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Anticipating the cost of drought events in France by super learning

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Abstract

Drought events are the second most expensive type of natural disaster within the legal framework of the French natural disasters compensation scheme. In recent years, droughts have been remarkable in their geographical scale and intensity. We develop a new methodology to anticipate the cost of a drought event in France. The methodology hinges on super learning and takes into account the complex dependence structure induced in the data by the spatial and temporal nature of drought events.

1 Introduction

The French state has been facing severe drought events over the past years. The average annual cost of drought events between 2016 and 2020 is 1.1 billion EUROS, a fivefold increase relative to the 2002-2015 period. The recent cycle of extremely intense drought events raises two questions: will climate change perpetuate this pattern [[Bradford, 2000](#), [Iglesias et al., 2019](#)] and, if so, what cost will the French state incur?

In 2015 and 2018 ([[CCR, 2015](#)], [[CCR, 2018](#)]), Caisse Centrale de Réassurance (CCR) launched a study to assess the impact of climate change on the damages caused by natural disasters based on the Intergovernmental Panel on Climate Change (IPCC) scenarios RCP 4.5 and RCP 8.5. Resorting to ARPEGE simulations of the climate in 2050 provided by Météo-France, CCR simulated damages in France in 2050 and concluded that the annual cost in 2050 could increase, depending on the

scenario, by 3% (under scenario RCP 4.5) or 23% (under scenario RCP 8.5). Unfortunately, the latter is more likely today than the former.

In [Charpentier et al., 2021], the authors address the problem of predicting the cost of a drought event using Generalized Linear Models (GLM) and tree-based machine learning algorithms. For a given drought event, for each city, the number of claims and the average cost are predicted, then a city-specific predicted cost is obtained by multiplying these two numbers. The aforementioned city-specific predictions exploit several drought indices, topsoil clay concentration, the year, number of policies and their related insured values, and a binary variable indicating whether the city has already formulated a request for the government declaration of natural disaster.

In our study, like Charpentier et al. [2021], we exploit the Soil Wetness Index (SWI) as a drought indice [it is referred to as the Standardised Soil Water Index by Charpentier et al., 2021]. Moreover, we also use sequential cross-validation to take into account the time dependence structure in our data set. In contrast to Charpentier et al. [2021], we rely on a richer description of the cities obtained by data enrichment (more details to follow). Unlike them, we predict the city-specific costs only for those cities that have obtained the government declaration of natural disaster (more on the legal framework of the natural disasters compensation scheme can be found in [Charpentier et al., 2021, section 2.1]). We emphasize that the problem we tackle is therefore less challenging than theirs. Finally, we make predictions based on a new stacking algorithm that adapts the Super Learning methodology [van der Laan et al., 2007, Benkeser et al., 2018] to our framework. Our theoretical analysis of the so-called one-step ahead sequential Super Learner reveals that we can take advantage of the structure of our data set, which consists of a *short* time-series where each time-specific observation is a large network of *many* slightly dependent data [Ecoto et al., 2021].

Organization of the article. Section 2 presents the data we collected and used in this study. Section 3 describes the one-step ahead sequential Super Learner. Section 4 exposes and comments on the results we obtain. Section 5 closes the article and discusses directions for future work.

2 Data

The data set we use is obtained by merging several data sets of different natures. Some of these data sets are provided by the cedents. The others are collected by us from other sources.

Of note, in the rest of this study, France refers to *Metropolitan* or *Mainland* France. Drought events are not a threat in Overseas France (essentially because there is little clay in these parts of the country).

2.1 Data from cedents

CCR reinsures 95% of the French natural disasters insurance market. Contractually, CCR's cedents must share their portfolios and claims data. Over the years, CCR has thus gathered a collection of locations and characteristics of insured goods and claims data. From 1990 to present, the collection covers roughly 22% to 97% of all the French claims.

2.2 Data from other sources

The data set, based so far on data provided by cedents only, is then enriched with data from other sources, namely the National Institute for Statistical and Economic Studies (INSEE), the Geographic National Institute (IGN), the French Geological Survey (BRGM) and Météo-France. The new features supplementing the description of the cities are seismic hazard and climatic zone, clay shrinkage-swelling hazards, tree coverage rate, area, population and years of construction. Lastly, we benefit from the Soil Wetness Index (SWI) as described in [Charpentier et al., 2021, section 2.3].

2.3 City-level data processing

Some data are available at the house-level (namely, the cost of claim and insured sum), but most are not. In particular, the SWI is available at a 8×8 km² resolution, while the 90%-quantile of the French cities area is 30 km². Consequently, we choose to work at a city level and thus aggregate the features that have a higher resolution. Details follow.

