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ML-CI: Machine Learning Confidence Intervals for Covid-19 forecasts

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Abstract

Epidemic forecasting has always been challenging and the recent Covid-19 outbreaks emphasizes it. We introduce a novel approach to address the problem of evaluating confidence intervals (CI) of time series prediction forecasts for compartmental models, using machine learning. We evaluate our approach using real data of the Covid pandemic on 27 countries. Compartmental models were trained taking into account non pharmaceutical governmental measures. A Random Forest regressor was trained, using various engineered features, to predict the forecasting error for various horizons on synthetic data, then applied to estimate CI on real data forecasts. Our method outperforms baselines using forecast likelihood as metric.

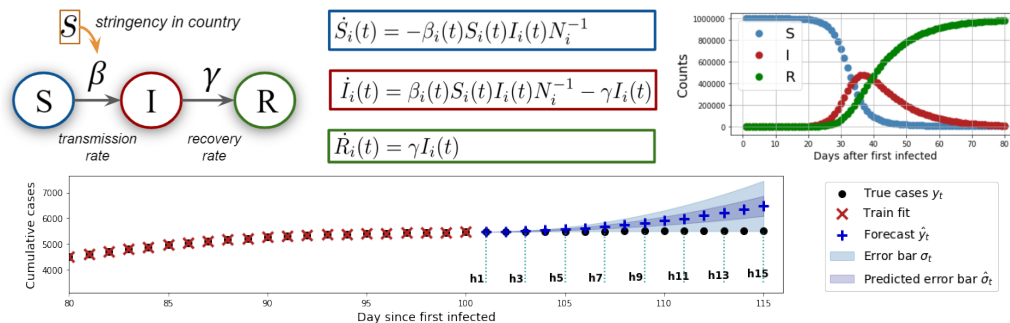


Figure 1: [Top] Compartmental Susceptible-Infected-Recovered model (SIR), with dynamic transmission rate β oppositely related to the stringency of government Non-Pharmaceutical Interventions (NPI), and a fixed recovery rate $\gamma = 07$. [Bottom] Country cumulative cases (sum of S and R compartments). Model fit (red crosses) and 15 day forecasts (blue crosses). A ML model is trained as estimator $\hat{\sigma}_t$ of errors σ_t on synthetic data at each horizon t ; then applied to real data.

Since January 2020, policy-making has been steered by Covid-19 cases and deaths forecasts. Forecasting methods encompass epidemiological compartmental models [1][2] and deep learning models [3][4][5] among others. Poorly advised policies can greatly impact populations with human and economical loss [6]. Due to the high degree of uncertainty of predictions, point-wise forecasts are less relevant than interval forecasts. But, despite the vast amount of literature on Covid-19 forecasting, few studies have provided confidence intervals (CI) [7]. In addition, the few papers mentioning CI, rarely document the actual methods used for interval forecasting. Bayesian approaches including Gaussian processes [8], have gained in popularity, but make unverifiable assumptions [9][10][11][12]. In this paper, we present a global method (Figure 1) mapping the decision-making process to the disease evolution with a Confidence Intervals estimated with a Machine Learning method (ML-CI).

Table 1: Negative log-likelihood for the 15-day horizon interval forecast for 27 countries. Best methods are highlighted in bold (smaller values are better).

	United Kingdom	United States	Poland	Portugal	Belgium	Bulgaria	Canada	Denmark	Finland
ML-CI (OURS)	13	15	17	14	11	113	12	10	9
Naive	14	18	128	18	11	385	18	11	11
Bootstrap	13	18	284	633	56	565	14	77	35
	France	Germany	Russia	India	Israel	Italy	Japan	Norway	Netherlands
ML-CI (OURS)	13	12	16	12	10	13	9	11	11
Naive	13	12	121	128	10	21	13	9	12
Bootstrap	16	16	20	17	54	26	53	9	184
	Luxembourg	South Africa	Greece	Australia	Austria	South Korea	Spain	Sweden	Taiwan
ML-CI (OURS)	11	12	9	9	10	10	13	11	9
Naive	14	63	9	7	9	7	11	10	7
Bootstrap	10	18	8	7	10	7	15	11	284

