Trading Weather
How Efficient are Markets?

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Simon: "I say, it's wonderful how you country people really know weather."

Mrs. Drudge: "Know whether what?"

Source: *Tom Stoppard's the Real Inspector Hound*

Outline

I. Summary

II. Weather Derivatives Market

III. The Data

IV. Testing for Market Efficiency

V. Conclusion

Note: Participate at any point in presentation.

I. Summary

- **The Weather Market seems to be very efficient, despite it's lack of depth and liquidity.**

Implications:

(1) Markets don't necessarily need large volume to be efficient.

(2) Markets without the possibility of inside information might be more likely to be efficient

I. Summary

- The forecasts for HDD and CDD contracts in 50 years show signs of "global warming", which seems to be correlated with population changes in cities.

II. Weather Derivatives Market

Exchange: CME

Start Trading Date: 1999

Value of Market: $22B (September 2005)

Value of Other Markets: $76B (Natural Gas 2006)

Types of Contracts: Futures, Options, Future Strips

Contracts Based Upon HDD and CDD.

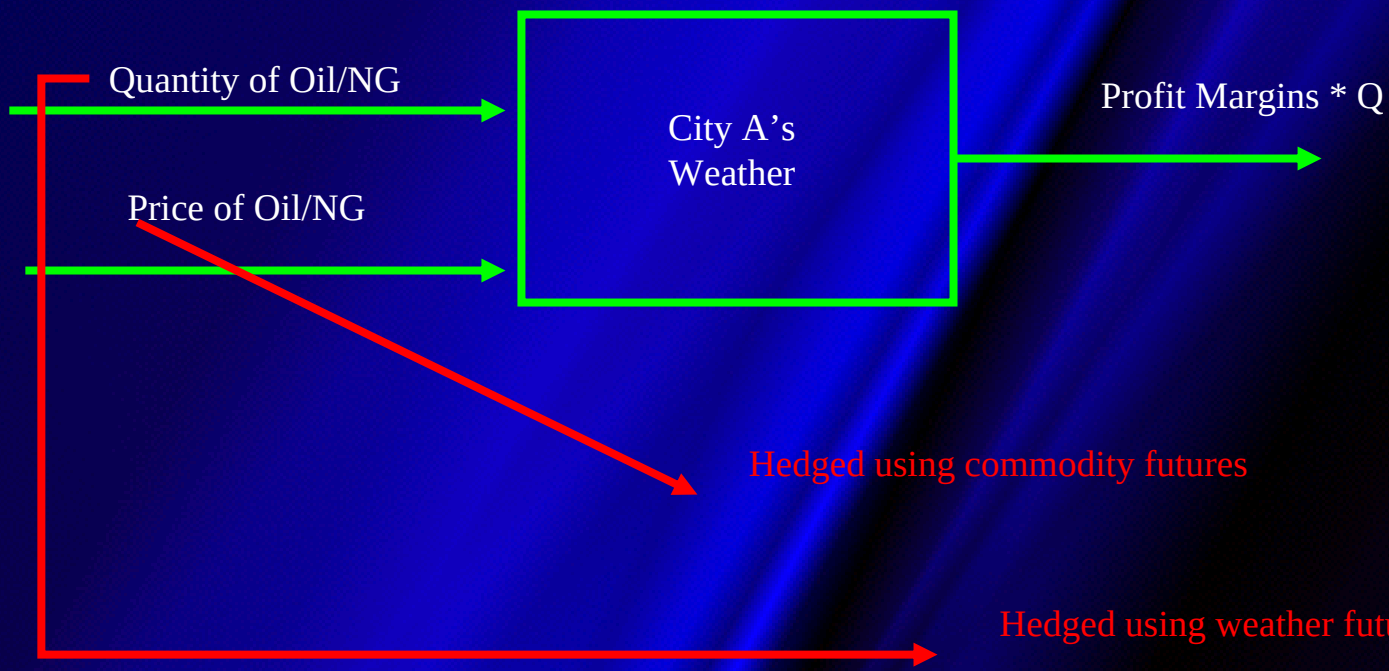
II. Weather Derivatives Market

Users:

- Oil Distributors
- Energy Traders
- Institutional Banks
- Re Insurers
- Hedge Funds

II. Weather Derivatives Market

Users: Oil distributors wanting to hedge both Q and P to smooth profits.



II. Weather Derivatives Market

HDD = heating degree day

$$HDD_{i,y,m,d} \equiv \max(65 - T_{i,y,m,d}, 0)$$

CDD = cooling degree day

CDD = max (65-T,0)

where

$$T_{i,y,m,d} \equiv \frac{H_{i,y,m,d} + L_{i,y,m,d}}{2}$$

II. Weather Derivatives Market

- Futures contracts trade on accumulation of daily HDD (or CDD)

$$HDD_{i,y,m} \equiv \sum_{d=1}^{D(y,m)} HDD_{i,y,m,d}$$

II. Weather Derivatives Market

Table 1: CME Weather Contract Specifications

Trading Hours	*Futures products* trade electronically only on CME Globex from Monday through Friday from 3:45 PM to 3:15PM (central time) of the following day, and on Sundays from 5:30 PM to 3:15 PM. On the last trading day they trade until 9 AM. *Option products* trade only Monday through Friday from 8:15 AM to 3:15 PM on the CME trading floor.
Contract Size	\$20 times the monthly index. The monthly index is provided by the Earth Satellite Corporation.
Minimum Tick Fluctuation	One degree day index point.
Settlement	Cash settled. All contracts that remain open at the termination of trading of a particular contract shall be settled using the respective CME Degree Days Index for that city and that contract season, using the methodology in effect on that date, on the first Exchange business day that is at least two calendar days after the derivatives contract month.
Maximum Order Size	10,000 contracts net long or short in all contract months combined.
Trading Venue	Only options can be traded via open outcry; the futures products are traded exclusively on the CME Globex electronic trading platform.

II. Weather Derivatives Market

EXAMPLE: February 28, 2005. An oil distributor would like to hedge fluctuations in oil heating demand in March 2005.

- Contract closed at 305.
- The actual value for March was 349.
- Market overestimated HDD, but was close.

II. Weather Derivatives Market

Table 2: Example of Weather and Weather HDD Futures for Atlanta in March, 2006

Date	Tmax	Tmin	Tavg	HDD	Cumulative HDD	HDD March Futures Closing Prices
3/1/2006	71	50	60.5	4.5	4.5	290
3/2/2006	70	55	62.5	2.5	7	275
3/3/2006	56	41	48.5	16.5	23.5	235
3/4/2006	61	32	46.5	18.5	42	NA
3/5/2006	66	38	52	13	55	NA
3/6/2006	69	48	58.5	6.5	61.5	210
3/7/2006	60	38	49	16	77.5	245
3/8/2006	66	41	53.5	11.5	89	240
3/9/2006	69	44	56.5	8.5	97.5	257
3/10/2006	76	53	64.5	0.5	98	250
3/11/2006	78	61	69.5	0	98	NA
3/12/2006	80	61	70.5	0	98	NA
3/13/2006	75	61	68	0	98	300
3/14/2006	69	44	56.5	8.5	106.5	325
3/15/2006	61	37	49	16	122.5	320
3/16/2006	65	41	53	12	134.5	320
3/17/2006	69	45	57	8	142.5	315
3/18/2006	59	39	49	16	158.5	NA
3/19/2006	53	44	48.5	16.5	175	NA
3/20/2006	55	39	47	18	193	335
3/21/2006	68	40	54	11	204	345
3/22/2006	54	35	44.5	20.5	224.5	342
3/23/2006	52	38	45	20	244.5	343
3/24/2006	51	38	44.5	20.5	265	337
3/25/2006	51	33	42	23	288	NA
3/26/2006	54	30	42	23	311	NA
3/27/2006	61	34	47.5	17.5	328.5	350
3/28/2006	56	48	52	13	341.5	350
3/29/2006	73	48	60.5	4.5	346	350
3/30/2006	74	50	62	3	349	351
3/31/2006	77	55	66	0	349	350
4/3/2006	NA	NA	NA	NA	NA	349

III. The Data

- FUTURES DATA: CME/Bloomberg – CLOSE, BID, ASK, VOLUME, and OPEN INTEREST
- WEATHER DATA: National Climatic Data Center – HIGH and LOW temps
- WEATHER FORECASTS: National Climatic Data Center, National Weather Service MOS (Model Output Statistics)

III. The Data

Table 3: List of Weather Stations and Weather Futures Contracts

Weather Location	Station	WBAN
Atlanta Hartsfield Airport	KATL	13874
Baltimore-Washington International Airport	KBWI	93721
Boston Logan Airport	KBOS	14739
Chicago O'Hare International Airport	KORD	94846
Cincinnati Northern Kentucky Airport	KCVG	93814
Dallas Fort Worth Airport	KDFW	3927
Des Moines International Airport	KDSM	94847
Detroit Metro Airport	KDTW	14933
Houston Bush Intercontinental Airport	KIAH	12960
Kansas City International Airport	KMCI	3947
Las Vegas McCarran Airport	KLAS	23169
Minneapolis-St. Paul International Airport	KMSP	14922
New York La Guardia Airport	KLGA	14732
Philadelphia International Airport	KPHL	13739
Portland International Airport	KPDX	24229
Sacramento Executive Airport	KSAC	23232
Salt Lake City International Airport	KSLC	24127
Tucson International Airport	KTUS	23160

III. The Data

Table 4: Summary Statistics of Weather Futures Contracts

City and Contract Type	First Contract Traded	Average Daily Volume	Number of Trading Days w/ Volume
Atlanta HDD	10:1999	57.82	1445
Atlanta CDD	7:1999	42.43	659
Baltimore HDD	11:2005	24.84	73
Baltimore CDD	6:2006	18.27	29
Boston HDD	3:2003	470.51	499
Boston CDD	6:2003	49.95	145
Chicago HDD	10:1999	49.06	586
Chicago CDD	6:2002	60.69	335
Cincinnati HDD	10:1999	34.74	427
Cincinnati CDD	5:2002	39.70	307
Dallas HDD	10:2002	25.78	283
Dallas CDD	6:2000	39.76	290
Des Moines HDD	3:1999	78.48	866
Des Moines CDD	7:2000	31.90	237
Detroit HDD	4:2008	0.17	2
Detroit CDD	12:2012	0.00	0
Houston HDD	3:2003	68.34	180
Houston CDD	9:2003	570.83	1507

