Elasticities

\[ \frac{\partial \ln GSP}{\partial \ln X} \]

(Blue box indicates significant at 10%)

<table>
<thead>
<tr>
<th>Sector</th>
<th>HDD</th>
<th>CDD</th>
<th>Total Precip</th>
<th>Precip Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.00</td>
<td>-0.19</td>
<td>0.28</td>
<td>-0.12</td>
</tr>
<tr>
<td>Communications</td>
<td>0.13</td>
<td>0.06</td>
<td>0.06</td>
<td>0.17</td>
</tr>
<tr>
<td>Construction</td>
<td>-0.01</td>
<td>0.06</td>
<td>-0.01</td>
<td>0.26</td>
</tr>
<tr>
<td>FIRE</td>
<td>0.15</td>
<td>0.06</td>
<td>0.54</td>
<td>-0.08</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.18</td>
<td>0.02</td>
<td>0.49</td>
<td>-0.22</td>
</tr>
<tr>
<td>Mining</td>
<td>0.25</td>
<td>0.04</td>
<td>-3.52</td>
<td>1.10</td>
</tr>
<tr>
<td>Retail Trade</td>
<td>0.04</td>
<td>0.03</td>
<td>-0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Services</td>
<td>0.04</td>
<td>0.00</td>
<td>0.33</td>
<td>-0.05</td>
</tr>
<tr>
<td>Transportation</td>
<td>-0.03</td>
<td>0.01</td>
<td>-0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Utilities</td>
<td>0.00</td>
<td>0.08</td>
<td>-0.59</td>
<td>-0.28</td>
</tr>
</tbody>
</table>
Weather Sensitivity Analysis

Goal: evaluate how GSP varies as a result of variation in weather

\[ \ln GSP_{it} = \alpha_i + \beta + \sum_{k=1}^{N} \ln kit + \frac{1}{2} \sum_{k=1}^{N} \sum_{l=1}^{N} \gamma_{k1} \ln X_{kit} \ln lit + \epsilon_{it} \]

11 Sector Models:

\[ Q = f(K, L, E; W; Year, State) \]

• average K, L, E over 1996-2000
• set ‘Year’ to 2000
• run historical weather data 1931-2000 through each sector model for each state
• fitted GSP values by sector by state by year
  – 11 sectors
  – 48 states
  – 70 “years” of state-sector GSP fitted to year 2000 “economic structure”
### Aggregated by State
(Billions $2000)

<table>
<thead>
<tr>
<th>State</th>
<th>Mean</th>
<th>Max</th>
<th>Min</th>
<th>Range</th>
<th>% Range</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>633.3</td>
<td>679.6</td>
<td>594.0</td>
<td>85.6</td>
<td>13.5%</td>
<td>1</td>
</tr>
<tr>
<td>Alabama</td>
<td>92.0</td>
<td>93.9</td>
<td>81.7</td>
<td>12.2</td>
<td>13.3%</td>
<td>2</td>
</tr>
<tr>
<td>California</td>
<td>1019.4</td>
<td>1080.5</td>
<td>968.6</td>
<td>111.9</td>
<td>11.0%</td>
<td>3</td>
</tr>
<tr>
<td>Wyoming</td>
<td>13.7</td>
<td>14.3</td>
<td>12.8</td>
<td>1.4</td>
<td>10.5%</td>
<td>4</td>
</tr>
<tr>
<td>Ohio</td>
<td>312.0</td>
<td>330.6</td>
<td>298.4</td>
<td>32.2</td>
<td>10.3%</td>
<td>5</td>
</tr>
<tr>
<td>Delaware</td>
<td>30.2</td>
<td>30.6</td>
<td>29.6</td>
<td>1.0</td>
<td>3.3%</td>
<td>44</td>
</tr>
<tr>
<td>Maine</td>
<td>27.0</td>
<td>27.4</td>
<td>26.5</td>
<td>0.9</td>
<td>3.3%</td>
<td>45</td>
</tr>
<tr>
<td>Montana</td>
<td>17.2</td>
<td>17.4</td>
<td>16.9</td>
<td>0.6</td>
<td>3.3%</td>
<td>46</td>
</tr>
<tr>
<td>Louisiana</td>
<td>109.5</td>
<td>111.2</td>
<td>107.6</td>
<td>3.6</td>
<td>3.3%</td>
<td>47</td>
</tr>
<tr>
<td>Tennessee</td>
<td>141.1</td>
<td>142.8</td>
<td>139.3</td>
<td>3.5</td>
<td>2.5%</td>
<td>48</td>
</tr>
</tbody>
</table>
Relative Sensitivity of State Economic Output to Weather Variability
## Aggregated by Sector

