Joint-Outcome Information Markets for Climate Risks

Conditional Forecasting with the LMSR

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- ▶ Roulston, Kaivanto: "Joint-outcome prediction markets for climate risks", under review
- Roulston, Kaivanto: "Can expert prediction markets forecast climate-related risks? Probabilistic calibration and information-add", under review
- Roulston, Day, Kaplan, Kaivanto: "Prediction-market innovations can improve climate-risk forecasts", Nature Climate Change 2022

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- Multiplicity of methodological & procedural choice abundance of
 - Berg, Köbel, Rigobon, "Aggregate Confusion: The Divergence of ESG Ratings", *RoF* 2022
 - Menkveld et al., "Nonstandard Errors", JoF 2024
 - Sognnaes et al., "A multi-model analysis of long-term emissions and warming implications of current mitigation efforts", NCC 2021
 - 'single dataset, many researcher' studies in psychology, economics, statistics, neuroscience, ...
- Incentives adverse
- Multi-disciplinary problem need a level playing field and mechanism for integrating
- Circularity problem unconditional forecasts unhelpful for policy making
- Data gaps still substantial



Two methods for eliciting and aggregating (expert or non-expert) beliefs about climate-related variables:

- 1. When verifiable outcome will (eventually) be realized: 'Subsidized' LMSR prediction markets
- 2. Outcome of interest not ultimately verifiable, but is subjective:: Bayesian Truth Serum + Surprisingly Common Criterion



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Motivation recap LMSRs solve the challenges

LMSR agorithmic market maker

Trading environment Logarithmic Market Scoring Rule (LMSR)

Quality of forecasts

Calibration Information-add

Joint-Outcome Markets

Design challenge Outcome space Results



- Incentives Participants rewarded in proportion of the information they impound into the market; 'incentive-compatible mechanism'
- Multiplicity of methodological choice Participation invited from users of different approaches, different models
- Multi-disciplinary problem Participation invited also from country specialists in politics, energy policy, economics, ...
- Circularity problem Resolved with joint-outcome markets, giving conditional forecasts

Pre-funded expert prediction markets, with algorithmic market maker

Specifically: joint-outcome markets, e.g. temp anomaly x CO₂ concentration



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- rather than open 'pay to play' (!), participation by invitation only, and each market is pre-funded with an endowment of real fiat
- each participant endowed with on-platform credits
- optionally: participant endowment transferable between markets
- when market closes, each contract for the realised outcome becomes worth 1 credit; all others become worthless i.e. Arrow securities
- credits can be redeemed at a pre-defined exchange rate
 (e.g. 1 on-platform credit = £1) from the pre-funded payout pool
- participants can sell their contracts early; there is no need to hold to maturity

Trading environment: interface





Trading environment: defining a contract on outcome '8'





Trading environment: order for 100 contracts





Trading environment: contract on '9 or more'





Live market: CAHM24 price-probabilities



outcome	pric	e date (d.m.y)
0	0.00	3 30.06.2024
1	0.00	6
2	0.01	8
3	0.03	1
4	0.03	2
5	0.04	6
6	0.06	9
7	0.09	3
8	0.10	6
9	0.10	9
10	0.11	1
11	0.10	7
12	0.08	8
13	0.06	5
14	0.04	6
15	0.02	4
16	0.01	6
17	0.01	2
18	0.00	8
19	0.00	5
>=20	0.00	4





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Logarithmic Market Scoring Rule (LMSR)



• Cost function
$$C(\mathbf{q}) = b \log \left(\sum_{i=1}^{m} e^{q_i/b} \right)$$

- q_i the mm's exposure to outcome i
- m the number of outcomes
- b the liquidity parameter determines the mm's maximum net loss
- ▶ prevailing (marginal) price of each outcome *j*: $p_j = \frac{\partial C}{\partial q_j} = \frac{e^{q_j/b}}{\sum_{i=1}^m e^{q_i/b}}$
- n.b. prices are normalised, hence can be directly interpreted as probabilities
- ► asking price for order that changes mm's exposure from q_i to $q_i + w_i$: $C(\mathbf{q} + \mathbf{w}) - C(\mathbf{q})$
- the reward participants receive is linear in the logarithmic scoring rule



- the LMSR mm is designed to lose money in return for information; there is no bid-ask spread, neither is there a trading commission
- it is a "strictly proper scoring rule", hence incentive compatible
- under the LMSR, the mm's maximum payout is bounded from above by b log m
- hence real-money market/experiments can be run, with non-negligible fiat incentives, with mathematical certainty of staying within *ex ante* budgetary limits



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24 markets successfully run with platform

