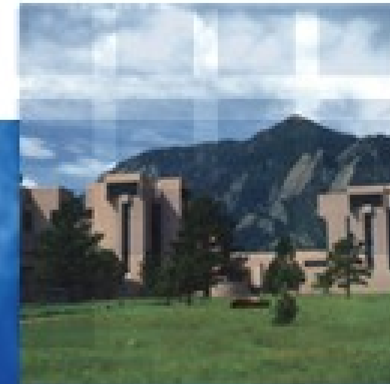
NCAR



Assessing the Economic Impacts of Weather and Value of Weather Forecasts

Jeffrey K. Lazo

Societal Impacts Program
National Center for Atmospheric Research
Boulder, CO. USA 80307

lazo@ucar.edu

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
- User-relevant economics

Meteorologist relevant economics

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

Please raise you hand if you work for a *<u>public</u>* enterprise that gets it's 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!

Meteorologist relevant economics

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!”

Meteorologist relevant economics

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!”

Meteorologist relevant economics

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)

Worl

- **The vision o … e and international cooperation … ces and related environmen … d well-being of people throu … all nations**

  (http://www.w

Do weather agencies "verify" their mission?

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)

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**

Cost-Loss Model

		Weather Outcomes	
		Adverse Wx	No Adverse Wx
Action	Protect	C	C
	Do Not Protect	L	0

- **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)**

Cost-Loss Model

		Weather Outcomes	
		Adverse Wx	No Adverse Wx
Acti on	Protect	C	C
	Do Not Protect	L	0

- **Decision Context: Maximize Expected Value**
- **Decision Context: Minimize Expected Loss**
- **Chose Action = min(C, p*L)**
- **Protect if $C < p*L$**

rearranging $C/L < p$

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 x 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 = 36.5/365 = 0.10
- Decision Rule: Protect if C < p*L or if C/L < p
- Protect if $1 M < 0.10 * $1.2 B … Protect if $1 M < $120 M
- or if $1M/$1.2 B < 0.10 … Protect if 0.0008333 < 0.10
- Total Cost of Decision = 365 days * $1M/day = $365 M/yr

		Weather Outcomes	
		T<32F	T>32F
Action	De-Ice	$1 M	$1 M
	Don't De-Ice	$1.2 B	$0

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**

Annual Cost (Climatology)	**$365.0 M/yr**
Annual Cost (Perfect Forecast)	**$ 36.5 M/yr**
Value of Perfect Forecast	**$ 328.5 M/yr**

		Weather Outcomes	
		T<32F	**T>32F**
Action	**De-Ice**	$1 M	NA
	Don't De-Ice	NA	$0

Cost-Loss Model

		Weather Outcomes	
		Adverse Wx	No Adverse Wx
Action	Protect	**C**	**C**
	Do Not Protect	**L**	**0**

- **Value of forecast**
- **Improvement over "counterfactual"**
  - **Climatology**
  - **Persistence**
  - **Existing forecast system**
- **Add information on forecast probabilities on the weather outcomes**

Cost-Loss Model

		Weather Outcomes	
		Adverse Wx	No Adverse Wx
Actio n	Protect	**C**	**C**
	Do Not Protect	**L**	**0**

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

Cost-Loss Model

		Weather Outcomes	
		Adverse Wx	No Adverse Wx
Actio n	Protect	**C**	**C**
	Do Not Protect	**L**	**0**

- **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**

Verification Analysis of Cost-Loss Model References

- Murphy, A.H., 1969. On Expected -Utility Measures in Cost-Loss Ratio Decision Situations. Applied Meteor
  - 9 referenc
- Murphy, A.H.,. uation and Measures of th w. 104:1058-1065.
  - 20 referen
- Murphy, Katz, \ he Value of Forecasts in th Weather Review. 113(5):801-813
  - 20 referen
- Richardson, D. kshop on Meteorological 1999 pp.209-213
  - 5 referenc
- Lee, K-K., and for decision-making proble 3 (2007). (www.interscie
  - 21 referen

References	Economics
21	0
9	0
20	2
20	0
5	0
36	2
111	4

- Verkade, J. S. a gle value and probability forecasting for flood warning. Hydrol. Earth Syst. Sci., 15, 3751–3765.
  - 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

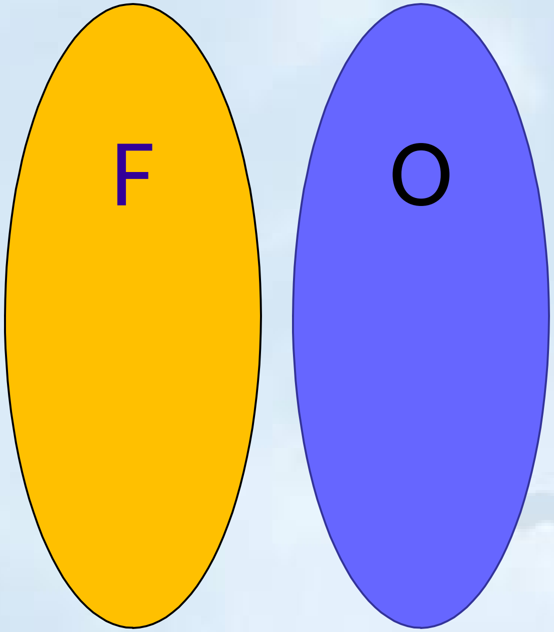
- **User relevant verification**
  - **Who are the users**
  - **What is relevant to them**
  - **How do we measure that**
  - **How do we use user-relevant verification to improve forecasting?**