**(Billions $2000)**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Mean</th>
<th>Max</th>
<th>Min</th>
<th>Range</th>
<th>%Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholesale trade</td>
<td>601.5</td>
<td>607.8</td>
<td>594.5</td>
<td>13.3</td>
<td>2.20%</td>
</tr>
<tr>
<td>Retail trade</td>
<td>761.5</td>
<td>771.2</td>
<td>753.9</td>
<td>17.3</td>
<td>2.27%</td>
</tr>
<tr>
<td>FIRE</td>
<td>1,639</td>
<td>1,713.1</td>
<td>1,580.6</td>
<td>132.5</td>
<td>8.08%</td>
</tr>
<tr>
<td>Communications</td>
<td>237.3</td>
<td>243.4</td>
<td>232.3</td>
<td>11.1</td>
<td>4.68%</td>
</tr>
<tr>
<td>Utilities</td>
<td>212.9</td>
<td>220.8</td>
<td>206.0</td>
<td>14.9</td>
<td>6.98%</td>
</tr>
<tr>
<td>Transportation</td>
<td>276.1</td>
<td>280.7</td>
<td>271.0</td>
<td>9.8</td>
<td>3.53%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>1,524.8</td>
<td>1,583.2</td>
<td>1,458.2</td>
<td>125.1</td>
<td>8.20%</td>
</tr>
<tr>
<td>Construction</td>
<td>3,742.5</td>
<td>3,843.0</td>
<td>3,664.2</td>
<td>17.7</td>
<td></td>
</tr>
<tr>
<td><strong>Total National</strong></td>
<td><strong>7,692.0</strong></td>
<td><strong>7,813.9</strong></td>
<td><strong>7,554.2</strong></td>
<td><strong>258.7</strong></td>
<td><strong>3.36%</strong></td>
</tr>
</tbody>
</table>
Aggregate National Sensitivity

• Annual variability 3.36% variability (±1.7%) in annual US GDP
  – ~$485B variability (±$243B) of 2008 GDP ($14.44 T)
  – ~$532B variability (±$243B) of 2012 GDP ($15.85 T)
• Coefficient of variation (the standard deviation divided by the mean) is .0071 (7/10 of 1%)
• For 2008 US GDP
  – 68% of time less than ±$103B
  – 95% of time less than ±$205B
  – 0.2% of time more than ±$307B
    • Every 500 years more than ±1.9% of GDP
2. VALUE OF CURRENT FORECASTS

Objective
- What is the economic value of current weather forecasts?
- Back-of-the-envelope” estimate

Method
- Nationwide survey >1,500 respondents to assess
  • where, when, and how often they obtain weather forecasts
  • how they perceive forecasts
  • how they use forecasts
  • the value they place on current forecast information.

- Implemented online with restricted access to only invited participants

- Simplified valuation approach

The National Weather Service (NWS) is the primary source of weather forecasts, watches, and warnings for the United States. In addition to normal weather forecasts of precipitation, temperature, cloudiness, and winds, the NWS also provides:

- Severe weather (such as thunderstorms and tornadoes) forecasts, watches, and warnings
- Hurricane forecasts, watches, and warnings
- Fire weather forecasts, watches, and warnings
- Forecasts used for aviation and marine commerce

All this information is also provided to media (including television, radio, and newspapers) and private weather services (such as The Weather Channel). How important to you is the information provided by the NWS that is listed above?