III. The Data

Table 5: Summary Statistics of Weather Temperatures

		Average of Daily Values			
City	WBAN	Maximum	Minimum	Average	S.D.
Atlanta	13874	72.31	53.32	62.81	14.55
Baltimore	93721	65.77	45.65	55.70	16.98
Boston	14739	59.19	44.08	51.63	17.02
Chicago	94846	59.04	41.01	50.05	19.27
Cincinnati	93814	63.72	44.53	54.13	17.87
Dallas	3927	76.74	56.24	66.48	15.82
Detroit	94847	58.96	41.70	50.34	18.67
Des Moines	14933	59.97	41.07	50.54	20.66
Houston	12960	79.71	59.48	69.59	13.14
Kansas City	3947	64.72	44.64	54.66	19.37
Las Vegas	23169	80.04	57.39	68.71	16.99
Minneapolis	14922	55.05	37.51	46.41	21.83
New York	14732	62.92	49.08	55.99	17.08
Philadelphia	13739	64.80	47.47	56.14	17.25
Portland	24229	63.13	45.86	54.50	11.50
Sacramento	23232	73.98	48.59	61.28	11.59
Salt Lake City	24127	64.14	41.81	52.98	18.59
Tucson	23160	83.80	55.76	69.78	14.20

III. The Data

Table 6: Summary Statistics of Weather Temperature Forecasts

		Average of Daily Values														
		Forecasts for Maximum Temperature								Forecasts for Minimum Temperature						
City	nobs	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7
Atlanta	1003.00	72.07	71.84	71.58	71.10	71.40	71.28	70.85	70.62	52.77	52.67	52.65	53.28	53.02	53.27	52.99
Baltimore	1003.00	65.17	64.92	64.48	63.96	63.84	63.84	63.51	63.48	45.17	45.06	44.95	44.84	45.00	45.15	45.03
Boston	1003.00	58.67	57.97	58.39	57.10	56.92	57.20	56.77	57.04	44.40	44.23	43.76	43.74	43.71	43.55	43.40
Chicago	1003.00	57.91	57.88	57.63	57.43	57.34	57.19	57.03	56.93	41.50	41.12	41.32	41.16	40.85	40.84	40.78
Cincinnati	1003.00	63.44	63.05	62.72	62.41	62.47	61.90	61.71	61.16	44.81	44.67	44.70	45.08	44.94	44.68	44.85
Dallas	1003.00	76.26	76.52	76.68	75.67	75.80	75.50	75.16	75.27	56.97	57.23	57.01	56.77	56.85	56.55	56.23
Detroit	1003.00	58.07	57.73	57.37	56.86	56.78	57.14	57.13	56.97	41.67	41.63	41.21	41.48	41.40	41.34	41.43
Des Moines	1003.00	59.47	58.95	59.00	58.78	58.44	58.43	58.52	58.85	41.36	41.32	41.16	40.89	40.67	40.91	40.91
Houston	1003.00	78.87	79.19	79.46	79.31	79.09	79.24	78.95	78.49	60.37	60.65	60.97	60.96	60.85	60.73	60.36
Kansas City	1003.00	64.14	64.22	64.14	63.96	63.99	63.69	63.52	63.56	45.43	45.34	45.30	44.98	44.92	44.72	44.70
Las Vegas	1003.00	79.93	79.74	80.10	79.71	79.52	79.99	79.82	80.33	58.00	58.29	58.33	57.75	57.22	57.49	57.50
Minneapolis	1003.00	54.47	53.95	53.84	53.37	53.10	52.92	53.04	53.21	37.82	37.64	37.61	37.46	37.17	37.43	37.41
New York	1003.00	62.38	61.90	62.11	60.80	60.79	60.82	60.64	60.36	49.43	48.97	48.84	48.59	48.55	48.53	48.40
Philadelphia	1003.00	64.51	64.14	63.62	63.15	63.19	63.19	62.98	62.61	47.62	47.33	47.18	47.16	47.28	47.39	47.06
Portland	1003.00	60.28	60.35	60.22	60.57	60.70	60.83	61.09	61.46	44.55	44.61	44.94	44.90	45.23	45.31	45.31
Sacramento	1003.00	72.11	72.01	72.20	72.15	72.41	72.59	72.68	72.98	47.55	47.65	47.51	47.36	47.78	47.81	48.27
Salt Lake City	1003.00	60.57	61.68	61.61	62.62	62.07	62.27	62.47	61.90	41.14	41.47	41.01	41.30	41.30	41.92	42.16
Tucson	1003.00	82.99	83.25	83.20	83.59	83.68	83.65	83.97	84.05	56.49	56.34	56.07	55.69	55.55	55.93	55.43

IV. Testing for Market Efficiency

1. Raw returns to holding contracts
2. Market forecasts versus simple alternative models
3. Overreaction/Underreaction to weather surprises

IV. Testing for Market Efficiency

1. Raw returns to holding contracts

Table 7: Summary Statistics of Returns from Holding Weather Derivative Contracts

	HDD						CDD					
City	Mean	*t*-stat	S.D.	Max	Min	nobs	Mean	*t*-stat	S.D.	Max	Min	nobs
Atlanta	9.76	0.87	98.49	1139.03	-38.56	136.00	-3.89	-0.82	33.08	81.95	-172.22	108.00
Baltimore	-0.32	-4.81	8.35	25.60	-16.67	30.00	-20.93	-1.23	57.75	11.10	-124.00	5.00
Boston	-1.75	-0.55	9.15	18.35	-30.23	90.00	-6.06	-0.82	37.36	50.18	-230.77	57.00
Chicago	-2.45	-0.21	7.26	14.22	-56.53	199.00	2.75	1.34	39.33	174.87	-166.67	113.00
Cincinnati	-1.78	-0.53	11.38	50.73	-55.63	144.00	-2.69	-1.08	28.66	62.51	-120.00	98.00
Dallas	-4.04	-0.39	16.60	37.01	-51.00	110.00	-6.74	-0.42	28.45	15.10	-163.16	100.00
Des Moines	36.85	0.24	96.26	357.08	-21.92	123.00	-5.29	-0.55	27.55	28.79	-206.67	89.00
Detroit	-0.54	.	.	-0.54	-0.54	1.00	.	.	.	.	.	0.00
Houston	6.79	0.71	33.24	120.00	-72.16	48.00	-10.68	-0.60	38.21	16.88	-163.16	35.00
Kansas City	-1.34	-0.70	9.08	40.63	-24.70	95.00	-22.28	-0.32	54.48	61.78	-182.35	57.00
Las Vegas	-2.58	-1.51	28.73	56.28	-82.67	54.00	-13.68	-0.35	38.42	7.27	-163.16	63.00
Minneapolis	-1.80	-0.40	8.27	58.65	-19.00	132.00	-13.41	-0.28	29.73	23.97	-157.89	65.00
New York	-4.12	-0.14	8.68	19.21	-45.59	216.00	-1.00	-3.48	41.31	128.17	-182.35	142.00
Philadelphia	-0.65	-1.44	7.77	17.29	-33.67	69.00	-12.14	-0.47	46.32	49.30	-206.67	67.00
Portland	1.39	0.86	6.44	18.08	-8.49	29.00	-23.33	-0.50	76.07	207.66	-250.00	42.00
Sacramento	524.95	0.25	789.77	2968.26	-47.35	36.00	-8.62	-0.70	49.30	121.04	-176.47	67.00
Saint Louis	-6.06	-0.15	1.31	-5.13	-6.98	2.00	.	.	.	.	.	0.00
Tucson	-13.65	-0.59	48.60	57.61	-123.02	37.00	-22.72	-0.32	55.39	51.17	-206.67	57.00

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Static Model 1: Historical Average of HDD

$$\overline{HDD}^{HIST}_{i,y,m} \equiv \frac{1}{y - y_0} \sum_{y'=y_0}^{y-1} HDD_{i,y',m}$$

Static Model 2: MOS 7-day Forecasts (adjusted)

$$\overline{HDD}^{MOS}_{i,y,m} \equiv D(y,m) HADJ_{i,y,m,7} \frac{1}{7} \sum_{j=1}^{7} \overline{HDD}^{MOS}_{i,y,m-1,D(y,m-1),j}$$

Static Model 3: Market HDD on last day trading of prior month

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Question: How do you measure model success?