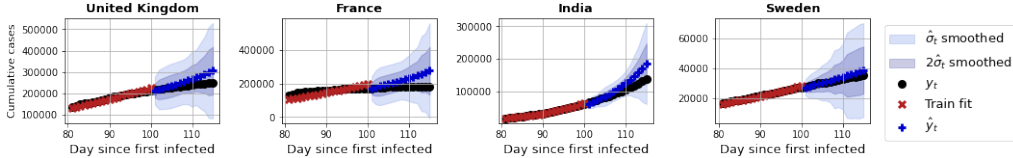


Figure 2: Examples of error bar prediction with our method ML-CI.

We focus on the widely used compartmental Susceptible-Infected-Recovered model (SIR) [1], from which we forecast Covid-19 cumulative cases (Figure 1). We limit our study to this simple model because more complex models have shown only minor (or null) performance advantage [7], and comparing predictive models is not the object of this paper. SIR models are trained on 27 countries from the OxCGRT dataset [13], which provides cumulative cases and government Non-Pharmaceutical Interventions (NPIs), from January 2020 to December 2020. We fit as few parameters as possible: The recovery rate γ is fixed as $1/N_r$, with N_r the average number of days to recover [2]. The transmission rate β is obtained through an affine transformation of the Oxford index summarizing all NPIs. The two parameters of the affine transformation are fit, on a 100 day window, using a dual annealing optimization, essentially a simulated annealing approach with a local search ([Documentation](#)).

The novel contribution of this paper is a method for estimating confidence intervals, based on training a Random Forest (RF) regressor, inspired by recent work [12]. To train the regressor, we created a simulated dataset of 2000 virtual countries, using the SIR model described above, displaying a wide range of NPI scenarios. The inputs to the RF regressor include a variety of features derived from past data, such as past errors, past cumulative forecasts, past daily case forecasts, and past stringency. We train one regressor per horizon h , for a 15 day forecast, using as target value the absolute difference between prediction and actual number of cases. Subsequently, the output of the RF regressor h is used to estimate the forecast error at horizon h , for predictions made on real data by a SIR model. We use a simple heuristic to lightly smooth the error bar. Our code is available on [Github](#).

We compare our method (ML-CI) with two baseline methods for computing error bars: (1) a naive method [14] assuming a simple diffusion model, advocating to use $s_{t-15:t}\sqrt{h}$, where $s_{t-15:t}$ is the average RMSE over the past 15 days, and h the prediction horizon; (2) a bootstrap approach using as prediction error the standard deviation of predictions of 4 SIR models trained on data subsamples. Table 1 shows negative log-likelihood performance for a Gaussian error model, at 15-day horizon forecast. Figure 2 provides examples of 15-day forecasts for a few countries (results on all 27 countries are in Appendix).

Our preliminary results are encouraging, indicating that ML regression is a viable alternative method to more conventional techniques, for predicting confidence intervals in forecasting applications. Robust methods for epidemiological time series interval forecasting being in great need, this line of research to obtain reliable confidence intervals seems promising. Our future work includes conducting systematic experiments on more countries and with a time sliding window, and compare ML-CI with more baseline methods on a variety of datasets. Improvements may be obtained by experimenting with other machine learning regressors, better feature engineering, and calibrating the output of the regressor. Together with improvements in our forecasting model (e.g. taking into account mobility data and people compliance to NPIs) we hope to advance the state of the art.

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¹Transatlantic team github repository: <https://github.com/transatlantic-team>.