Relationship of economics to verification

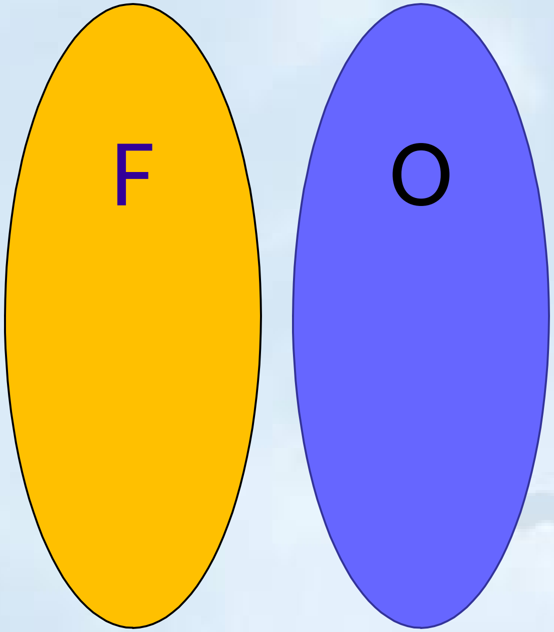
- **Impact based warning**
  - **Forecast - severe weather and 10 people will die in the storm tomorrow.**
  - **Impacts Forecast A – 10 die**
  - **Impacts Forecast B – 0 die**
  - **Which forecast “verifies”?**
  - **Which is the better forecast?**

```
903
WFUS53 KFSD 050022
TORFSD
IAC035-050100-
/O.NEW.KFSD.TO.W.0020.131005T0022Z-131005T0100Z/

BULLETIN - EAS ACTIVATION REQUESTED
TORNADO WARNING
NATIONAL WEATHER SERVICE SIOUX FALLS SD
722 PM CDT FRI OCT 4 2013

...TORNADO EMERGENCY FOR WASHTA...

THE NATIONAL WEATHER SERVICE IN SIOUX FALLS HAS IS

* TORNADO WARNING FOR...
  CHEROKEE COUNTY IN NORTHWEST IOWA...

* UNTIL 800 PM CDT

* AT 720 PM CDT...A LARGE AND EXTREMELY DANGEROUS
  LOCATED NEAR WASHTA...AND MOVING NORTHEAST AT 30

  THIS IS A TORNADO EMERGENCY FOR WASHTA. TAKE COV
  IS A PARTICULARLY DANGEROUS SITUATION.

  THIS IS A PARTICULARLY DANGEROUS SITUATION.

  HAZARD...DAMAGING TORNADO.

  SOURCE...EMERGENCY MANAGEMENT CONFIRMED TORNADO.

  IMPACT...YOU ARE IN A LIFE THREATENING SITUATION
           DEBRIS MAY BE DEADLY TO THOSE CAUGHT WI
           MOBILE HOMES WILL BE DESTROYED. CONSIDE
           TO HOMES...BUSINESSES AND VEHICLES IS L
           COMPLETE DESTRUCTION IS POSSIBLE.

* THE TORNADO WILL BE NEAR...
  QUIMBY AROUND 730 PM CDT.
  CHEROKEE AROUND 745 PM CDT.
  AURELIA AROUND 750 PM CDT.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

HEAVY RAINFALL MAY HIDE THIS TORNADO. DO NOT WAIT
THE TORNADO. TAKE COVER NOW.

&&
LAT...LON 4259 9585 4291 9565 4291 9550 4283 9538
      4269 9539 4256 9569 4256 9577
TIME...MOT...LOC 0023Z 225DEG 27KT 4260 9567

TORNADO...OBSERVED
TORNADO DAMAGE THREAT...CATASTROPHIC
```

Good forecast or bad forecast?



Valuable forecast or valueless forecast?



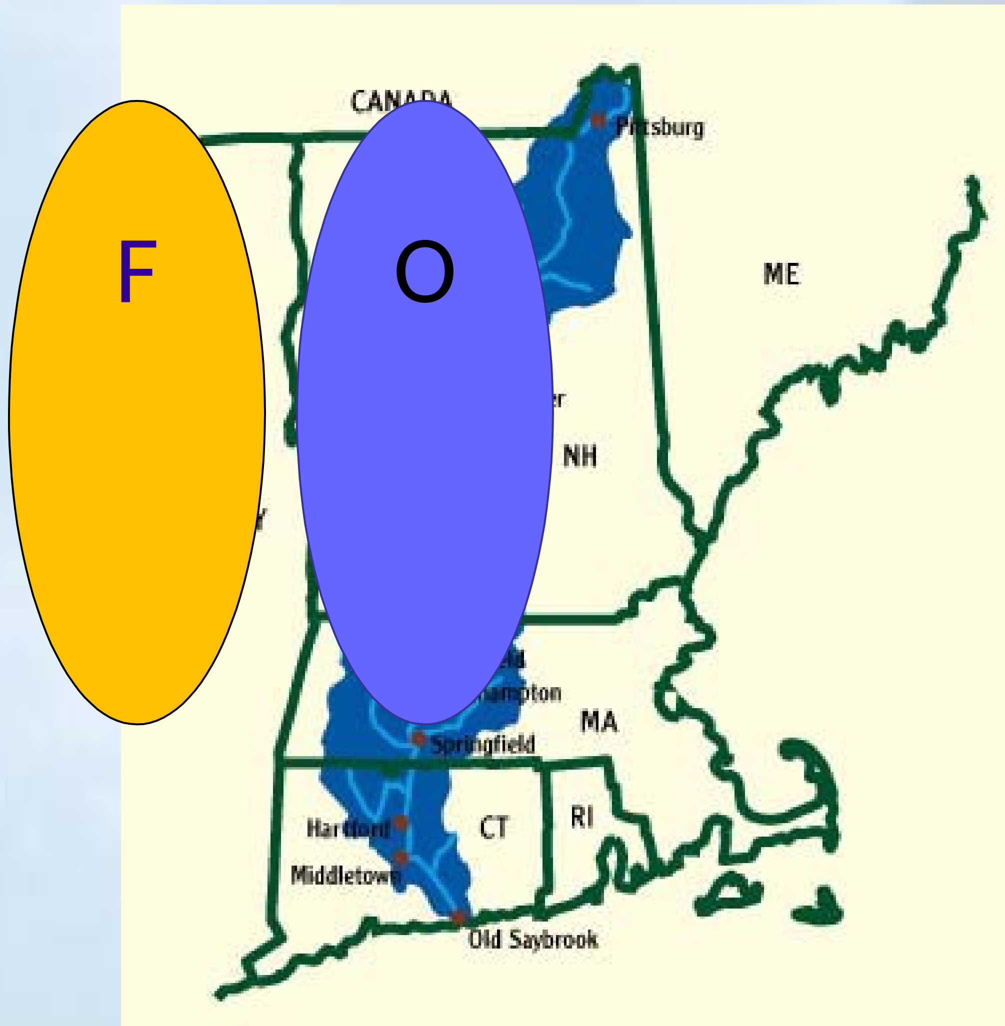
Is there a relationship between “Good Forecast” and “Valuable forecast”?

What is the relationship between “Good Forecast” and “Valuable forecast”?