MAE = mean absolute error

$$MAE = \frac{1}{N}\sum_{i=1}^{N} | (HDD_{Forecast} - HDD_{Actual}) |$$

RMSE = room mean squared error

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (HDD_{Forecast} - HDD_{Actual})^2}$$

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Table 8: Static Models' Forecast Performance

		Historical		MOS Forecasts		Market	
Contract Type	Statistics	RMSE	MAE	RMSE	MAE	RMSE	MAE
HDD	Mean	99.36	72.50	166.04	118.83	47.93	37.86
	Max	146.08	106.53	244.49	158.38	95.95	73.29
	Min	52.04	36.58	97.56	79.51	12.17	10.63
	nobs	470.00	470.00	452.00	452.00	158.00	158.00
CDD	Mean	54.86	40.13	209.46	111.61	33.25	28.56
	Max	92.14	69.94	436.12	202.84	57.43	44.67
	Min	25.98	19.53	96.66	68.53	8.60	7.00
	nobs	340.00	340.00	323.00	323.00	74.00	74.00

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Table 9: Static Models' Forecast Performance By City

City	Historical			MOS Forecasts				Market			
	RMSE	nobs	MAE	nobs	RMSE	nobs	MAE	nobs	RMSE	nobs	MAE	nobs
	HDD											
at	86.34	24.00	59.09	24.00	205.75	23.00	132.43	23.00	44.62	13.00	34.73	13.00
ba	94.62	27.00	68.85	27.00	137.77	26.00	108.96	26.00	65.78	5.00	52.70	5.00
bo	84.88	29.00	58.83	29.00	139.49	28.00	105.41	28.00	40.44	11.00	32.05	11.00
ch	124.50	29.00	87.33	29.00	188.12	28.00	138.07	28.00	73.75	15.00	57.00	15.00
ck	128.76	26.00	87.91	26.00	210.97	25.00	154.51	25.00	75.50	17.00	65.35	17.00
da	104.11	21.00	76.18	21.00	193.57	20.00	122.64	20.00	77.48	10.00	62.85	10.00
dm	142.29	27.00	100.03	27.00	216.76	26.00	149.51	26.00	95.95	12.00	72.25	12.00
de	120.27	29.00	89.22	29.00	152.75	28.00	119.73	28.00	.	0.00	.	0.00
ho	65.76	21.00	46.55	21.00	151.54	20.00	94.46	20.00	35.29	3.00	27.67	3.00
kc	138.11	26.00	96.25	26.00	209.16	25.00	147.91	25.00	94.36	14.00	73.29	14.00
lv	84.18	22.00	69.86	22.00	97.56	21.00	79.51	21.00	34.77	10.00	21.55	10.00
mn	146.08	28.00	106.53	28.00	205.99	27.00	158.38	27.00	64.53	11.00	49.55	11.00
ny	109.60	28.00	81.52	28.00	144.58	27.00	106.37	27.00	54.14	16.00	43.44	16.00
ph	104.22	28.00	79.10	28.00	129.33	27.00	98.92	27.00	30.93	7.00	24.00	7.00
po	52.74	30.00	41.65	30.00	132.55	29.00	87.38	29.00	48.75	6.00	43.50	6.00
sa	52.04	27.00	36.58	27.00	125.45	26.00	91.65	26.00	12.17	4.00	11.00	4.00
sl	85.32	28.00	65.57	28.00	244.49	27.00	156.85	27.00	.	0.00	.	0.00
tu	64.61	20.00	53.98	20.00	102.89	19.00	86.32	19.00	14.24	4.00	10.63	4.00

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Table 10: Static Models' Forecast Performance By Month

Month	Historical			MOS Forecasts				Market			
	RMSE	nobs	MAE	nobs	RMSE	nobs	MAE	nobs	RMSE	nobs	MAE	nobs
						HDD						
1.00	184.35	54.00	151.31	54.00	130.94	54.00	122.15	54.00	67.25	28.00	57.05	28.00
2.00	95.27	54.00	78.24	54.00	136.06	54.00	123.39	54.00	42.75	30.00	38.11	30.00
3.00	92.11	54.00	80.01	54.00	160.35	54.00	130.90	54.00	40.55	26.00	37.37	26.00
4.00	77.65	54.00	69.54	54.00	65.53	54.00	53.56	54.00	31.94	5.00	29.56	5.00
5.00	49.52	29.00	44.07	29.00	81.28	29.00	69.38	29.00	.	0.00	.	0.00
6.00	16.56	23.00	15.16	23.00	12.96	23.00	12.12	23.00	.	0.00	.	0.00
7.00	8.08	3.00	8.08	3.00	2.34	3.00	2.34	3.00	.	0.00	.	0.00
8.00	5.79	11.00	5.75	11.00	7.03	11.00	7.00	11.00	.	0.00	.	0.00
9.00	27.86	27.00	24.22	27.00	54.87	27.00	53.06	27.00	.	0.00	.	0.00
10.00	64.93	53.00	55.57	53.00	181.24	35.00	172.83	35.00	45.07	11.00	43.32	11.00
11.00	70.78	54.00	64.49	54.00	193.20	54.00	159.16	54.00	29.94	26.00	27.65	26.00
12.00	110.87	54.00	91.79	54.00	262.55	54.00	224.98	54.00	81.25	32.00	73.37	32.00
						CDD						
1.00	5.19	6.00	4.31	6.00	8.13	6.00	7.03	6.00	.	0.00	.	0.00
2.00	4.79	8.00	4.01	8.00	8.62	8.00	7.76	8.00	.	0.00	.	0.00
3.00	17.43	23.00	15.43	23.00	23.23	23.00	20.29	23.00	.	0.00	.	0.00
4.00	18.83	48.00	14.96	48.00	115.75	48.00	105.99	48.00	14.00	1.00	14.00	1.00
5.00	51.25	36.00	47.38	36.00	189.96	36.00	180.90	36.00	55.63	4.00	55.63	4.00
6.00	56.63	36.00	51.57	36.00	376.65	36.00	357.95	36.00	32.26	19.00	29.02	19.00
7.00	72.92	36.00	65.83	36.00	76.73	36.00	70.71	36.00	33.84	16.00	31.13	16.00
8.00	79.90	36.00	74.22	36.00	122.03	36.00	116.77	36.00	41.97	18.00	39.04	18.00
9.00	55.99	36.00	51.44	36.00	56.21	36.00	51.18	36.00	31.56	14.00	30.52	14.00
10.00	36.32	50.00	30.62	50.00	55.12	33.00	52.92	33.00	7.50	2.00	7.50	2.00
11.00	23.51	18.00	20.23	18.00	17.12	18.00	14.30	18.00	.	0.00	.	0.00
12.00	7.64	7.00	7.00	7.00	11.37	7.00	9.51	7.00	.	0.00	.	0.00

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Three dynamic models in the sense, that every day of the month there is a new forecast based on information about weather that occurred up that point in the month.

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Dynamic Model 1: Current Month's Average (adjusted)

$$\overline{HDD}^{HIST}_{i,y,m,d} \equiv D(y,m) HADJ_{i,y,m,d} \frac{1}{d} \left(\sum_{d'=1}^{d} HDD'_{i,y,m,d} \right)$$

Dynamic Model 2: MOS 7-day Forecasts (adjusted)

$$\overline{HDD}^{MOS}_{i,y,m,d} \equiv D(y,m) HADJ_{i,y,m,d+k} \frac{1}{d+k} \left(\sum_{d'=1}^{d} HDD_{i,y,m,d} + \sum_{j=1}^{k} \overline{HDD}^{MOS}_{i,y,m,d,j} \right)$$

Dynamic Model 3: Market HDD on prior day

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Table 11: Dynamic Models' Forecast Performance

		Historical		MOS Forecasts		Market	
Contract Type	Statistics	RMSE	MAE	RMSE	MAE	RMSE	MAE
HDD	Mean	171.18	88.17	144.13	71.19	36.74	27.48
	Max	336.10	136.04	273.20	107.94	58.34	53.50
	Min	80.12	50.56	52.16	32.79	1.50	1.50
	nobs	14268.00	14268.00	13392.00	13392.00	1052.00	1052.00
CDD	Mean	135.44	57.01	122.88	52.31	21.89	16.33
	Max	232.76	102.03	245.27	99.99	33.42	26.86
	Min	88.71	39.45	78.65	31.82	15.40	12.15
	nobs	10381.00	10381.00	9519.00	9519.00	505.00	505.00

IV. Testing for Market Efficiency

2. Market forecasts versus simple alternative models

Table 12: Dynamic Models' Forecast Performance By City

City	Historical				MOS Forecasts				Market			
	RMSE	nobs	MAE	nobs	RMSE	nobs	MAE	nobs	RMSE	nobs	MAE	nobs
	HDD											
at	179.65	729.00	92.75	729.00	162.44	676.00	84.95	676.00	48.40	70.00	26.54	70.00
ba	163.89	819.00	80.97	819.00	163.22	763.00	74.42	763.00	35.33	30.00	27.07	30.00
bo	120.53	881.00	71.67	881.00	102.45	823.00	60.18	823.00	40.34	53.00	32.01	53.00
ch	196.89	881.00	106.18	881.00	151.19	823.00	80.85	823.00	42.53	134.00	31.59	134.00
ck	336.10	789.00	136.04	789.00	273.20	734.00	107.94	734.00	43.74	101.00	32.26	101.00
da	278.92	637.00	118.86	637.00	198.69	616.00	87.57	616.00	33.90	66.00	25.02	66.00
dm	198.29	820.00	113.41	820.00	168.49	764.00	93.23	764.00	58.34	79.00	40.68	79.00
de	145.61	881.00	89.13	881.00	124.37	823.00	71.25	823.00	1.50	1.00	1.50	1.00
ho	173.57	637.00	80.81	637.00	124.59	616.00	58.49	616.00	32.24	31.00	22.76	31.00
kc	191.06	789.00	109.04	789.00	169.66	734.00	86.93	734.00	38.13	83.00	27.89	83.00
lv	80.12	668.00	50.56	668.00	52.16	646.00	32.79	646.00	25.90	37.00	20.51	37.00
mn	183.82	850.00	109.37	850.00	149.18	793.00	84.08	793.00	42.35	97.00	31.19	97.00
ny	115.05	850.00	69.79	850.00	112.57	793.00	62.76	793.00	40.30	150.00	30.80	150.00
ph	117.97	850.00	72.55	850.00	106.28	793.00	60.08	793.00	31.83	52.00	23.00	52.00
po	110.47	912.00	55.88	912.00	103.07	853.00	45.62	853.00	30.21	16.00	21.56	16.00
sa	159.48	819.00	71.53	819.00	142.92	763.00	63.64	763.00	28.86	17.00	19.29	17.00
sl	227.54	850.00	102.75	850.00	228.93	793.00	92.14	793.00	53.78	2.00	53.50	2.00
tu	102.29	606.00	55.76	606.00	60.89	586.00	34.54	586.00	33.71	33.00	27.55	33.00