<table>
<thead>
<tr>
<th>Not at all important</th>
<th>A little important</th>
<th>Somewhat important</th>
<th>Very important</th>
<th>Extremely important</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All of the activities of the National Weather Service (NWS) are paid for through taxes as a part of the federal government. This money pays for all of the observation equipment (such as satellites and radar), data analysis, and products of the NWS (including all the forecasts, watches, and warnings).

Suppose you were told that every year about $2 of your household's taxes goes toward paying for all of the weather forecasting and information services provided by the NWS. Do you feel that the services you receive from the activities of the NWS are worth more than, exactly, or less than $2 a year to your household?

- a) Worth more than $2 a year to my household
- b) Worth exactly $2 a year to my household
- c) Worth less than $2 a year to my household

Randomly used different $$$/yr with different respondents
2. VALUE OF CURRENT FORECASTS

2. VALUE OF CURRENT FORECASTS

Results

- value of current wx information ~$286 / household / year
- ~114,384,000 households in US (2006)
- $31.5 billion total per year value to U.S. households

- compares to U.S. public and private sector meteorology costs of $5.1 billion/yr
- benefit-cost ratio of 6.2 to 1.0

- Note: “back-of-the-envelope” approach used suggests need for better methods to derive current value estimates

3. VALUE OF IMPROVED FORECASTS

• **Objective**
  - evaluate households’ values for improved hurricane forecasts and warnings
  - Hurricane Forecast Improvement Project (HFIP)

• **Methods**
  - non-market valuation – conjoint analysis
  - survey development
    - expert input
    - focus groups
    - cognitive interviews
    - pre-tests
    - small sample pre-test (80 subjects) - Miami, FL.
    - full implementation
      - Online implementation – 1,218 responses
      - Gulf and Atlantic coast hurricane vulnerable areas up to N. Carolina

Chapter 3. VALUE OF IMPROVED FORECASTS
**CHOICES BETWEEN IMPROVEMENT PROGRAMS**

The table below shows two different programs, Program A and Program B, for improving hurricane forecasts. You are now being asked to compare all of one column (Program A) to all of the next column as a different program (Program B).

Please indicate which Program, if you had to choose, you would prefer.

**Program A** improves *landfall location* to within 25 miles from within 50 miles and would cost an additional $12 per year to your household. No other forecast characteristic would change.

**Program B** improves *time of expected landfall* to 4 hours from 5 hours, improves *landfall location* to within 25 miles from within 50 miles and would cost an additional $24 per year to your household.

<table>
<thead>
<tr>
<th>Accuracy of Current Forecasts</th>
<th>Program A</th>
<th>Program B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of landfall</td>
<td>accurate to within 5 hours</td>
<td>No change</td>
</tr>
<tr>
<td>Landfall location</td>
<td>within 50 miles</td>
<td>25 miles</td>
</tr>
<tr>
<td>Maximum wind speed</td>
<td>within 15 miles per hour</td>
<td>No change</td>
</tr>
<tr>
<td>Rapid changes in wind strength</td>
<td>forecast rapid changes if it occurs 20% of the time</td>
<td>No change</td>
</tr>
<tr>
<td>Storm surge depth</td>
<td>plus or minus 5 feet</td>
<td>No change</td>
</tr>
<tr>
<td>Storm surge information</td>
<td>no separate storm surge information</td>
<td>No change</td>
</tr>
<tr>
<td>Extended forecasts</td>
<td>5 days</td>
<td>No change</td>
</tr>
<tr>
<td>Increase in Annual Cost to Your Household</td>
<td>$12 per year</td>
<td>$24 per year</td>
</tr>
</tbody>
</table>

I would prefer (please click on the program you prefer)
3. Random Utility Model (RUM)

- utility is linear combination of choice attributes and a random error
  \[ U_{ij} = \beta' x_{ij} + \epsilon_{ij}, \quad i = A, B; \quad j = 1, ..., 8 \]

- \( U_{ij} \) = utility of alternative \( i \) in choice set \( j \)

- vector \( \beta \) are marginal utilities
  - For the cost attribute, \( \beta \) measures the marginal utility of money and is expected to be negative because increased cost implies decreased utility (or disutility).