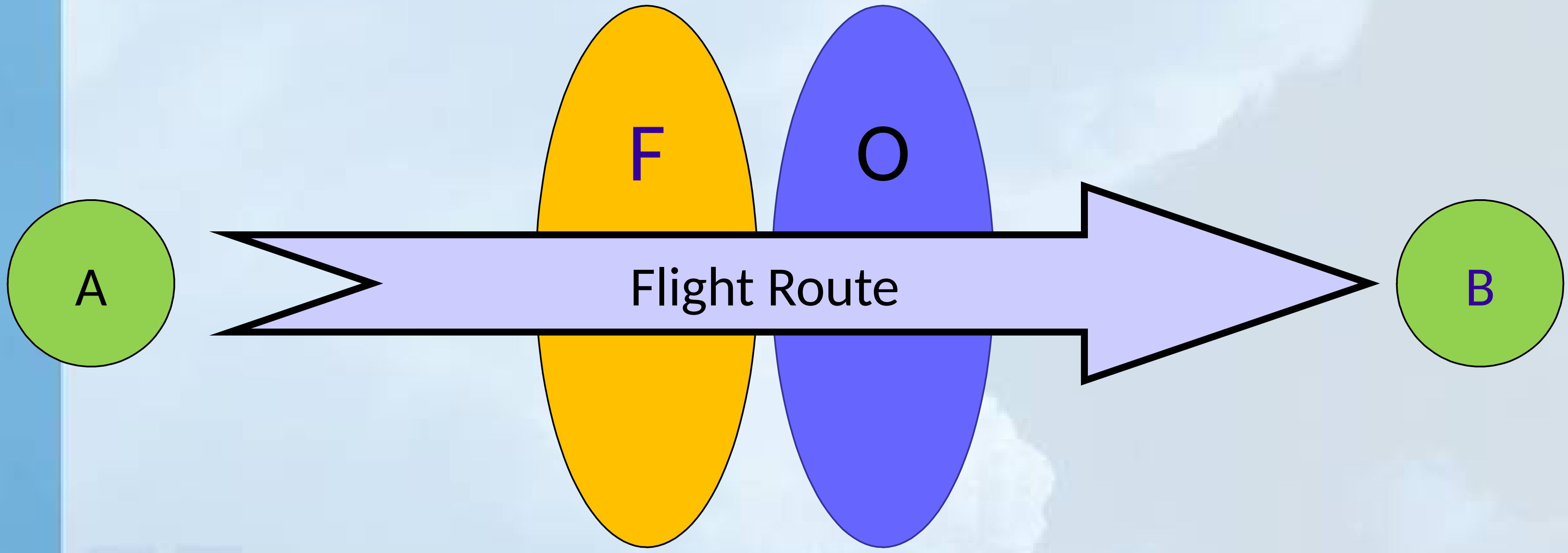
Valuable forecast or valueless forecast?

If I'm a water manager for this watershed, it's a <u>valueless</u> forecast…

If I'm a water manager for this watershed, it may be an <u>expensive</u> forecast…



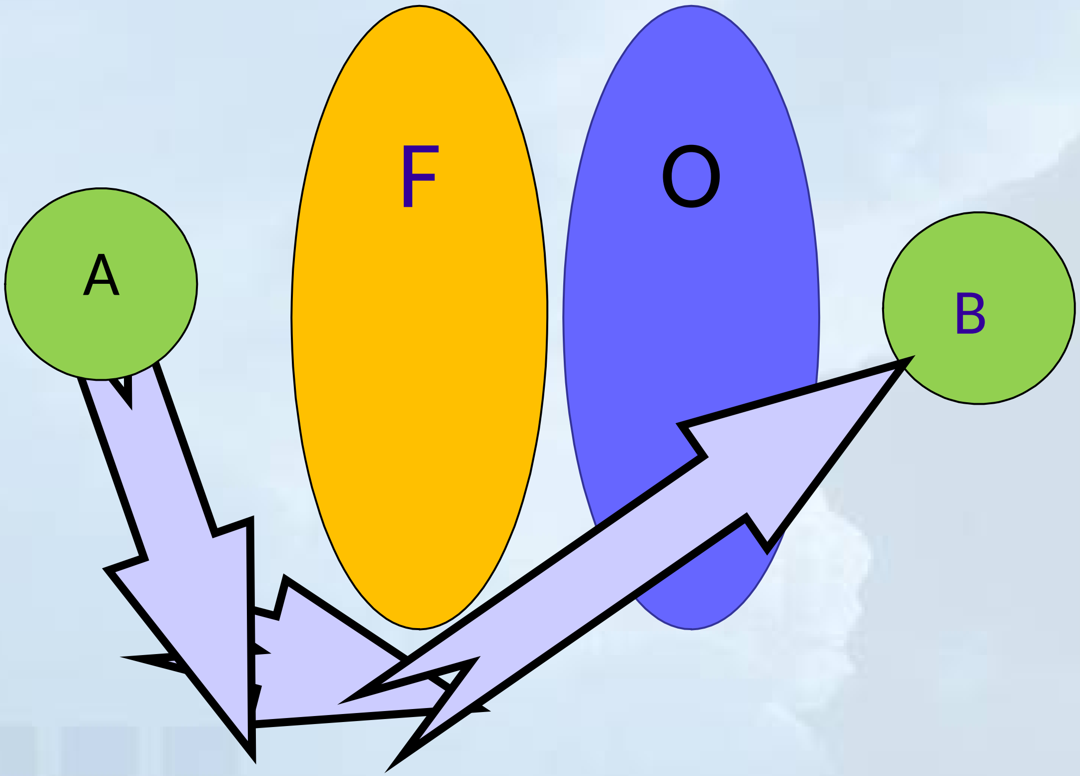
Valuable forecast or valueless forecast?



If I'm an aviation traffic strategic planner…

It might be a <u>valuable</u> 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?**

Weather Information Value Chain

- **What is the weather information value chain?**
  - **Conceptual model of the value creation process**
  - **Emphasize this is *<u>not</u>* 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:" $\max \; U\left(\bar{X}\right) \text{ subject to } \bar{P}'\bar{X} \leq Y$

- **U is the utility function**
- **P is the vector of prices**
- **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:

$$U = V\left(\bar{P}, Y\right)$$

Maximum utility attainable at given prices, $\bar{P}$, and income, Y

What does economic value mean?

$$U = V\left(\bar{P}, Y\right)$$

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

$U = V\left(\bar{P}, Y \mid W\right)$ Maximum utility attainable at given prices, $\bar{P}$, income, Y, and weather W.

Given initial $\bar{P}^0$, Y^0 and W^0 achieve: $U^0 = V\left(\bar{P}^0, Y^0 \mid W^0\right)$

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)*

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

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)