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Appendix

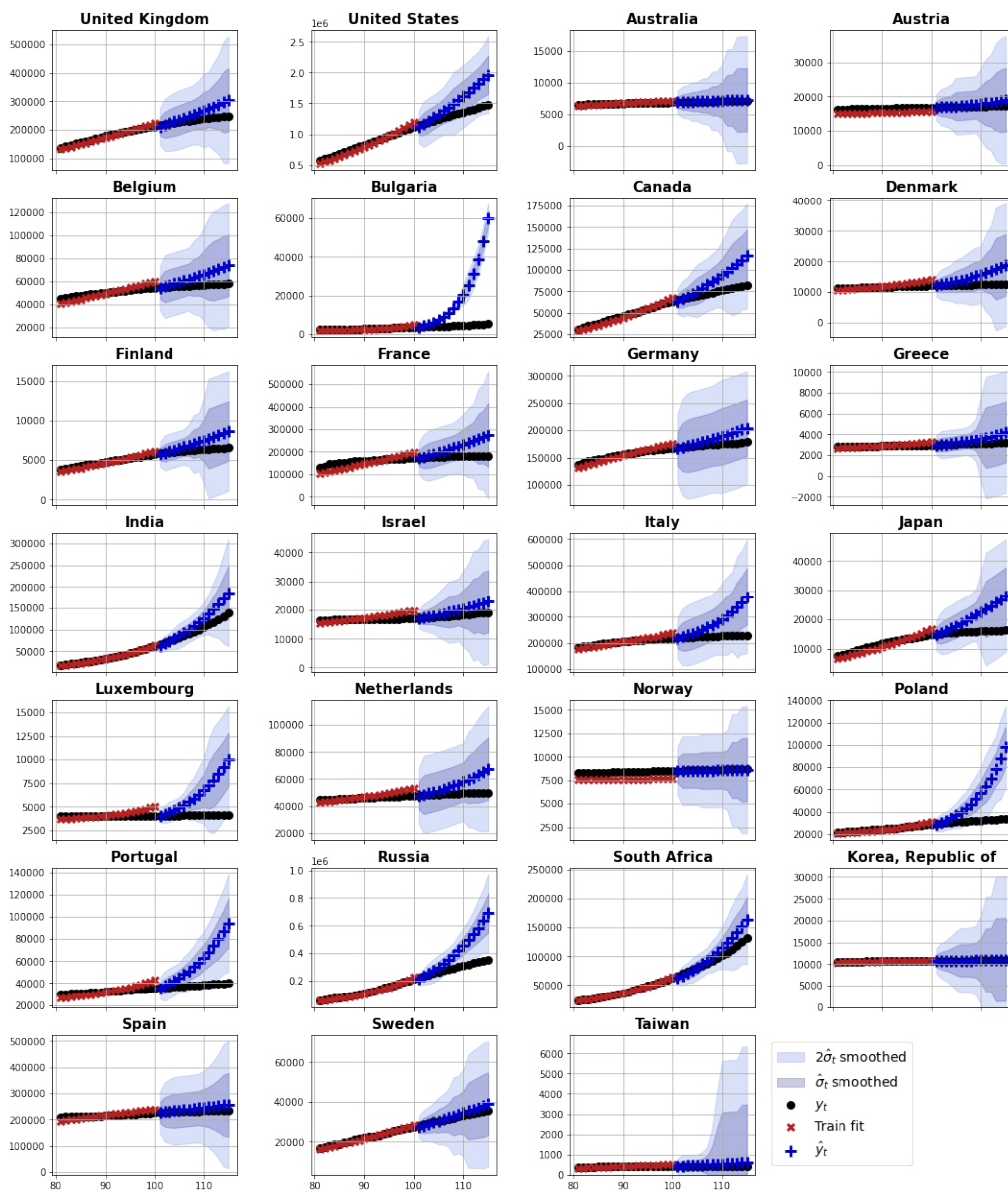


Figure 3: Error bar prediction with our method ML-CI for 27 countries.