IV. Testing for Market Efficiency

Table 14: Dynamic Models Forecast Performance By Day of Month

	Historical				MOS Forecasts				Market			
Day	RMSE	nobs	MAE	nobs	RMSE	nobs	MAE	nobs	RMSE	nobs	MAE	nobs
						HDD						
1.00	309.46	470.00	208.43	470.00	263.63	456.00	175.08	456.00	48.27	95.00	41.74	95.00
2.00	333.45	470.00	215.12	470.00	282.01	456.00	183.75	456.00	50.72	74.00	43.73	74.00
3.00	348.88	470.00	220.45	470.00	300.34	456.00	191.25	456.00	31.52	70.00	26.96	70.00
4.00	302.25	470.00	194.79	470.00	253.52	456.00	163.98	456.00	40.19	78.00	34.12	78.00
5.00	252.61	470.00	168.95	470.00	216.98	456.00	139.88	456.00	41.15	92.00	34.90	92.00
6.00	237.32	470.00	157.90	470.00	197.18	456.00	128.49	456.00	33.87	86.00	28.40	86.00
7.00	221.04	470.00	151.00	470.00	172.08	456.00	113.96	456.00	35.14	83.00	29.03	83.00
8.00	205.31	470.00	143.88	470.00	154.91	456.00	104.11	456.00	29.93	73.00	25.99	73.00
9.00	188.03	470.00	132.78	470.00	137.32	456.00	91.16	456.00	29.78	77.00	24.99	77.00
10.00	169.28	470.00	120.07	470.00	130.98	456.00	86.25	456.00	26.10	61.00	22.94	61.00
11.00	150.89	470.00	107.05	470.00	121.93	456.00	78.94	456.00	23.90	52.00	20.23	52.00
12.00	135.41	470.00	95.61	470.00	106.81	456.00	70.15	456.00	17.37	49.00	13.78	49.00
13.00	122.95	470.00	85.91	470.00	98.66	456.00	64.20	456.00	18.22	37.00	15.14	37.00
14.00	112.36	470.00	78.80	470.00	95.21	456.00	61.48	456.00	15.93	34.00	13.58	34.00
15.00	107.56	470.00	75.47	470.00	88.81	456.00	58.20	456.00	10.36	34.00	8.89	34.00
16.00	96.89	470.00	70.14	470.00	78.15	456.00	52.35	456.00	7.66	26.00	7.03	26.00
17.00	89.56	470.00	64.91	470.00	70.96	456.00	47.23	456.00	3.35	14.00	3.29	14.00
18.00	81.87	470.00	59.48	470.00	60.84	456.00	41.14	456.00	2.01	7.00	1.95	7.00
19.00	73.02	470.00	54.34	470.00	53.07	456.00	37.15	456.00	7.63	6.00	6.69	6.00
20.00	66.85	470.00	49.47	470.00	44.89	456.00	32.09	456.00	3.50	1.00	3.50	1.00
21.00	60.47	470.00	44.94	470.00	40.68	456.00	29.48	456.00	4.00	1.00	4.00	1.00
22.00	54.11	470.00	39.00	470.00	38.07	456.00	27.94	456.00	11.00	1.00	11.00	1.00
23.00	45.09	470.00	32.91	470.00	32.23	456.00	24.45	456.00	.	0.00	.	0.00
24.00	36.89	470.00	27.08	470.00	27.08	456.00	21.09	456.00	321.50	1.00	321.50	1.00
25.00	30.66	470.00	22.66	470.00	24.60	456.00	19.19	456.00	.	0.00	.	0.00
26.00	25.74	470.00	19.31	470.00	21.15	456.00	16.42	456.00	.	0.00	.	0.00
27.00	20.69	470.00	15.46	470.00	18.15	456.00	13.73	456.00	.	0.00	.	0.00
28.00	15.28	470.00	10.98	470.00	13.82	420.00	10.35	420.00	.	0.00	.	0.00
29.00	10.49	434.00	7.56	434.00	9.37	402.00	6.68	402.00	.	0.00	.	0.00
30.00	4.77	416.00	2.93	416.00	5.12	258.00	3.88	258.00	.	0.00	.	0.00
31.00	0.00	258.00	0.00	258.00	.	0.00		0.00	.	0.00	.	0.00

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises

- On Tuesday, weather is much higher than expected, do market participants overreact or underreact to the news???

- If they do either systematically, markets are not efficient, if they don't, in line with efficiency.

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises

- Surprise Measure 1: T – E(T), where E(T) = average temperature historically on that day.
- Surprise Measure 2: T – E(T), where E(T) is the MOS forecast for that particular day.
- Surprise Measure 3: T – E(T), where E(T) is the implied temperature extracted from market prices that day

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises

Methodology:

(1) Split surprises into quintiles (lowest to highest).

(2) On days of surprise compute the returns to buying HDD or CDD contracts at the close of trading.

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises

   If overreaction should see:

   HDD: Higher returns in quintile 5 versus quintile 1.

   CDD: Lower returns in quintile 5 versus quintile 1.

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises

   LOGIC:

   Tuesday: Temperature lower (higher) than expected. I infer too much for this on rest of month's weather and thus trade HDD too high (too low) versus rational investor. Thus, buying HDD contract at close should lead to lower (higher) than average returns.

   CDD are the reverse.

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises

- Since results are qualitatively the same, will show for the "best" measure of surprise, measure 3.

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises

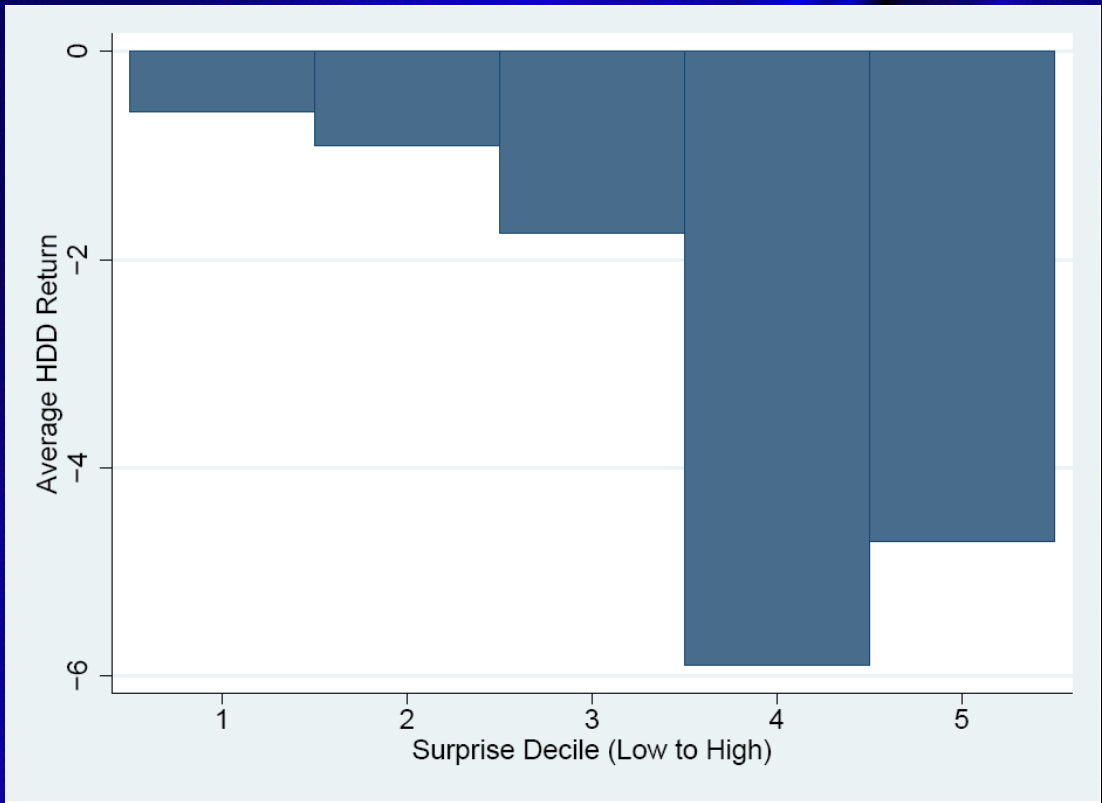


Figure 6: Overreaction to Weather Surprises by Quintile for HDD and Surprise Measure 3

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IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises

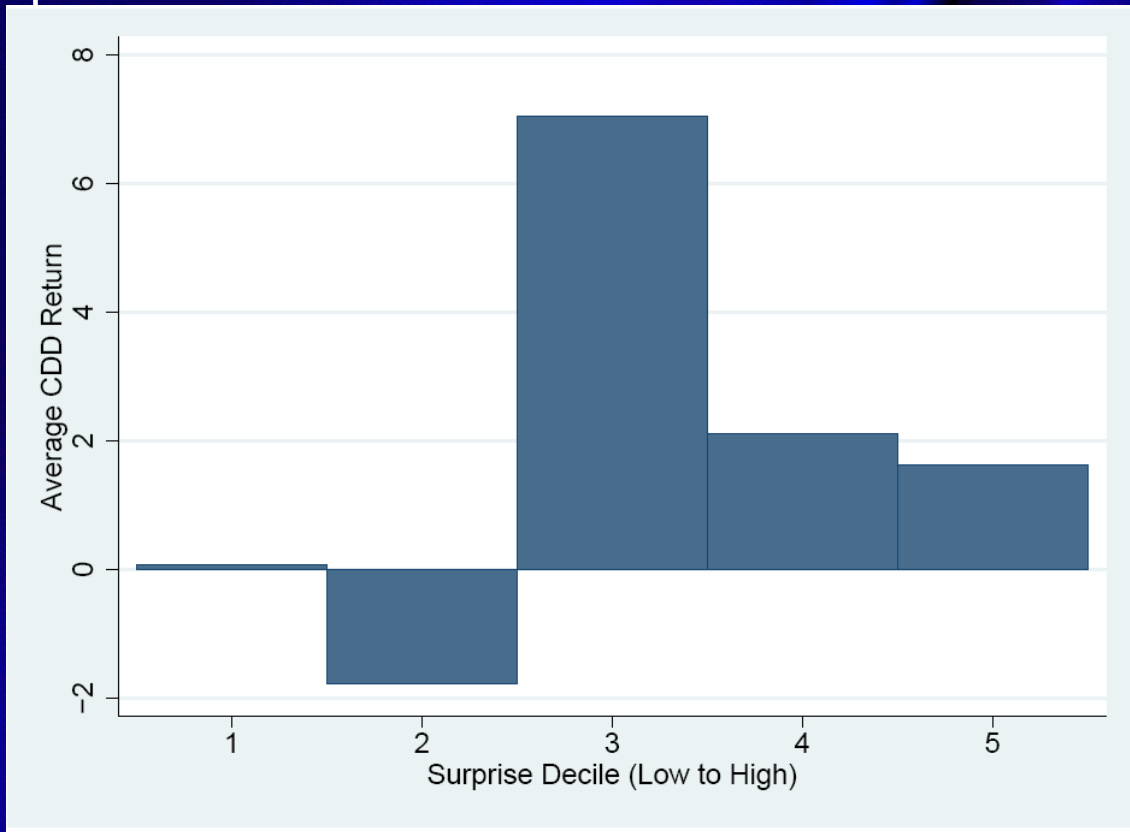

Figure 7: Overreaction to Weather Surprises by Quintile for CDD and Surprise Measure 3