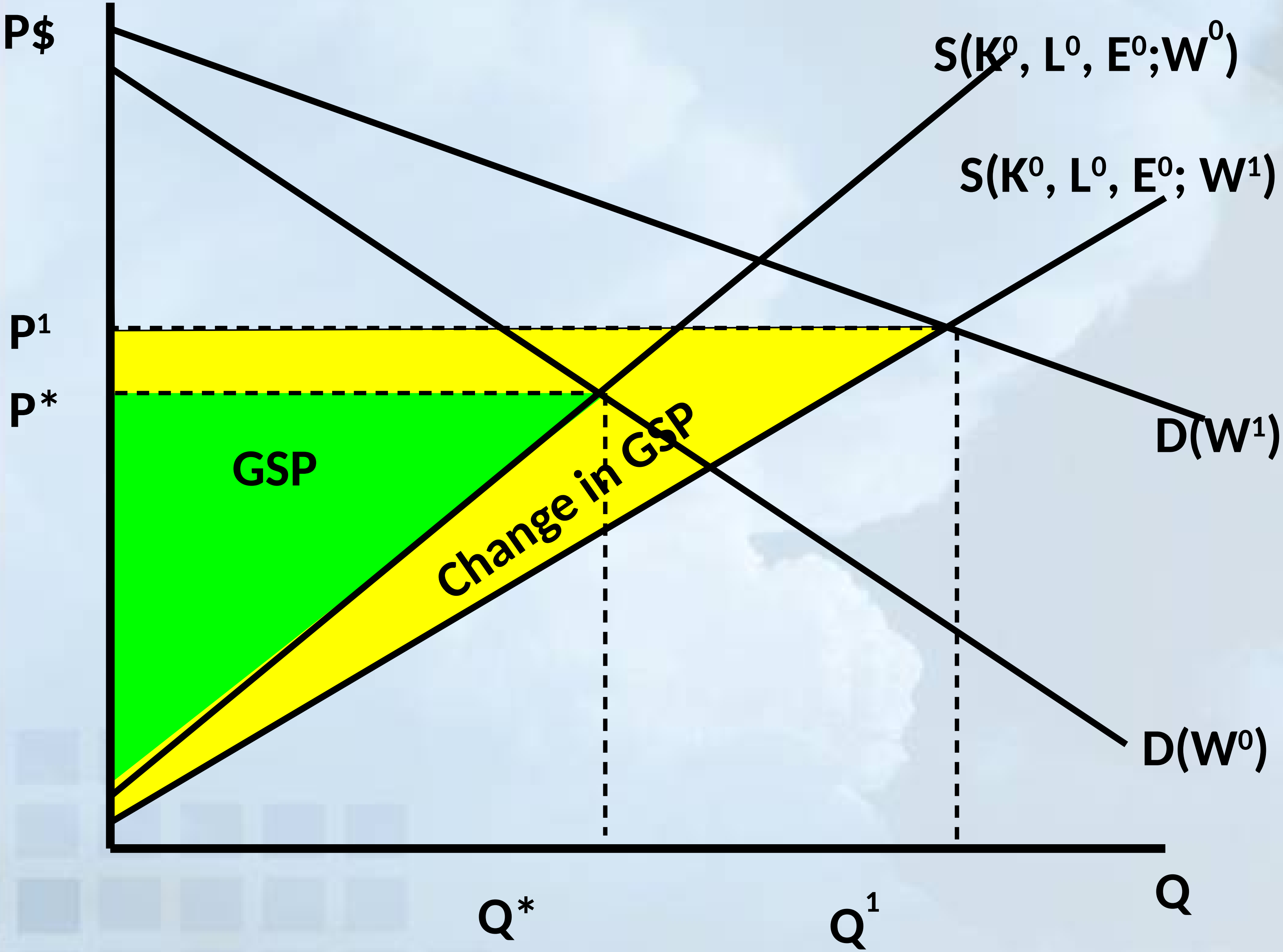
"... the third column lists the contribution to the GDP of industries with a (subjectively determined) weather sensitivity on operations, demand, or price."

TABLE 2. Weather and climate sensitive components of the gross domestic product (GDP; $ billion). The first two columns are from the Bureau of Economic Analysis industry accounts data for 2000; the third column lists the contribution to the GDP of industries with a (subjectively determined) weather sensitivity on operations, demand, or price.

Industries (1987 standard industrial classification)	GDP components ($ billion)	Weather sensitive components ($ billion)
Agriculture, forestry, and fishing	**135.8**	**135.8**
Farms	79.0	79.0
Agricultural services, forestry, and fishing	56.7	56.7
Mining	**127.1**	**109.6**
Coal mining	10.1	10.1
Oil and gas extraction	99.5	99.5
Other mining	17.5	0.0
Construction	**463.6**	**463.6**
Manufacturing	**1,566.6**	**—**
Transportation and public utilities	**825.0**	**786.5**
Transportation		
Railroad transportation	22.9	22.9
Local and interurban passenger transit	18.7	18.7
Trucking and warehousing	126.0	126.0
Water transportation	14.8	14.8
Transportation by air	93.0	93.0
Other transportation	38.5	0.0
Communications	281.1	281.1
Electric, gas, and sanitary services	230.0	230.0
Wholesale trade	**674.1**	**—**
Retail trade	**893.9**	**893.9**
Finance, insurance, and real estate	**1,936.2**	**379.1**
Security and commodity brokers	144.2	144.2
Insurance carriers	167.7	167.7
Insurance agents, brokers, and service	67.3	67.3
Other finance, insurance, real estate	1,557.1	—
Services	**2,164.6**	**261.2**
Hotels and other lodging places	86.5	86.5
Auto repair, services, and parking	93.9	93.9

Industries (1987 standard industrial classification)	GDP components ($ billion)	Weather sensitive components ($ billion)
TOTAL GROSS DOMESTIC PRODUCT	9,872.9	3,859.1

What is Weather Sensitivity?



Economic Modeling

transcendental logarithmic (translog) functional form

$$\ln GSP_{it} = \alpha_i + \delta t + \sum_{k=1}^{N} \beta_k \ln X_{kit} + \tfrac{1}{2}\sum_{k=1}^{N}\sum_{l=1}^{N} \gamma_{kl} \ln X_{kit} \ln X_{lit} + \varepsilon_{it}$$

GSP – Gross State Product

_X_ – economic & weather inputs (K, L, E, Temp, Precip) (indexed with _k_)

_i_ – state

_t_ – year

α– state specific fixed effects

δ – “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 <u>does</u> 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

Sector 2000 GDP	Billions (2000$)
Agriculture	98
Communications	458
Construction	436
Finance-Insurance-Real Estate (FIRE)	1,931
Manufacturing	1,426
Mining	121
Retail Trade	662
Services	2,399
Transportation	302
Utilities	189
Wholesale Trade	592
Total Private Sector	8,614
Government	1,135
Total GDP	9,749

Econometric Methods

$$\ln GSP_{it} = \alpha_i + \beta \delta t + \sum_{k=1}^{N} \beta_k \ln X_{kit} + \frac{1}{2}\sum_{k=1}^{N}\sum_{l=1}^{N}\gamma_{kl} \ln X_{kit} \ln X_{lit} + \varepsilon_{it}$$

- **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

$$\partial \ln GSP \big/ \partial \ln X$$

(blue box indicates significant at 10%)

Sector	Capital	Labor	Energy
Agriculture	1.10	0.44	-0.01
Communications	1.12	0.31	-0.14
Construction	0.48	1.14	0.12
FIRE	0.98	0.39	-0.20
Manufacturing	0.48	0.62	0.09
Mining	1.20	0.60	0.10
Retail Trade	0.91	0.54	-0.04
Services	0.94	0.64	-0.07
Transportation	0.94	0.33	0.07
Utilities	1.11	-0.31	-0.03
Wholesale	0.50	0.78	-0.02

“Weather Input” Elasticities

$$\partial \ln GSP / \partial \ln X$$

(blue box indicates significant at 10%)

