The Value of Weather Forecasts

Evidence from Labor Responses to Accurate Versus Inaccurate Temperature Forecasts in China

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Introduction

Short-term weather forecasts, a common and popular public good in the modern world, affect labor decisions of time allocations. Using a novel dataset of city-level, day-ahead weather forecasts in China collected through video transcriptions over a period of more than 2000 days since 2010, I estimate laborers' hours worked per day as flexible functions of forecast daily maximum temperatures under different historical levels of forecast accuracy (represented by half-year rolling daily maximum temperature forecast RMSE). The results find large-magnitude (up to 4.5 and 1.2 hours per day) labor decreases under uncomfortable temperature forecasts (extreme heat above 30°C and medium cold 15°C-25°C), but only when forecasts are accurate (RMSE ≅ 1°C). By modeling this labor adaptation with weather forecasts, I am able to assess the considerable economic value of accurate weather forecasts. Specifically, 930 Yuan (148 USD, in 2015 currency) is gained per worker per year with each 1°C decrease in city forecast RMSE. For the entire country, an average 3.9% increase in city-level forecast accuracy from 2011 to 2015 generates a social benefit of 25.3 billion Yuan (4.03 billion USD) annually from the labor sector alone, nearly covering the annual cost of the national weather forecasting system.

Data

Weather Forecasts I collect the novel dataset of China's city-level daily weather forecasts by directly transcribing videos of the country's popular and uniform evening weather forecasts TV program, with Google Speech-to-Text API (*Figure 1*). The process provides direct daily forecasts for 31 provincial capital cities or centrally-administered municipalities in Mainland China year 2010 or afterwards, and I approximate the forecasts for 311 non-capital cities[1].
"Real" Weathers Realized daily climate data for 2009-2016 is sourced from ERA-Interim reanalysis data product, aggregated by population weights.
Labor Time-Use Individual reported "last week labor hours" are sourced from CHNS (China Health and Nutrition Survey), 2011 and 2015. After restricting to working age 16-65, the sample covers 52 cities from 12 provinces, over months July-December. Matched observations (with no missing weather forecast days) gives N=11,012.

Figure 1. Weather Forecast Data Collection by Video Transcription.

Step 1: Video File


```
},
{
  "alternatives": [
    {
      "transcript": "北京行淋上午18摄氏度哈尔滨多云转晴0下24到零下14度长春情理想20的零下11度沉阳多云转晴0下17到零下几度天津求零下14度的速度呼和浩特晴转多云0下14到零下一度阿鲁木齐情10下13到零下五度延川晴转多云0下10度到20度西宁行零下15度到七度兰州行零下六度的六度西安多元零下14度到14度拉萨多云转阴零下10度到七度",
      "confidence": 0.97082764
    }
  ]
},
{
  "alternatives": [
    {
      "transcript": "成都因不到10度重庆金七到九都贵阳阴转多云6到12度",
      "confidence": 0.93760645
    }
  ]
},
```


Step 2: Google Transcript

date	city	province	text	tmin	tmax	tavg
01jan2015	北京	北京	北京晴-5度到8度	-5	8	1.5
01jan2015	哈尔滨	黑龙江	哈尔滨多云转晴-24到-14度	-24	-14	-19
01jan2015	长春	吉林	长春晴-20到-11度	-20	-11	-15.5
01jan2015	沈阳	辽宁	沈阳多云转晴-17到-7度	-17	-7	-12
01jan2015	天津	天津	天津晴-4度到4度	-4	4	0
01jan2015	呼和浩特	内蒙古	呼和浩特晴转多云-14到-1度	-14	-1	-7.5
01jan2015	乌鲁木齐	新疆	乌鲁木齐晴-13到-5度	-13	-5	-9
01jan2015	银川	宁夏	银川晴转多云-10度到2度	-10	2	-4

Step 3: Final Cleaned Panel Data

Empirical Design

Measuring Daily Weather Forecast Accuracy Consider the medium-run average forecast accuracy of historical forecasts, measured by the root-mean-squared-error (RMSE) between realized and forecast daily maximum temperature[2] on a rolling window of half a year (R=183 days)[3]:

$$RMSE_{it}^{Tmax} = \sqrt{\frac{1}{R}\sum_{s=1}^{R}(Tmax_{it-s}^{real} - Tmax_{it-s}^{forecast})^2}$$

The RMSE metric features both spatial and temporal variations, and is contributed by various observed and unobserved factors.
Regression with Forecast Accuracy Interaction To answer the question of whether labor decisions respond to weather forecasts[4], I run the baseline regression with a second "treatment" of perceived forecast accuracy (RMSE), assuming labor decisions depend on both next-day forecast, and its perceived reliability:

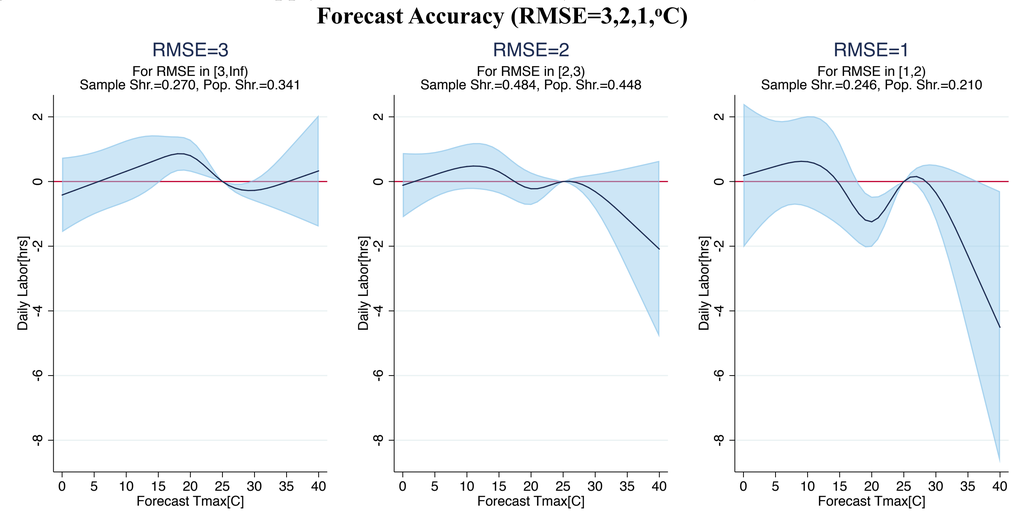
$$Labor_{ikt} = f(Tmax_{it}^{forecast}; \beta_0) + f(Tmax_{it}^{forecast}; \beta_1) \times RMSE_{it} + \gamma' \mathbf{X}_{it} + \epsilon_{ikt}$$

Here index *k* is individual surveyed, *i* is the city where forecast reflects, *t* is day (the 24-hour forecast is reported the previous night on *t-1*). Flexible function *f(.)* is taken restricted cubic spline with 5 knots, (5, 15, 20, 25, 35) (unit: °C). All variables sum up to weekly in match with the labor outcome variable. Controls include linear RMSE, quadratic realized precipitation, month and city fixed effects. Standard errors are clustered by cities.

Results

Reduced Labor Time Under Accurate Hot or Medium-Cold Temperature Forecasts As shown by the regression result (*Figure 2*), daily labor working hours on average decrease relative to 25°C (the human comfortable daily maximum temperature) under hot forecasts greater than 30°C, or medium-cold forecasts around 20°C[5]. In terms of the marginal effect, per 1°C decrease in forecast RMSE, labor hours per day is reduced (relative to 25°C) by 1.14 hours under 35°C of daily maximum temperature forecast, and 1.02 hours under 20°C.
Heterogeneity Analysis Allowing the labor-forecast relationship to vary by subgroups determined with labor characteristics, I estimate that the significant labor response to weather forecast accuracy is prominent only among the more "vulnerable" workers of higher age, lower education level, lower income, lower wage rate, or living rural. This is consistent with the theory of labor, where utility trade-off between working under uncomfortable temperatures and earnings for consumption determines the decision on daily labor supply.

Figure 2. Estimated Labor Supply (Hours Worked Per Day) Relative to 25°C, Under Different Perceived Forecast Accuracy (RMSE=3,2,1,°C)



Welfare Analysis

Based on the empirical results, I construct a single-period utility maximization model where labors choose their optimal working hours for the next day given today's weather forecast and its perceived accuracy. I evaluate worker's welfare as a function of weather forecast accuracy, using the main regression estimates, plus the referenced Chinese labor supply elasticity value. Main welfare analysis results are:

1. Worker welfare decreases with greater RMSE under hot or medium-cold realized temperatures.
2. Per unit (1°C) RMSE decrease contributes to an average welfare gain of 930 Yuan (148 USD) per worker per year (2015 currency).
3. Given the average 3.9% decrease of city-year average forecast RMSE from 2011 to 2015, the nation gains 25.3 billion (4.03 billion USD) annually (2015 currency) from the labor sector alone.

This valuation is of same order of magnitudes as the US mortality-forecast study (Shrader, Lemoine, and Bakkensen, 2023)[6]. It is also comparable to the annual expenditure of the agent managing these weather forecasts, China Meteorology Administration (26.3 billion Yuan in 2015).

Conclusions

This research shows that accurate day-ahead temperature forecasts affect the labor decisions of hours worked per day under hot and medium-cold temperature forecasts, but only when these forecasts are perceived as accurate. Through welfare analysis, I have found that the value of improving temperature forecast accuracy is high in modern society. Saving the disutilities working under uncomfortable temperatures in the labor sector alone would generate almost enough social benefit to cover the financial costs to maintain the national weather forecasting system. When more extremal weather events are expected under climate change, this highlights the importance of investing in forecasting technologies to enhance more reliable weather projections into the future.

References and Footnotes

1. By adjusting the forecasts of their provincial capital with the difference of the monthly average real temperatures in the previous year between non-capital and capital cities, the approximation results are not statistically different from existing provincial level forecasts for non-capital cities available on the Internet.
2. *Tmax* is chosen because labor activities are most relevant to daytime temperatures.
3. The particular definition of RMSE and rolling window size R is chosen based on maximized explanatory power of the main regression.
4. Standard global regression (estimating labor supply as a flexible function of forecast temperatures) cannot identify the impacts from forecasts, because forecast and realized temperatures are over 90% correlated.
5. The sensitivity to medium-cold is concentrated in the subsample of Southern China, which comes with lower winter heating accessibility, thus implying the substitutional relationship between heating and accurate forecasts both facilitate workers' adaptations to cold weathers.
6. Shrader, Jeffrey G., Laura Bakkensen, and Derek Lemoine. *Fatal Errors: The Mortality Value of Accurate Weather Forecasts*. No. w31361. National Bureau of Economic Research, 2023.

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