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises (2005-2008)

	HDD					CDD				
	Quintile (Lowest to Highest)					Quintile (Lowest to Highest)				
Day	1	2	3	4	5	1	2	3	4	5
1	.	.	.	.	.	.	.	.	.	.
2	-2.07	-1.05	-1.14	0.01	-10.13	13.27	.	-4.17	30.63	.
3	-3.56	-2.89	-2.67	-24.79	0.74	-6.66	3.45	8.72	24.40	.
4	-4.14	-3.58	-11.63	-9.82	-2.61	11.69	-13.29	33.40	4.40	.
5	-6.03	-3.73	-5.59	-2.90	.	-1.58	0.87	2.04	-19.08	-3.39
6	-1.65	-0.69	-5.05	3.61	-0.13	-3.98	-10.55	-4.85	2.44	-16.87
7	-3.42	-1.75	-4.17	2.60	-1.44	2.98	-4.39	-0.32	-1.28	.
8	1.67	-5.71	-2.68	3.46	-4.34	-3.07	0.21	-0.65	4.42	.
9	-1.36	0.27	-3.64	-0.50	-3.78	13.77	1.06	9.64	-5.25	.
10	-0.71	.	-16.13	0.27	-6.74	0.00	-2.03	2.19	7.69	.
11	-0.79	-17.14	-10.75	-3.10	-1.41	1.80	15.49	11.36	2.00	.
12	-1.50	-0.79	-7.44	-1.73	-1.59	3.62	-1.64	2.43	.	.
13	0.21	.	-0.77	.	-0.44	0.62	-4.35	.	.	.
14	-0.12	0.06	-2.34	1.00	.	2.32	.	.	1.18	.
15	-0.13	.	1.47	0.22	0.49	1.16	1.72	.	-1.89	.
16	.	-6.25	1.05	.	.	-0.50	1.06	0.37	-4.35	.
17	-1.03	-0.28	-1.34	.	.	0.65	.	.	.	.
18	.	.	.	.	.	.	.	.	.	.
19	.	.	.	.	.	0.00	.	.	.	.
20	.	.	.	.	.	.	.	.	.	.
21	.	.	.	.	.	.	.	.	.	.
22	.	.	.	.	.	.	.	.	.	.
23	.	.	.	.	.	.	.	.	.	.
24	.	.	.	.	.	.	.	.	.	.
25	.	.	.	.	.	.	.	.	.	.
26	.	.	.	.	.	.	.	.	.	.
27	.	.	.	.	.	.	.	.	.	.
28	.	.	.	.	.	.	.	.	.	.
29	.	.	.	.	.	.	.	.	.	.
30	.	.	.	.	.	.	.	.	.	.
31	.	.	.	.	.	.	.	.	.	.

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises (1999-2008)

	HDD					CDD				
	Quintile (Lowest to Highest)					Quintile (Lowest to Highest)				
Day	1	2	3	4	5	1	2	3	4	5
1	.	.	.	.	.	.	.	.	.	.
2	59.12	0.20	59.92	0.63	-9.59	9.65	3.83	-17.76	8.35	12.04
3	96.65	1.71	-7.33	-10.74	-6.72	-0.52	-8.48	12.05	13.49	49.45
4	-3.31	1.31	-2.40	-5.23	-4.51	8.57	4.48	19.84	-6.27	-8.73
5	1.00	-3.44	4.25	-3.34	-0.16	-4.47	-7.01	6.95	.	-13.85
6	2.26	-0.44	-4.43	3.61	-0.13	-1.14	-2.38	-10.73	2.31	-2.69
7	-2.94	-2.36	42.27	-0.83	-0.63	1.37	-3.50	2.65	1.92	-4.28
8	82.66	-6.15	16.05	2.41	0.13	1.50	-3.16	-1.56	8.29	-0.10
9	97.46	-2.12	-0.24	0.27	-1.64	2.27	13.72	3.03	-2.55	11.10
10	96.55	1.15	-7.85	-2.28	-5.15	-14.81	-1.07	2.59	-1.57	0.18
11	2.42	-14.77	-4.85	-4.71	-1.99	1.75	9.21	-7.41	3.00	-13.93
12	0.92	-2.13	.	-2.04	-1.73	1.12	6.30	2.40	2.43	1.20
13	0.21	.	-0.77	.	0.88	0.31	-3.90	.	.	.
14	-0.32	0.13	-2.34	1.00	.	1.59	.	0.64	1.26	-1.38
15	-0.13	.	0.98	0.39	0.49	2.21	1.72	-0.69	-1.10	0.18
16	1.47	.	-8.22	0.73	.	0.44	.	0.60	-2.60	.
17	-5.43	0.05	-0.96	-1.34	.	-0.72	.	0.65	.	.
18	.	.	.	0.32	.	.	.	.	.	.
19	.	.	.	.	.	.	0.00	.	.	.
20	20.00	.	.	.	.	.	.	.	.	.
21	.	.	.	.	.	.	.	.	.	.
22	490.99	.	.	.	.	.	.	.	.	.
23	493.39	.	.	.	.	.	.	.	.	.
24	494.71	.	.	.	.	.	.	.	.	.
25	.	.	.	.	.	.	.	.	.	.
26	-3.04	.	.	.	.	.	.	.	.	.
27	.	.	.	.	.	.	.	.	.	.
28	.	.	.	.	.	.	.	.	.	.
29	.	.	.	.	.	.	.	.	.	.
30	.	.	.	.	.	.	.	.	.	.
31	.	.	.	.	.	.	.	.	.	.

IV. Testing for Market Efficiency

3. Overreaction/Underreaction to Weather Surprises (1999-2008)

Day	HDD								CDD							
	Sample Size		t-statistics				Mann-Whitney Tests		Sample Size		t-statistics				Mann-Whitney Tests	
	N_1	N_2	t-stat	p_u	p_l	p	U	z-statistics	N_1	N_2	t-stat	p_u	p_l	p	U	z-statistics
1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2	13.00	9.00	0.93	0.82	0.18	0.36	62.00	-0.23	8.00	4.00	-0.21	0.42	0.58	0.84	20.00	-0.68
3	6.00	7.00	1.14	0.86	0.14	0.28	19.00	0.29	11.00	2.00	-2.23	0.02	0.98	0.05	17.00	-1.18
4	5.00	10.00	0.25	0.60	0.40	0.81	25.00	0.00	8.00	2.00	0.72	0.75	0.25	0.49	4.00	1.04
5	8.00	2.00	0.12	0.55	0.45	0.90	9.00	-0.26	7.00	3.00	1.97	0.96	0.04	0.08	5.00	1.25
6	12.00	2.00	0.39	0.65	0.35	0.70	10.00	0.37	7.00	2.00	-0.05	0.48	0.52	0.96	7.00	0.00
7	13.00	3.00	-0.87	0.20	0.80	0.40	25.00	-0.74	6.00	2.00	0.43	0.66	0.34	0.68	4.00	0.67
8	7.00	7.00	1.04	0.84	0.16	0.32	9.00	1.98	3.00	3.00	0.49	0.68	0.32	0.65	4.00	0.22
9	7.00	5.00	0.85	0.79	0.21	0.41	13.00	0.73	2.00	3.00	-0.97	0.20	0.80	0.40	5.00	-1.15
10	6.00	7.00	1.14	0.86	0.14	0.28	9.00	1.71	1.00	1.00	.	.	.	.	1.00	-1.00
11	3.00	3.00	4.34	0.99	0.01	0.01	0.00	1.96	9.00	1.00	.	.	.	.	1.00	1.22
12	3.00	1.00	.	.	.	.	1.00	0.45	6.00	1.00	.	.	.	.	3.00	0.00
13	1.00	2.00	.	.	.	.	1.00	0.00	.	.	.	.	.	.	.	.
14	.	.	.	.	.	.	.	.	3.00	4.00	0.71	0.75	0.25	0.51	3.00	1.06
15	5.00	1.00	.	.	.	.	4.00	-0.88	2.00	2.00	0.34	0.62	0.38	0.77	2.00	0.00
16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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24	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
25	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
26	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
27	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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30	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

IV. Testing for Market Efficiency

4. Intermarket Efficiency

- Is there evidence across cities? (only done on monthly data).

Step 1: For each beginning of month, compute:

$$\Delta_{y,m}^{Hist} = \begin{pmatrix} \overline{HDD}_{1,y,m}^{HIST} - \overline{HDD}_{2,y,m}^{HIST} & \overline{HDD}_{1,y,m}^{HIST} - \overline{HDD}_{3,y,m}^{HIST} & \cdots \\ & \overline{HDD}_{2,y,m}^{HIST} - \overline{HDD}_{3,y,m}^{HIST} & \cdots \\ & & \ddots \end{pmatrix}$$

which is just historical beginning of month differences between various cities.

IV. Testing for Market Efficiency

4. Intermarket Efficiency

- Is there evidence across cities? (only done on monthly data).

Step 2: For each beginning of month, compute the actual market differences in HDD (or CDD):

$$\Delta_{y,m,d}^{MKT} = \begin{pmatrix} F_{1,y,m,d} - F_{2,y,m,d} & F_{1,y,m,d} - F_{3,y,m,d} & \cdots \\ & F_{2,y,m} - F_{3,y,m} & \cdots \\ & & \ddots \end{pmatrix}$$

which is just the market's HDD differences across cities.