- \( X = \)
  - accuracy of time of landfall
  - accuracy of projected location of landfall
  - accuracy of maximum wind speed
  - accuracy of wind speed change
  - accuracy of storm surge depth
  - provision of separate storm surge
  - extended forecast information
  - annual household cost

- \( \epsilon = \) random disturbance
3. VALUE OF IMPROVED FORECASTS

\[ U_{ij} = \beta' x_{ij} + \varepsilon_{ij}, \quad i = A, B; \quad j = 1, ..., 8 \]

Random Utility Model (RUM)

- \( \varepsilon \) assumed independent, identically distributed, mean zero normal random variables, uncorrelated with \( x_{ij} \), with constant unknown variance \( \sigma \)
- Under these assumptions, the probability of choosing program 1, for example, is:

\[
P_{ij}^1 = P\left( U_{ij}^1 > U_{ij}^2 \right) = \Phi \left[ \beta' \left( x_{ij}^1 - x_{ij}^2 \right) / \sqrt{2\sigma} \varepsilon \right]
\]

- univariate standard normal cumulative distribution function
- Probit model for dichotomous choice
3. VALUE OF IMPROVED FORECASTS

Option to remain at status quo level:

19. Would you prefer to keep forecast accuracy the way it is now with no increased costs to my household or stay with the Program you indicated above at the cost indicated?

- Keep forecast accuracy the way it is now with no increased costs to my household.
- Undertake the program chosen above at the cost indicated.

\[
P\left( U_{ij}^{k_{ij}} > U_{ij}^{3-k_{ij}}, U_{ij}^{k_{ij}} > U_{ij}^{0} \right) = \Phi_{2} \left[ -\beta' \left( x_{ij}^{3-k_{ij}} - x_{ij}^{k_{ij}} \right) / \sqrt{2}\sigma_{\epsilon}, -\beta' \left( x_{ij}^{0} - x_{ij}^{k_{ij}} \right) / \sqrt{\sigma_{0} + \sigma_{\epsilon}} ; \rho \right] \]

\(\rho\) is the correlation between \(\left( \varepsilon_{ij}^{3-k_{ij}} - \varepsilon_{ij}^{k_{ij}} \right)\) and \(\left( \varepsilon_{ij}^{0} - \varepsilon_{ij}^{k_{ij}} \right)\)

- \(\Phi_{2}\) is the standard bivariate normal cumulative distribution function.
- Normalization is required and an additional parameter is identified – normalize \(\sigma_{\epsilon}\)
3. VALUE OF IMPROVED FORECASTS

Conditional Probit (AB and SQ choices)

N= 1201 (out of 1218) respondents who answered all 8 choice questions.  
9605 responses (out of 8*1201 = 9608) responses (3 refusals of St. Quo question)