Sector	HDD	CDD	Total Precip	Precip Variance
Agriculture	0.00	-0.19	0.28	-0.12
Communications	0.13	0.06	0.06	0.17
Construction	-0.01	0.06	-0.01	0.26
FIRE	0.15	0.06	0.54	-0.08
Manufacturing	0.18	0.02	0.49	-0.22
Mining	0.25	0.04	-3.52	1.10
Retail Trade	0.04	0.03	-0.13	0.13
Services	0.04	0.00	0.33	-0.05
Transportation	-0.03	0.01	-0.15	0.15
Utilities	0.00	0.08	-0.59	-0.28

Weather Sensitivity Analysis

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

$$\ln GSP_{it} = \alpha_i + \delta t + \beta_k \sum_{k=1}^{N} \ln X_{kit} + \frac{1}{2}\sum_{k=1}^{N}\sum_{l=1}^{N} \gamma_{kl} \ln X_{kit} \ln X_{lit} + \varepsilon_{it}$$

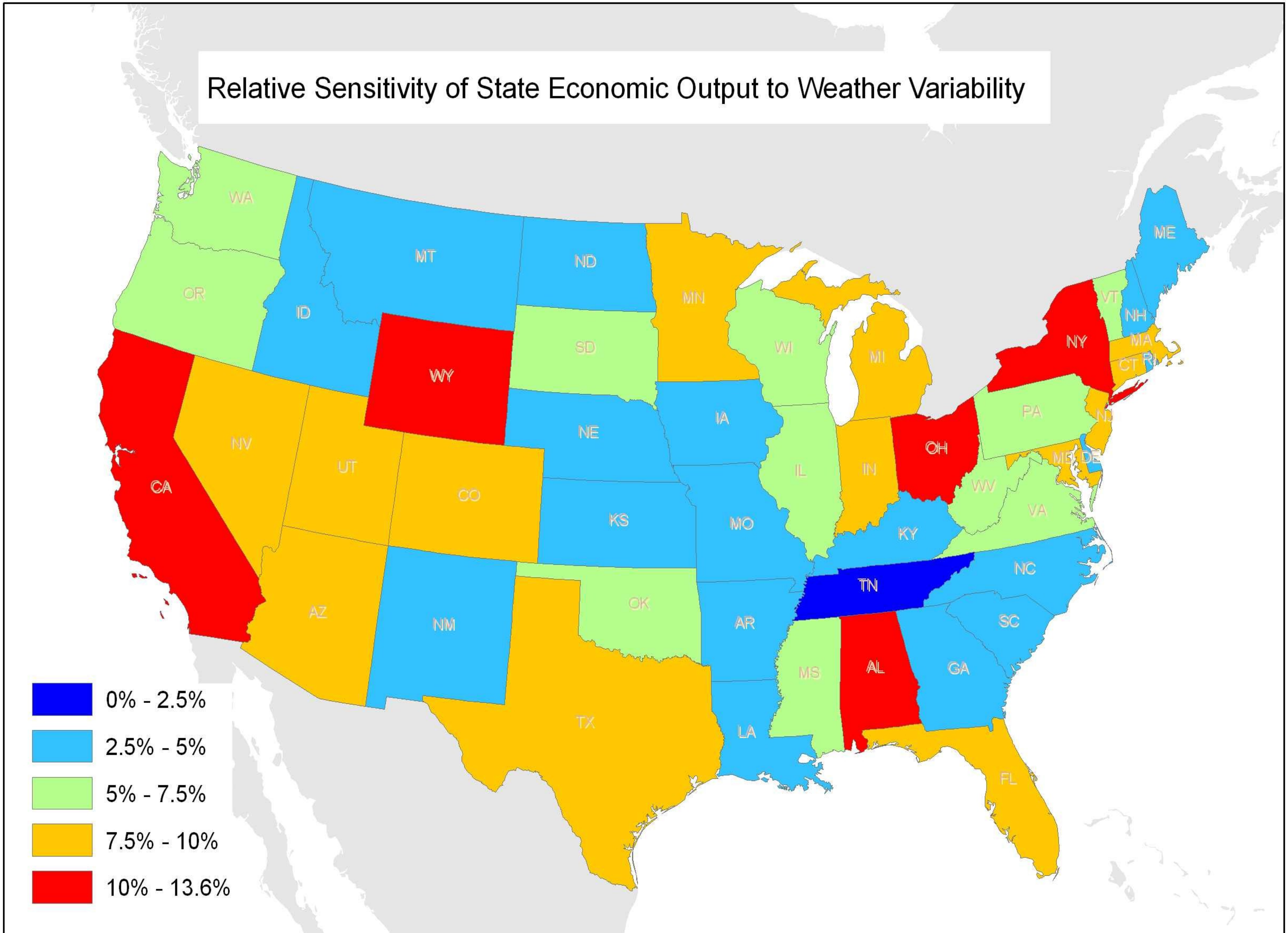
11 Sector Models:

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)

State	Mean	Max	Min	Range	% Range	Rank
New York	633.3	679.6	594.0	85.6	13.5%	1
Alabama	92.0	93.9	81.7	12.2	13.3%	2
California	1019.4	1080.5	968.6	111.9	11.0%	3
Wyoming	13.7	14.3	12.8	1.4	10.5%	4
Ohio	312.0	330.6	298.4	32.2	10.3%	5
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Delaware	30.2	30.6	29.6	1.0	3.3%	44
Maine	27.0	27.4	26.5	0.9	3.3%	45
Montana	17.2	17.4	16.9	0.6	3.3%	46
Louisiana	109.5	111.2	107.6	3.6	3.3%	47
Tennessee	141.1	142.8	139.3	3.5	2.5%	48


Relative Sensitivity of State Economic Output to Weather Variability
WA
OR
CA
ID
NV
MT
WY
UT
AZ
CO
NM
ND
SD
NE
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MS
MI
IN
KY
TN
AL
OH
GA
FL
SC
NC
VA
WV
PA
NY
VT
NH
ME
MA
RI
CT
NJ
DE
MD
0% - 2.5%
2.5% - 5%
5% - 7.5%
7.5% - 10%
10% - 13.6%

Aggregated by Sector

(Billions $2000)

Sector	Mean	Max	Min	Range	%Range
Agriculture	127.6	134.4	119.0	15.4	12.09%
Wholesale trade	601.5	607.8	594.5	13.3	2.20%
Retail trade	761.5	771.2	753.9	17.3	2.27%
FIRE	1,639.3	1,713.1	1,580.6	132.5	8.08%
Communications	237.3	243.4	232.3	11.1	4.68%
Utilities	212.9	220.8	206.0	14.9	6.98%
Transportation	276.1	280.7	271.0	9.8	3.53%
Manufacturing	1,524.8	1,583.2	1,458.2	125.1	8.20%
Construction	374.5	384.0	366.4	17.7	
Mining	102.0	108.9	94.2	14.7	
Total National	7,692.4	7,813.4	7,554.6	258.7	3.36%

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

Lazo, J.K., R.E. Morss, and J.L. Demuth. 2009. “300 Billion Served: Sources, Perceptions, Uses, and Values of Weather Forecasts.” Bulletin of the American Meteorological Society. 90(6):785-798

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?