IV. Testing for Market Efficiency

4. Intermarket Efficiency

We then compute the differences in absolute terms across the two matrices. We find the cities with the most extreme deviations and long the short the higher HDD city and go long the lower HDD city in the anticipation that they will converge.

$$\Delta^{MKT}_{y,m,d} - \Delta^{Hist}_{y,m}$$

IV. Testing for Market Efficiency

4. Intermarket Efficiency

Table 31: Tests for Intermarket Efficiency

Sample	r_L	r_S	$r_L - r_S$	nobs	t-stat
2005-2008	-1.65	-1.17	-0.48	14.00	1.00
1999-2008	21.63	-2.79	24.42	21.00	1.00

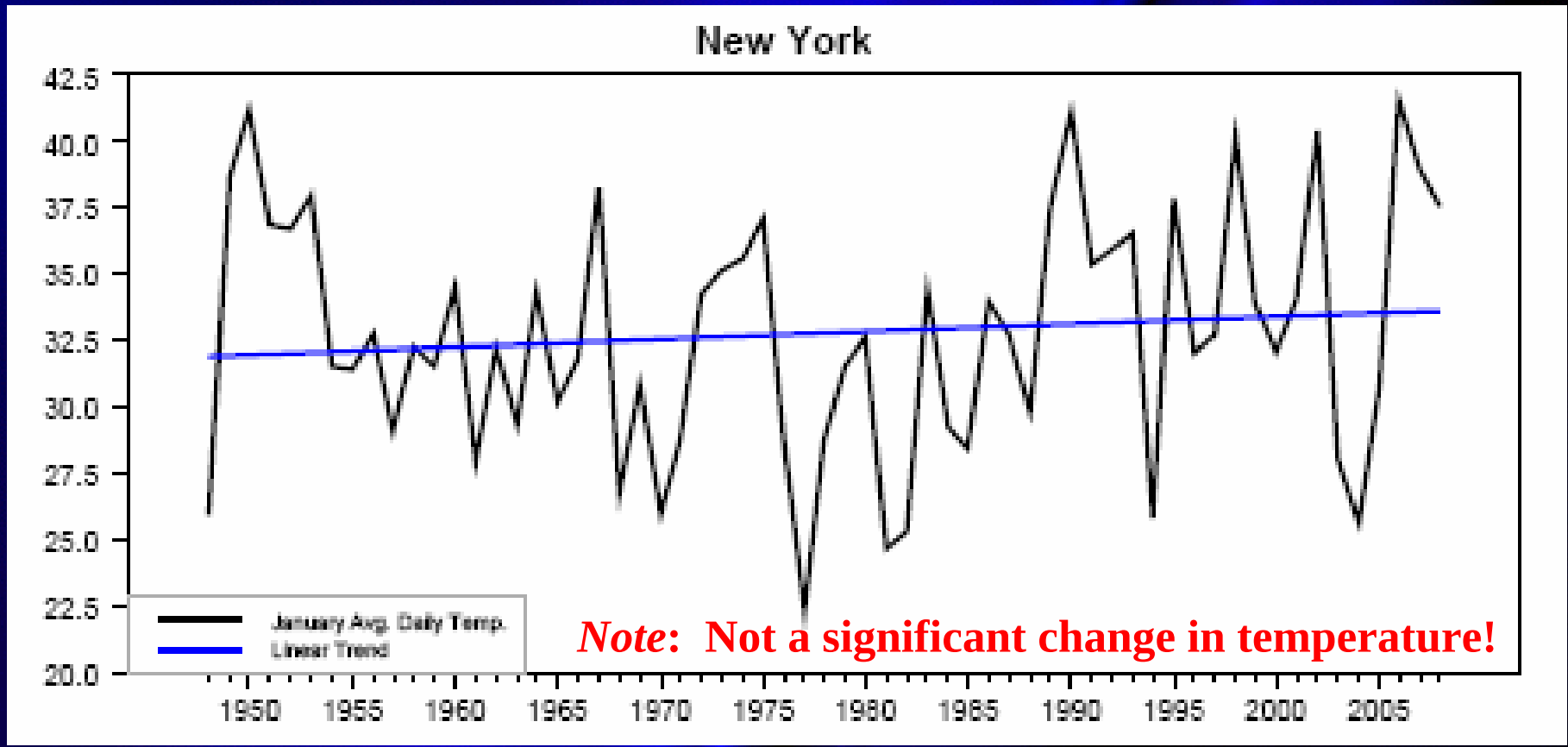
V. "Global Warming" and Trading Weather

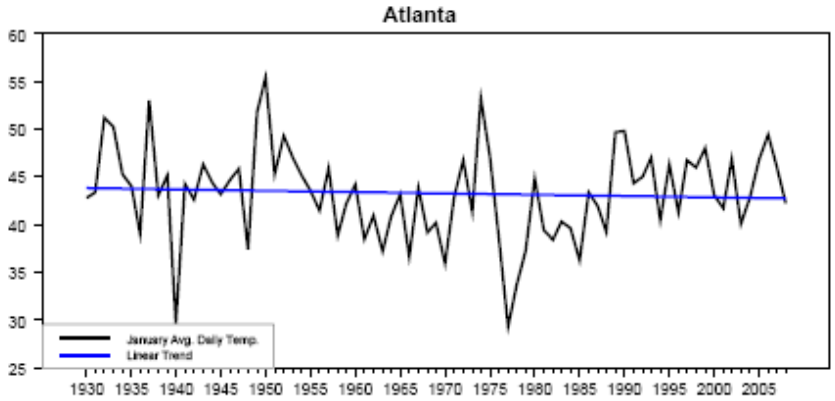
- Take historical data for each city going back as far as recordings were made.
- I actually take the average temperature of a particular month in a particular year and look at that trend. For the graphs that follow, January is used.
- Estimate a simple linear trend and test for significance of this trend (make sure to check for unit roots and all that stuff).

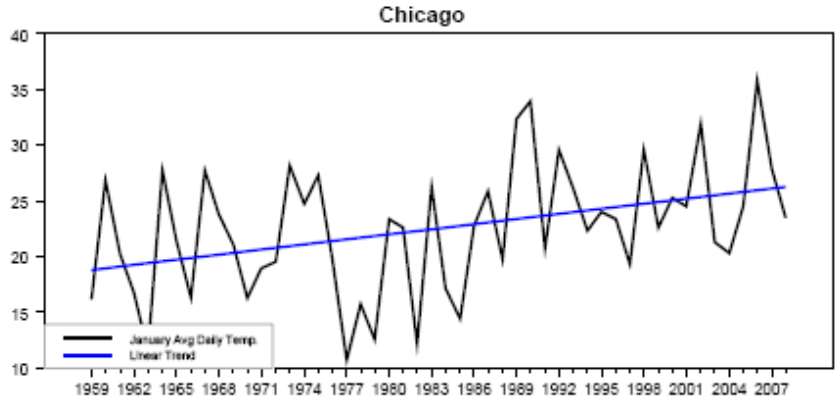
V. "Global Warming" and Trading Weather

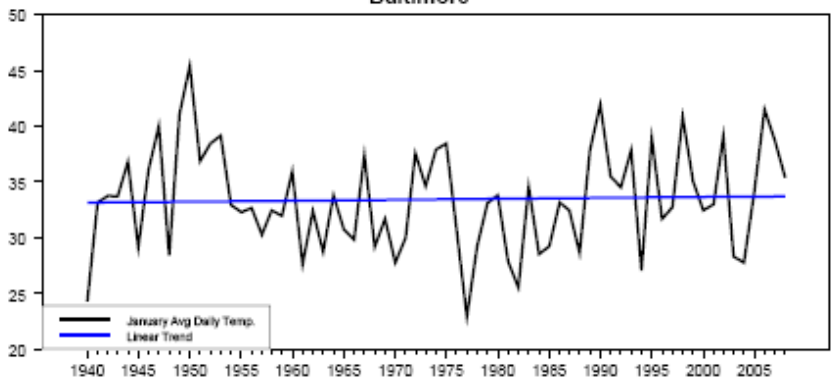
Note 1: Some people call this "heat bloom" which is the rising temperature due to urbanization and buildings. Most of my temperatures were taken at airports, so not clear whether "heat bloom" or "global warming".