<table>
<thead>
<tr>
<th></th>
<th>Beta</th>
<th>t-stat</th>
<th>WTP</th>
<th>Unit</th>
<th>Range</th>
<th>WTP Max Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfall Time</td>
<td>-0.052</td>
<td>-9.41</td>
<td>$1.27</td>
<td>hours</td>
<td>2 - 5</td>
<td>$3.81</td>
</tr>
<tr>
<td>Landfall Location</td>
<td>-0.009</td>
<td>-13.92</td>
<td>$0.21</td>
<td>miles</td>
<td>25 - 50</td>
<td>$5.26</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>-0.005</td>
<td>-2.51</td>
<td>$0.11</td>
<td>mph</td>
<td>7-15</td>
<td>$0.90</td>
</tr>
<tr>
<td>Change in Wind Speed</td>
<td>0.007</td>
<td>13.70</td>
<td>$0.16</td>
<td>%</td>
<td>20 - 60</td>
<td>$6.49</td>
</tr>
<tr>
<td>Surge Depth</td>
<td>-0.007</td>
<td>-1.30</td>
<td>$0.17</td>
<td>feet</td>
<td>2 - 5</td>
<td>$0.50</td>
</tr>
<tr>
<td>Surge Information</td>
<td>0.035</td>
<td>1.83</td>
<td>$0.85</td>
<td>yes/no</td>
<td>0 - 1</td>
<td>$0.85</td>
</tr>
<tr>
<td>Extended Forecast</td>
<td>0.035</td>
<td>3.68</td>
<td>$0.86</td>
<td>days</td>
<td>5 - 7</td>
<td>$1.72</td>
</tr>
<tr>
<td>Cost</td>
<td>-0.041</td>
<td>-48.39</td>
<td>$0.86</td>
<td></td>
<td></td>
<td>$19.52</td>
</tr>
</tbody>
</table>

3. VALUE OF IMPROVED FORECASTS

• Results
  – significant marginal values for improved accuracy of landfall, timing, specificity, extended forecast, etc.
  – total WTP for this average overall superior forecast (from baseline to maximum levels on all attributes) is $19.52 per household per year
  – 9,857,371 households ... $192,421,599 total annual benefit?
4. VALUE OF RESEARCH TO IMPROVE FORECASTS

• Objective
  – perform benefit-cost analysis for a new supercomputer for research to improve weather forecasting

• Methods
  – several economic methods applicable to benefit-cost analysis
    (1) benefits transfer
    (2) survey-based nonmarket valuation
    (3) discounting
    (4) value of statistical life
    (5) expert elicitation
    (6) influence diagramming, and
    (7) sensitivity analysis

4. VALUE OF RESEARCH TO IMPROVE FORECASTS
4. VALUE OF RESEARCH TO IMPROVE FORECASTS

• Results
  - benefits to households, agriculture, aviation evaluated
  - average total benefits from these three sectors were estimated at $116 million in present value (2002 US dollars)
  - Net Present Value (present value of benefits minus costs)
    - 3% real rate of discount = $104.60 million (2003 US dollars)
    - 5% real rate of discount = $ 53.17 million (2003 US dollars)
  - internal rate of return = 21.82%

• Policy Analysis / Decision Making
  - meet OMB regulatory requirements for a benefit-cost analysis study of a significant investment in research infrastructure

Some Other Things to Mention ...

• Ethical Issues
  – Efficiency versus Equity

• World Bank / USAID / WMO Book on Socio-Economic Benefit Analysis
  – https://drive.google.com/file/d/0BwdvoC9AeWjUX2dJblR6WIbMybU0/view

• Social Sciences
  – Anthropology
  – Sociology
  – Communication
  – History
  – Law
  – Geography
  – Linguistics
  – Political Science
  – Psychology
Economics and Weather ...

• Why talk about economics of weather enterprise?

• What to value? (i.e., objective of an economic study)
  – Economic impact of weather
  – Value of current forecasts
  – Value of improved forecasts
  – Value of research to improve forecasts
  – Value of ...

• How to value? (i.e., methods)
  – Primary studies versus using existing data / research
  – Market valuation or non-market valuation
  – Survey research, econometric models, expert elicitation, ...

• What level of detail / sophistication? (i.e., resources)
  – $25k benefit-cost assessment to $1M benefit analysis

• What is information from the study going to be used for?
  – will the study provide the right information for decision making?
THANKS FOR LISTENING!

QUESTIONS?

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References (available on http://www.sip.ucar.edu/publications.php)