Not at all important	A little important	Somewhat important	Very important	Extremely important

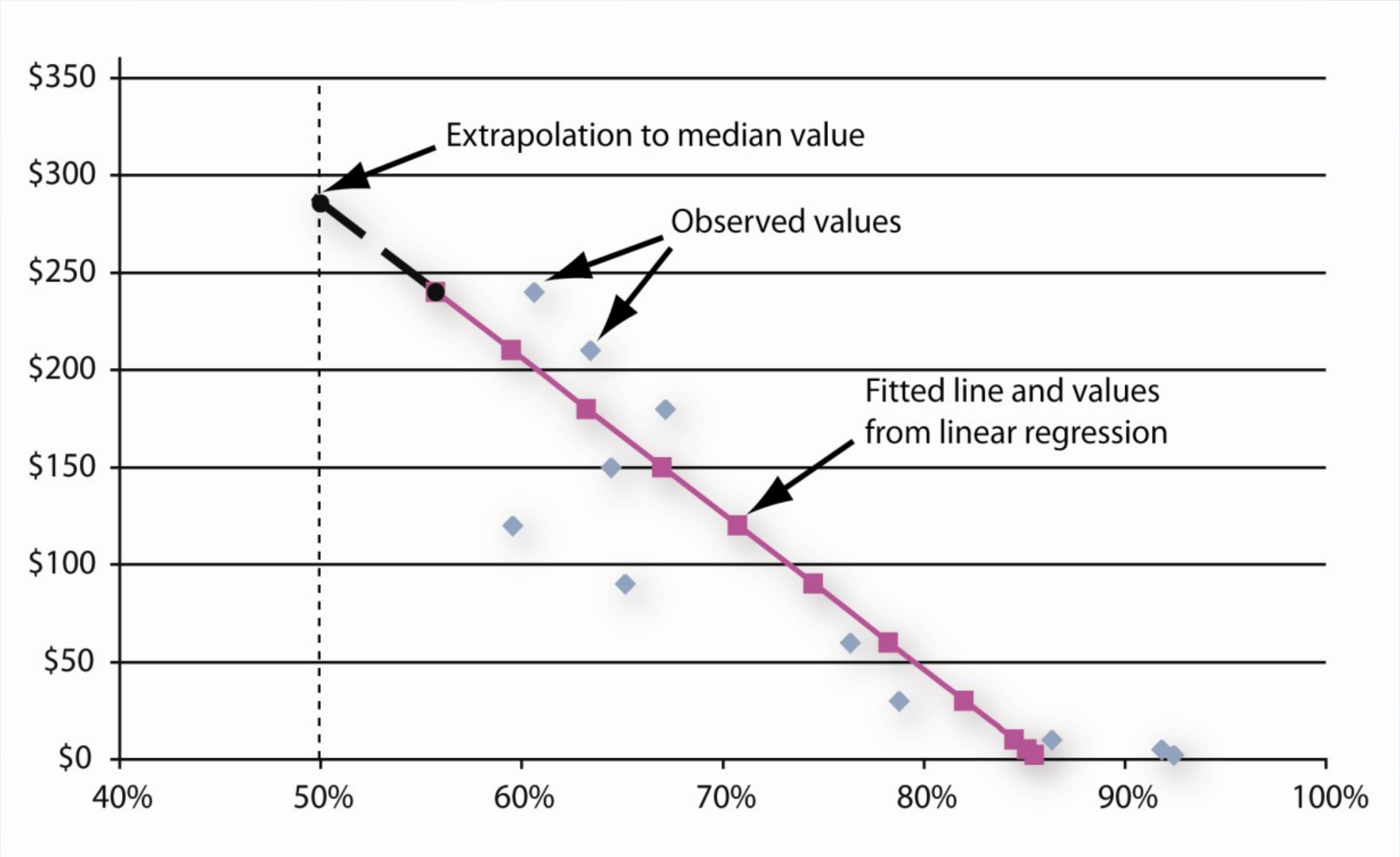
All of the activities of the National Weather Service (NWS) are paid for through taxes as a part of the federal government. This money pays for all of the observation equipment (such as satellites and radar), data analysis, and products of the NWS (including all the forecasts, watches, and warnings).

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 tha
b) Worth exactly $
c) Worth less than

Randomly used different $$$/yr with different respondents

2. VALUE OF CURRENT FORECASTS



Lazo, J.K., R.E. Morss, and J.L. Demuth. 2009. "300 Billion Served: Sources, Perceptions, Uses, and Values of Weather Forecasts." Bulletin of the American Meteorological Society. 90(6):785-798

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

Lazo, J.K., R.E. Morss, and J.L. Demuth. 2009. "300 Billion Served: Sources, Perceptions, Uses, and Values of Weather Forecasts." Bulletin of the American Meteorological Society. 90(6):785-798