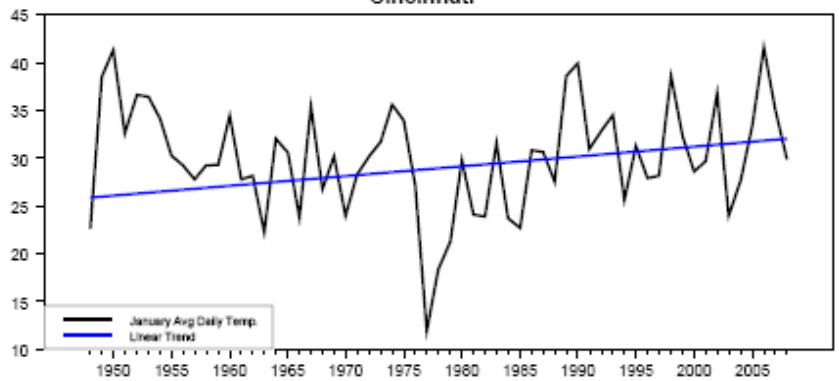
V. "Global Warming" and Trading Weather

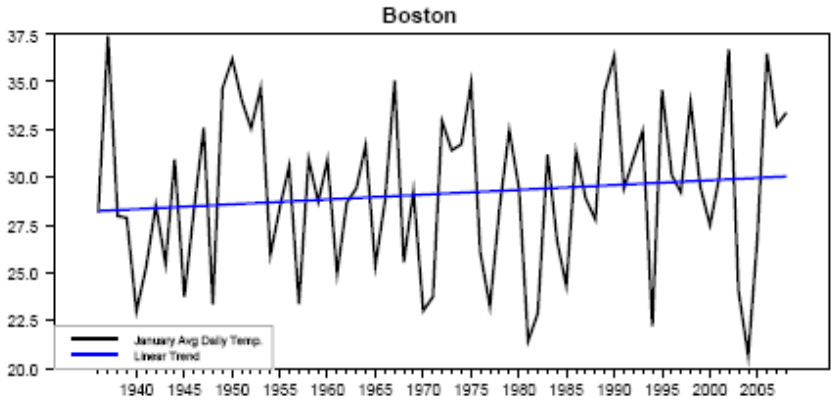


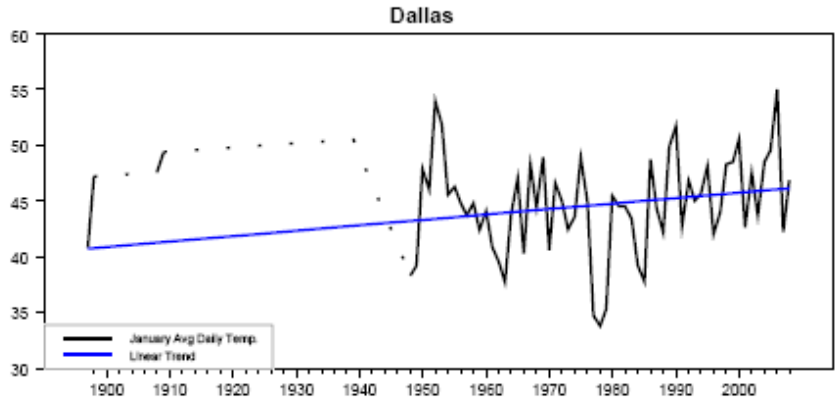

Atlanta
January Avg. Daily Temp.
Linear Trend

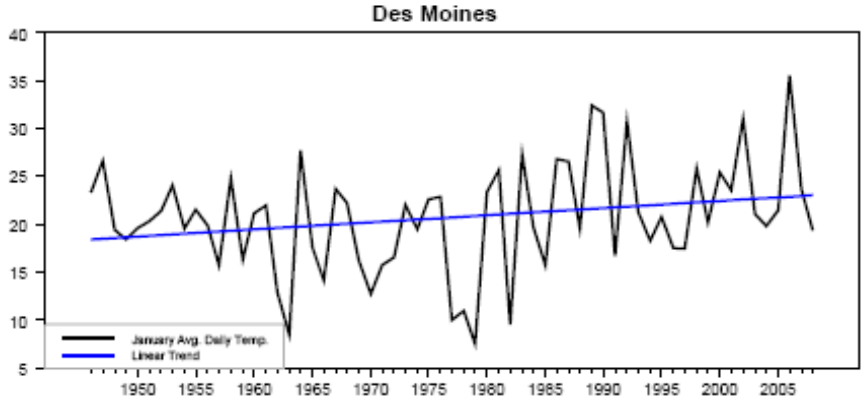

Chicago
January Avg Daily Temp.
Linear Trend

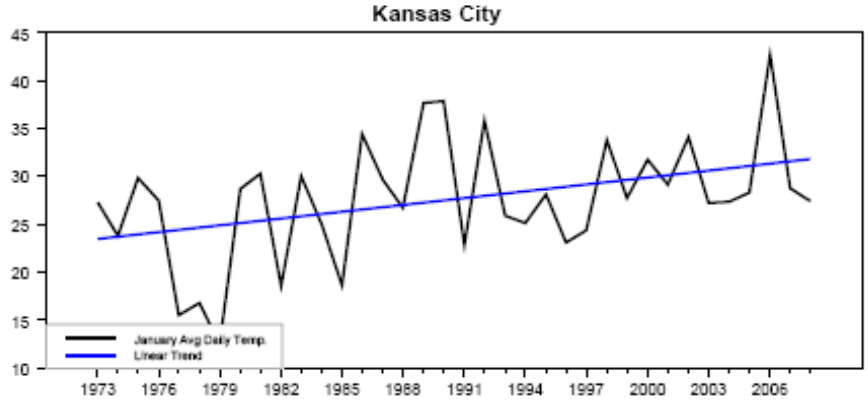

Baltimore
January Avg Daily Temp.
Linear Trend

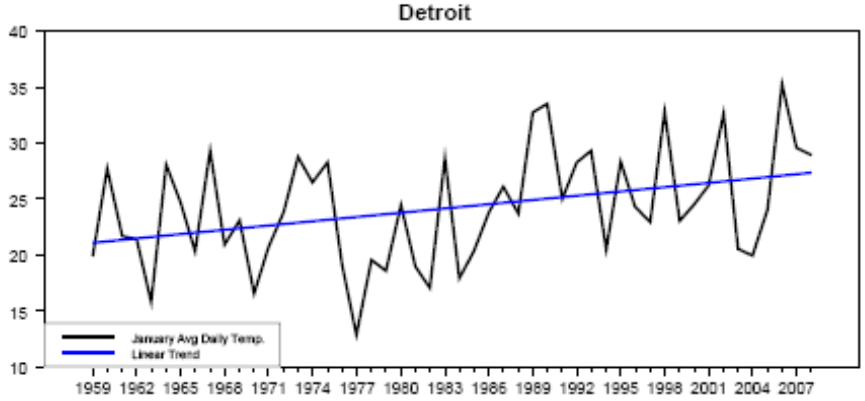

Cincinnati
January Avg Daily Temp.
Linear Trend

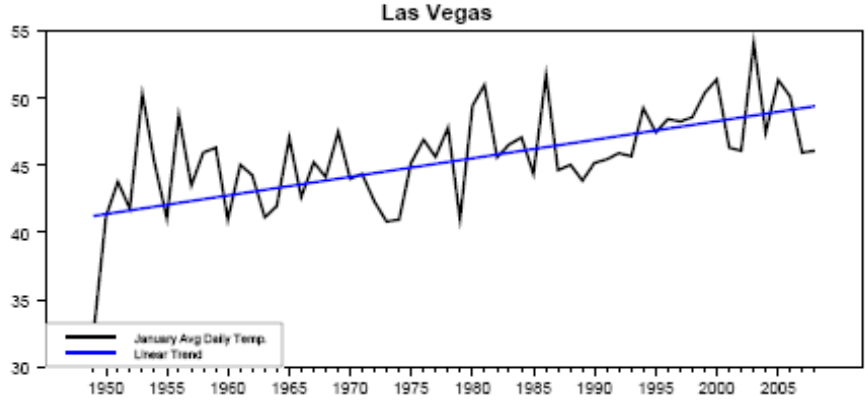

Boston
January Avg Daily Temp.
Linear Trend

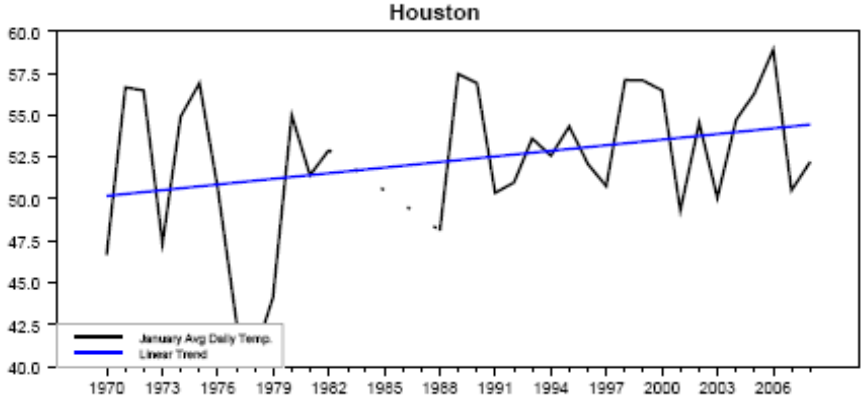

Dallas
January Avg Daily Temp.
Linear Trend

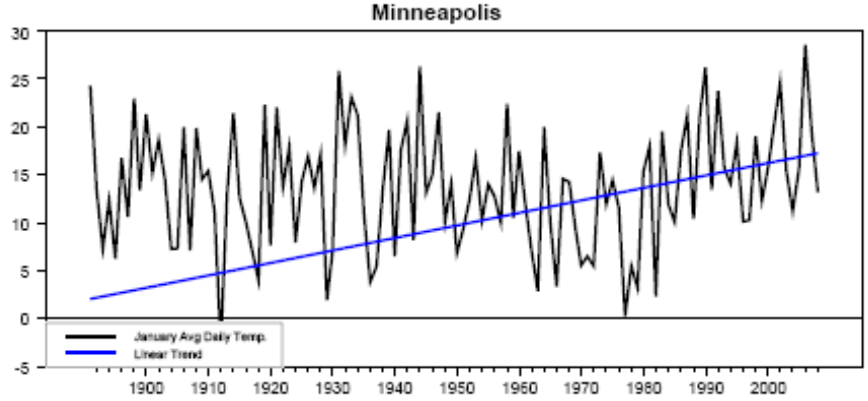

Des Moines
January Avg. Daily Temp.
Linear Trend

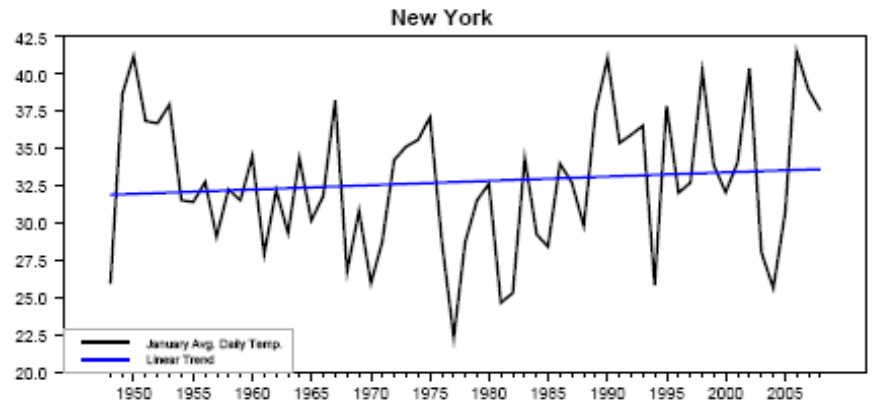

Kansas City
January Avg Daily Temp.
Linear Trend

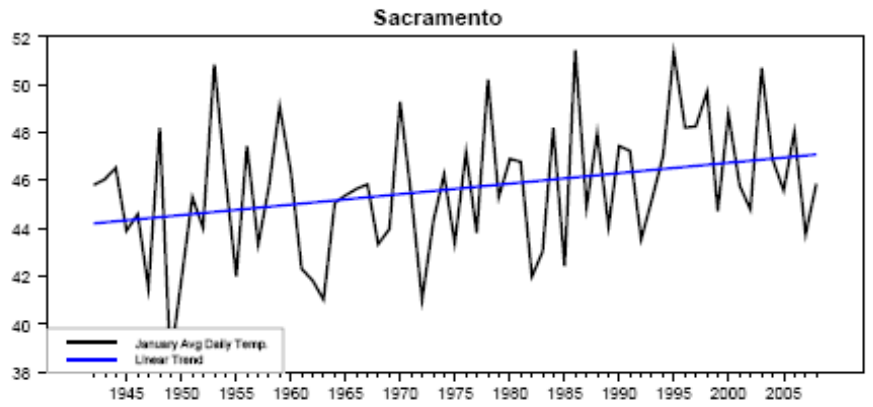

Detroit
January Avg Daily Temp.
Linear Trend

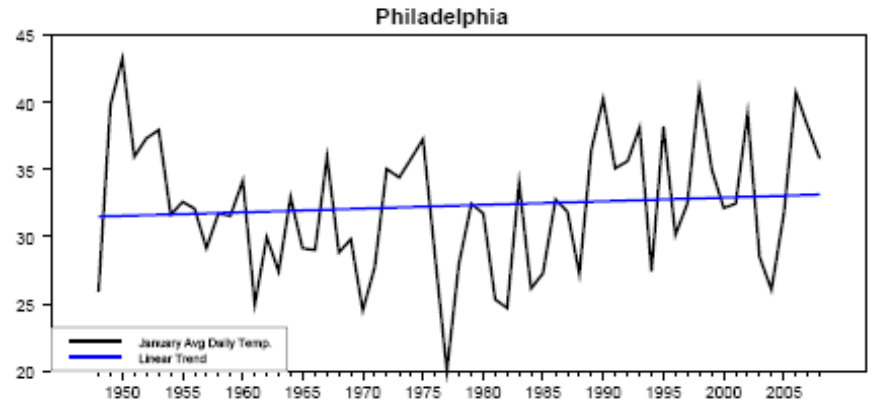

Las Vegas
January Avg Daily Temp.
Linear Trend

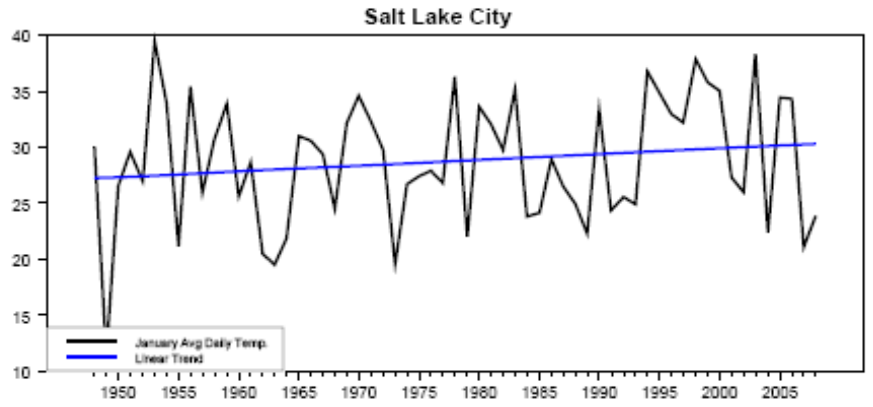

Houston
January Avg Daily Temp.
Linear Trend

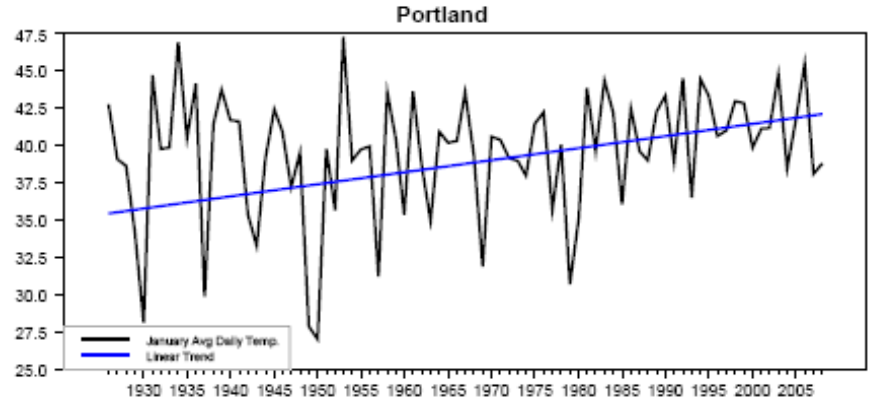

Minneapolis
January Avg Daily Temp.
Linear Trend

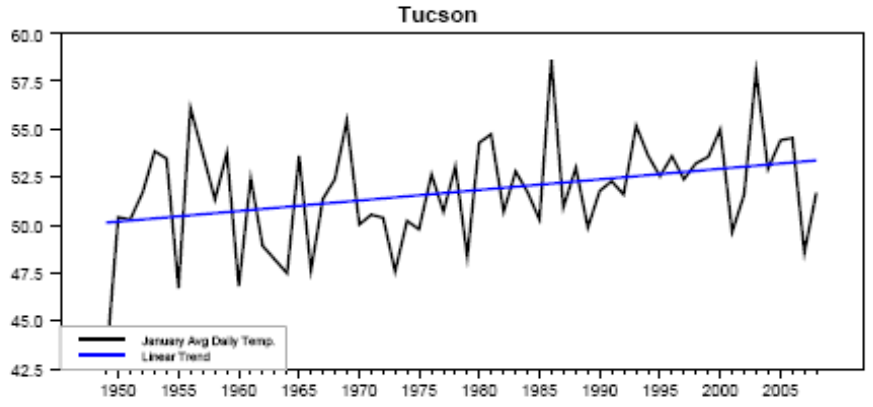

New York
January Avg. Daily Temp.
Linear Trend


Sacramento
January Avg Daily Temp.
Linear Trend


Philadelphia
January Avg Daily Temp.
Linear Trend


Salt Lake City
January Avg Daily Temp.
Linear Trend


Portland
January Avg Daily Temp.
Linear Trend


Tucson
January Avg Daily Temp.
Linear Trend

V. "Global Warming" and Trading Weather

- HDD and CDD Contracts for January and July in 2057.

Table 32: Forecasts for HDD and CDD Contracts for January and July 2057

	HDD (*January 2057*)				CDD (*July 2057*)			
City	2007	Forecast	Upper	Lower	2007	Forecast	Upper	Lower
Atlanta	705.5	666	1009.16	322.84	416.5	540.32*	690.6	390.04
Baltimore	917.5	974.81	1305.21	644.4	369	392.97	533.87	252.07
Boston	979.5	1109.07	1410.27	807.87	245	262.38	393.84	130.91
Chicago	1288	930.84*	1351.73	509.96	271	381.61*	549.42	213.79
Cincinnati	1088	856.15	1267.34	444.97	298	360.6	509.75	211.46
Dallas	576.5	527.32	829.53	225.11	580.5	630.52	791.49	469.54
Des Moines	1414	1100.65*	1503.04	698.26	366.5	369.15	548.99	189.31