PREDICTED VARIABLE	PERIOD	OPENING DATE	MAX. HORIZON (months)	TRADES
UK total rainfall	APR 2018	MAR 12 2018	2	2202
UK total rainfall	MAY 2018	MAR 12 2018	3	2529
UK total rainfall	JUN 2018	MAR 12 2018	4	1474
UK total rainfall	JUL 2018	MAR 12 2018	5	1189
UK total rainfall	AUG 2018	MAR 12 2018	6	1793
UK total rainfall	SEPT 2018	MAR 12 2018	7	14120
UK av. daily max temp	APR 2018	MAR 12 2018	2	2202
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NINO3.4SSTA	JUL 2019	APR 3 2019	4	385
NINO3.4SSTA	AUG 2019	APR 3 2019	5	84
NINO3.4SSTA	SEP 2019	APR 3 2019	6	93
NINO3.4SSTA	OCT 2019	APR 3 2019	7	90
NINO3.4SSTA	NOV 2019	APR 3 2019	8	78
NINO3.4SSTA	DEC 2019	APR 3 2019	9	13
NINO3.4SSTA	JAN 2020	APR 3 2019	10	20
NINO3.4SSTA	FEB 2020	APR 3 2019	11	180
NINO3.4SSTA	MAR 2020	APR 3 2019	12	296
Atlantic hurricanes	JUN-NOV 2020	AUG 14 2020	3	594
US hurricane landfalls	JUN-NOV 2020	AUG 14 2020	3	501
UK wheat yield	2020/21 season	FEB 1 2021	11	183



overleaf:

The evolution of the price distributions throughout each of the 24 markets. The black line represents the median of the implied probability distributions while the gray envelopes represent the 50% and 90% intervals. The green line is the outcome that was ultimately observed.

12 markets' price distribution plots





Remaining 12 markets' price distribution plots





Calibration plots





Reliability Q-Q curves for the 24 markets. Panels show the reliability of the forecasts at lead times of 120, 90, and 60 days. Gray envelopes represent reliability curves for perfectly reliable forecasts constructed by drawing synthetic verifications from the probability distributions implied by market prices. 95% of the reliability curves for these perfect forecasts lie within the envelope.



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Information added over climatological means (bits)





The mean relative information of the probability forecasts generated by the prediction markets. The forecasts were benchmarked against a climatological distribution estimated from historical observations of the variable being predicted. The error was estimated by bootstrap resampling of the forecast categories (UK temperature, UK rainfall, NINO3.4 SST, hurricanes, and UK wheat yield)



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Outcome space Results



- > We increase the number of partitions by more than an order of magnitude
 - The Gates-Hillman Prediction Market (CMU) outcome space had 365 partitions
- We are the first to construct and demonstrate the viability of the joint-outcome (two-dimensional) PM
 - This solves the circularity problem
- Can subjects engage with the complexity the 2D structure and large number of partitions – to effectively express and aggregate their views?



- ► 6 markets for UK: April, May, June, July, August, September 2018
- all markets opened 12 March 2018
- outcome: monthly average daily high temperature x monthly total rainfall
- ▶ temperature partition: 0.2C intervals between 0C and 25C; open intervals above & below
- ▶ rainfall partition: 5mm intervals between 0mm and 200mm, with open interval above
- 127x41 = 5,207 mutually exclusive and comprehensively exhaustive outcomes
- this fine partition of the outcome space can create a liquidity problem; but LMSR solves!
- participants can specify any combination of partitions (outcomes) as a 'contract'
- each claim on the partition containing the realised outcome becomes worth 1 credit; all others become worthless



- 28 teams from British universities (expertise in metereology, climate science, statistics, machine learning, economics)
- each team endowed with 1000 on-platform credits
- total incentive pool £55,000
 - 1st-place credit tally awarded £10,000
 - 2nd-place credit tally awarded £9,000
 - ▶ ...
 - 10th-place credit tally awarded £1,000
- gradual decline with placing intended to offset distortion introduced by tournament element



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Fig 1: Prices in the market for U.K. average daily high temperature and total monthly rainfall for July 2018 on 15 May 2018





Fig 2: Daily number of trades and volume for each of the monthly markets





Fig 3: Evolution of marginal price distributions for UK average daily high temperature and monthly rainfall, April to Sept 2018







https://www.crucialab.net/media/June2018.gif



- British university participants quickly adapted to prediction markets as a mechanism through which to contribute their expertise
- a number of teams made use of the API, and adopted specialised division of labour
- conditional forecasting via joint-outcome markets proved viable, even with large, fine-grained outcome spaces
- LMSR prediction markets a potential laboratory for sustainable finance experiments on sustainability-linked beliefs/exptation formation



Thank you!

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