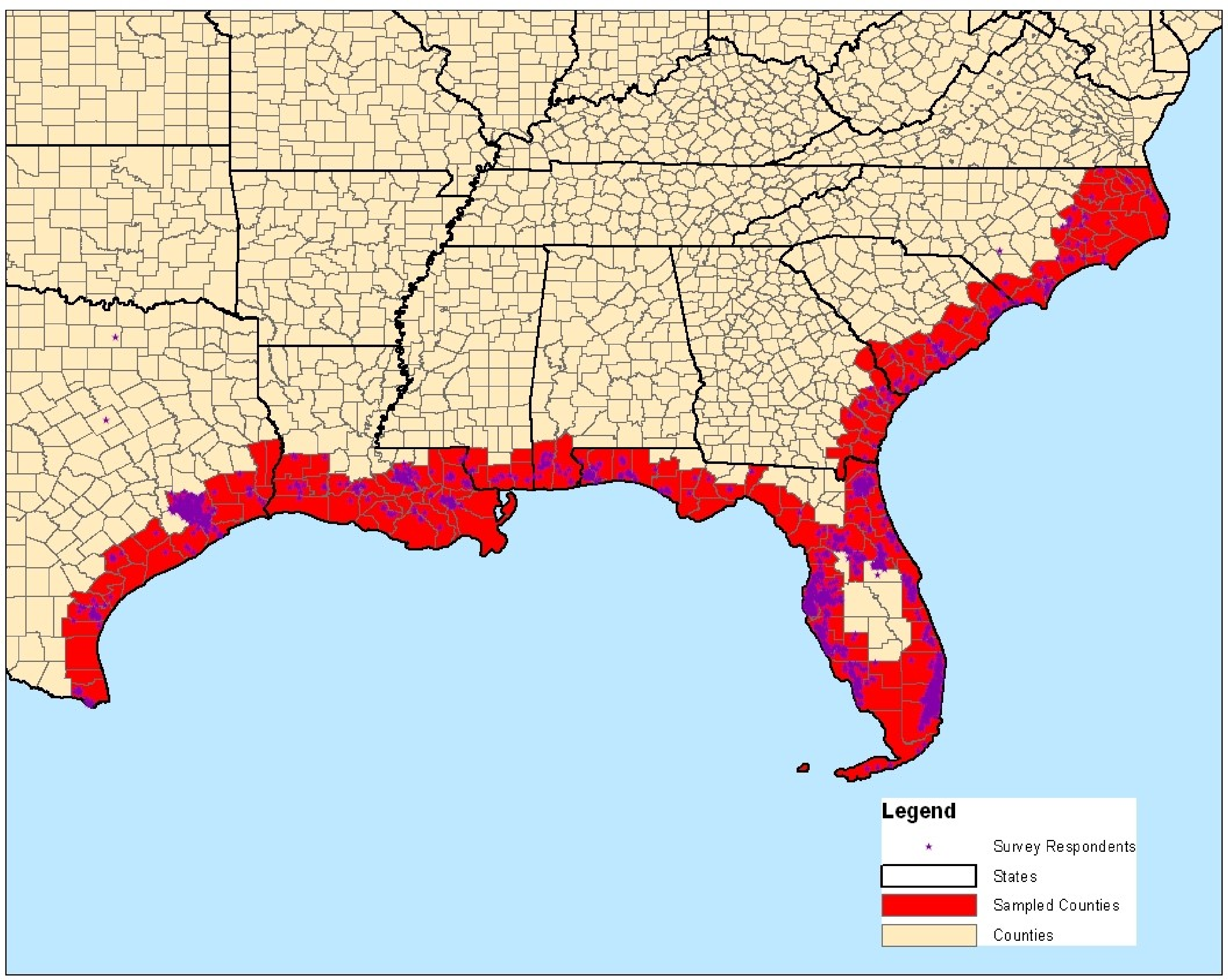
3. VALUE OF IMPROVED FORECASTS

- **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

Lazo, J.K. and D.M. Waldman. 2011. "Valuing Improved Hurricane Forecasts." Economics Letters. 111(1): 43-46.

Lazo, J.K., D.M. Waldman, B.H. Morrow, and J.A. Thacher. 2010. "Assessment of Household Evacuation Decision Making and the Benefits of Improved Hurricane Forecasting." Weather and Forecasting. 25(1):207-219

3. VALUE OF IMPROVED FORECASTS



CHOICES BETWEEN IMPROVEMENT PROGRAMS

16. **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.**

	Accuracy of Current Forecasts	Program A	Program B
Time of landfall	accurate to within 5 hours	No change	**4 hours**
Landfall location	within 50 miles	**25 miles**	**25 miles**
Maximum wind speed	within 15 miles per hour	No change	No change
Rapid changes in wind strength	forecast rapid changes if it occurs 20% of the time	No change	No change
Storm surge depth	plus or minus 5 feet	No change	No change
Storm surge information	no separate storm surge information	No change	No change
Extended forecasts	5 days	No change	No change
Increase in Annual Cost to Your Household		**$12 per year**	**$24 per year**
I would prefer (please click on the program you prefer)		**Program A** ☐	**Program B** ☐

3. Random Utility Model (RUM)

- utility is linear combination of choice attributes and a random error

$$U_{ij} = \beta' x_{ij} + \varepsilon_{ij}, \qquad i = A, B; \quad j = 1, \ldots, 8$$

- U_{ij} = utility of alternative *i* in choice set *j*
- vector *β* are marginal utilities
  - For the cost attribute, ß 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
- ε = random disturbance

3. VALUE OF IMPROVED FORECASTS

$$U_{ij} = \beta' x_{ij} + \varepsilon_{ij}, \qquad i = A, B; \quad j = 1, \ldots, 8$$

Random Utility Model (RUM)

- ε assumed independent, identically distributed, mean zero normal random variables, uncorrelated with x_{ij}, with constant unknown variance σ
- 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.

$$P\left(U_{ij}^{k_{ij}} > U_{ij}^{3-k_{ij}}, U_{ij}^{k_{ij}} > U_{ij}^{0}\right)$$

$$= \Phi_2\left[-\beta'\left(x_{ij}^{3-k_{ij}} - x_{ij}^{k_{ij}}\right) / \sqrt{2}\sigma_\varepsilon, -\beta'\left(x_{ij}^{0} - x_{ij}^{k_{ij}}\right) / \sqrt{\sigma_0 + \sigma_\varepsilon}; \rho\right]$$

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

- **Φ_2 is the standard bivariate normal cumulative distribution function.**
- **Normalization is required and an additional parameter is identified – normalize σ_ε**

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)

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

Lazo, J.K. and D.M. Waldman. 2011. "Valuing Improved Hurricane Forecasts." Economics Letters. 111(1): 43-46.
Lazo, J.K., D.M. Waldman, B.H. Morrow, and J.A. Thacher. 2010. "Assessment of Household Evacuation Decision Making and the Benefits of Improved Hurricane Forecasting." Weather and Forecasting. 25(1):207-219

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?