Detroit	1118	952.64*	1308.4	596.89	219	375.78*	516.7	234.86
Houston	413	166.47*	508.47	-175.54	532	669.05*	800.76	537.34
Kansas City	1164	660.91*	1195.54	126.28	385.5	355.84	575.04	136.64
Las Vegas	585.5	268.49*	512.55	24.43	941	1047.42*	1251.53	843.32
Minneapolis	1605.5	1198.71*	1651.23	746.2	340	316.78	507.14	126.41
New York	850.5	949.42	1276.57	622.26	394.5	416.96	560.51	273.42
Philadelphia	903.5	965.43	1315.2	615.65	380.5	457.69*	607.66	307.72
Portland	812.5	576*	848.88	303.11	177	241.75*	361.84	121.66
Sacramento	593	461.37*	648.66	274.09	317	361.82	507.87	215.78
Salt Lake City	1275.5	984.09	1387.49	580.7	587.5	567.37*	725.92	408.81
Tucson	413	274.71*	463.42	86.01	709.5	737.86	925.91	549.8

Note: The tables shows actual monthly values for HDD and CDD for January, 2007 and July, 2007 respectively. The forecasts for 2057 are based on a simple linear trend model of the form $HDD_t = \alpha + \beta T + \epsilon$, where T is growing by one for each year in the sample. The upper and lower 95% confidence intervals for the forecasts are also contained in the table. Finally, * represents an in-sample value for the trend coefficient significant at the 95% confidence level. The temperature series were tested for unit roots using Dickey-Fuller tests, in all cases, the hypothesis that the temperature series was a unit root was rejected.

V. "Global Warming" and Trading Weather

- Did some preliminary tests and whether there was a trend in temperature or not seems to be correlated with population growth in cities.
- Perhaps further evidence of man-made creation of global warming?
- More work should be done.

VI. Conclusion

- Weather trading markets seem to be very efficient.
- Even without liquidity and depth.
- No inside information possible.
- Might it also signal that markets without inside information are less likely to be influenced by bubbles and other inefficiencies that might arise from guessing about price movements due to informed traders?

VI. Conclusion

- Other reasons for efficiency:

1. Low volatility in temperature surprises.
2. Short-term nature of market (all contracts expire within one month in my work).

VII. Comments/Suggestions

1. Other ways to test for efficiency?
2. Suggestions/Criticisms of work?