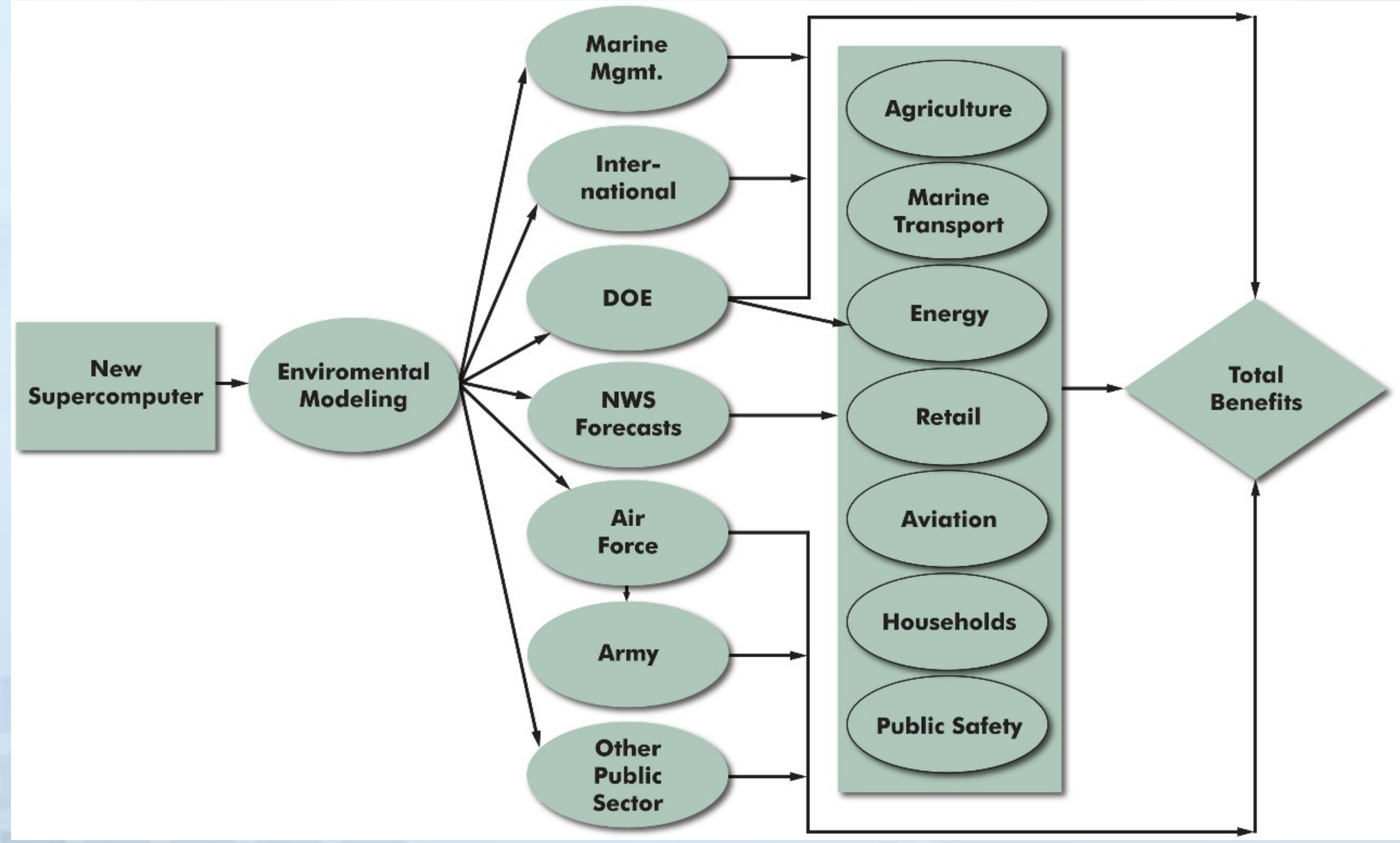
4. VALUE OF RESEARCH TO IMPROVE FORECASTS

- **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

Lazo, J.K., J. S. Rice, M. L. Hagenstad. 2010. "Benefits of Investing in Weather Forecasting Research: An Application to Supercomputing." Yuejiang Academic Journal. 2(1):18-39.

4. VALUE OF RESEARCH TO IMPROVE FORECASTS



4. VALUE OF RESEARCH TO IMPROVE FORECASTS

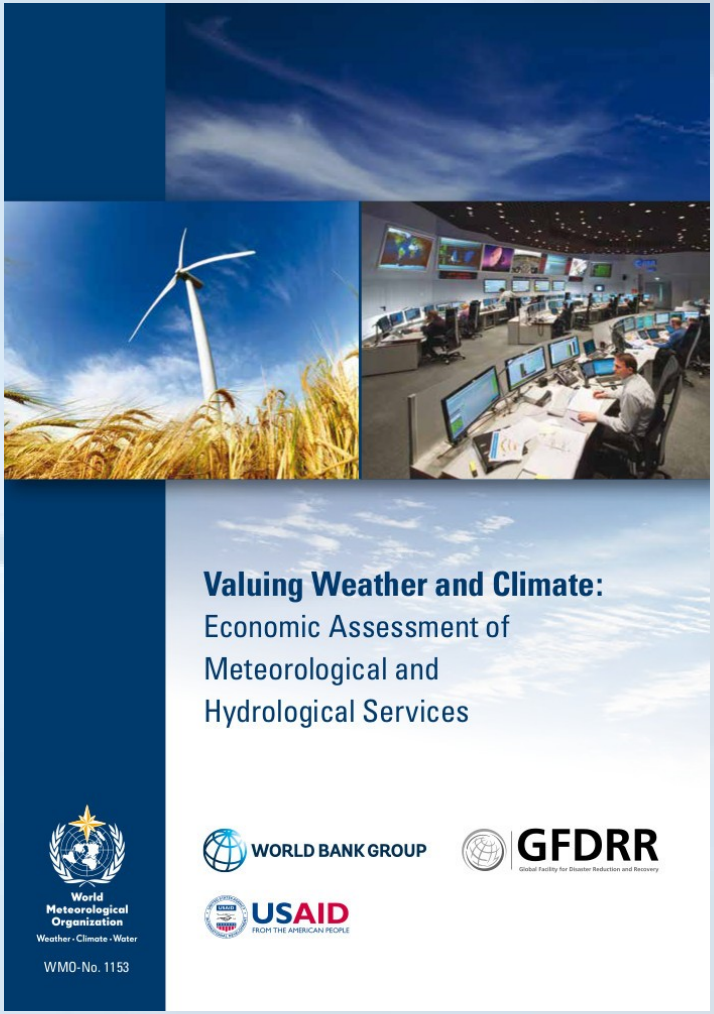
- **Results**
  - benefits to households, agriculture, aviation evaluated
  - average total benefits from these three sectors were estimated at $116 million in present value (2002 US dollars)
  - Net Present Value (present value of benefits minus costs)
    - 3% real rate of discount = $104.60 million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

Lazo, J.K., J. S. Rice, M. L. Hagenstad. 2010. "Benefits of Investing in Weather Forecasting Research: An Application to Supercomputing." Yuejiang Academic Journal. 2(1):18-39.

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/0BwdvoC9AeWjUX2dJblR6WlMybU0/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?

Jeff Lazo

lazo@ucar.edu

www.sip.ucar.edu

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

- Lazo, J.K. and D.M. Waldman. 2011. “Valuing Improved Hurricane Forecasts.” *Economics Letters*. 111(1): 43-46.
- Lazo, J.K., D.M. Waldman, B.H. Morrow, and J.A. Thacher. 2010. “Assessment of Household Evacuation Decision Making and the Benefits of Improved Hurricane Forecasting.” *Weather and Forecasting*. 25(1):207-219.
- Lazo, J.K., J. S. Rice, M. L. Hagenstad. 2010. “Benefits of Investing in Weather Forecasting Research: An Application to Supercomputing.” *Yuejiang Academic Journal*. 2(1):18-39.
- Lazo, J.K., M. Lawson, P.H. Larsen, and D.M. Waldman. June 2011 “United States Economic Sensitivity to Weather Variability.” *Bulletin of the American Meteorological Society*. 92: 709-720.
- Lazo, J.K., R.E. Morss, and J.L. Demuth. 2009. “300 Billion Served: Sources, Perceptions, Uses, and Values of Weather Forecasts.” *Bulletin of the American Meteorological Society*. 90(6):785-798.