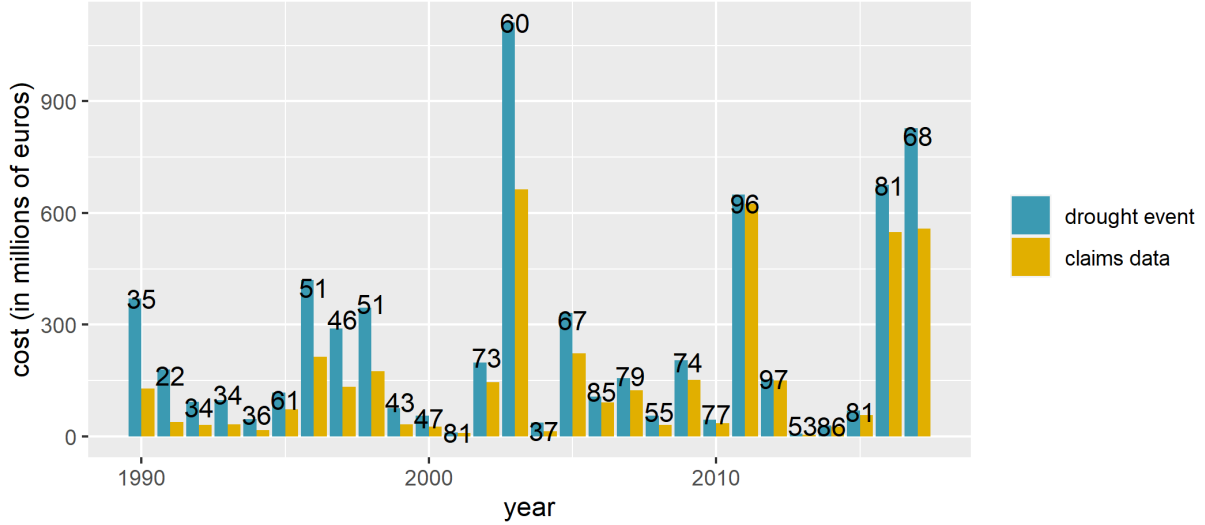


Figure 1: Estimated overall costs of drought events across France (blue) and provisional city-specific costs obtained by aggregating the costs of those claims filled in the claims data provided by the cedents (yellow). The ratios of the latter to the former range between 22% and 97%.

City-level costs of drought events. The cost of the damages in a city caused by a drought event (what will be our response variable) is unknown. However, on the one hand the overall cost across France is estimated by actuarial studies and, on the other hand, we know the costs of *those* claims filled in the claims data provided by the cedents which, unfortunately, only represent a fraction of all the claims.

Provisional city-specific costs are computed by aggregating by city the costs filled in the claims data provided by the cedents. Because these claims data are not exhaustive, the sum of all the provisional city-specific costs is smaller than the estimated overall cost. The (final) city-specific costs are proportional to the provisional city-specific costs in such a way that the sum of all the (final) city-specific costs equals the estimated overall cost.

Figure 1 illustrates the gaps between the estimated overall costs across France and the sum of the provisional city-specific costs. The ratios of the latter to the former range from 20% to 90%.

City-level SWI. For every time point and each city, the city-level SWI is the convex average of the SWIs of the 8×8 km² squares that overlap the city's area. The weights are proportional to the areas of the intersections.

City-level description. We quote the presentation of the city-level description from [Ecoto et al., 2021, section 3.2]:

For every time point and each city, a city-level description encapsulates the city’s profile. The description is multi-faceted. It contains: an indicator of whether or not a natural disaster was declared by the government; the overall insured value obtained by summing the insured values over the city’s area; a summary of the city’s clay hazard, defined as the proportions of houses falling in each of four categories of clay hazard; a summary of the city’s dwelling age, *i.e.*, how old houses are, under the form of the proportions of houses falling in each of four categories; the climatic and seismic zones (a five-category and a four-category variables); a summary of the city’s vegetation; the city’s number of houses, population, area, average altitude, and density, defined as the ratio of the number of houses to the area. In addition, a variety of features are described by quantiles that summarize distributions (*e.g.*, the 30-quantiles of the distribution of the house-specific product of SWI and insured value, or the 30-quantile of the distribution of the house-specific product of the ground slope and insured value, to mention just a few). Overall, the city-level description consists of a little more than 430 variables.

3 The one-step ahead sequential Super Learner

3.1 Presentation and theoretical performance

In [Ecoto et al., 2021], we developed and studied the so-called one-step ahead sequential Super Learner, an algorithm designed to learn a (stationary) feature of the law of a *short* time-series whose time-specific observations consists of *many* slightly dependent data-structures. The algorithm builds upon the canonical Super Learning methodology [van der Laan et al., 2007]. Its analysis reveals that our algorithm manages to make up for the *shortness* of the time-series thanks to the *manyness* of each time-specific observation because the latter are only slightly dependent. Here, we present an instance of the one-step ahead sequential Super Learner specifically built to anticipate the cost of drought events.

We let $(\bar{O}_t)_{t \geq 1}$ denote the time-series that formalizes the time-series described in section 2. At each time $t \in \mathbb{N}^*$, \bar{O}_t consists of a finite collection $(O_{\alpha,t})_{\alpha \in \mathcal{A}}$ of (α, t) -specific observations, where

each $\alpha \in \mathcal{A}$ represents a French city. For every $\alpha \in \mathcal{A}$, $O_{\alpha,t}$ decomposes as $O_{\alpha,t} := (Z_{\alpha,t}, X_{\alpha,t}, Y_{\alpha,t}) \in \mathcal{Z} \times \mathcal{X} \times [0, B] =: \mathcal{O}$ where $X_{\alpha,t} \in \mathcal{X}$ is the collection of covariates describing the city α on year t , $Z_{\alpha,t} \in \mathcal{Z}$ is the city-level SWI describing the drought event that year, and $Y_{\alpha,t} \in [0, B]$ is the city-specific cost of the drought event that year (known to take its values between 0 and a constant B). We assume that the mean conditional cost $\theta^* : (x, z) \mapsto \mathbb{E}[Y_{\alpha,t} | X_{\alpha,t} = x, Z_{\alpha,t} = z]$ does not depend on (α, t) or, in other terms, that it is a stationary feature of the law of $(\bar{O}_t)_{t \geq 1}$. This is the case if, given a time-specific city-description and SWI $(X_{\alpha,t}, Z_{\alpha,t})$, the mechanism that produces a cost after a drought event conditionally on $(X_{\alpha,t}, Z_{\alpha,t})$ does not depend on (α, t) , that is, remains constant throughout time and France.

In this project the one-step ahead sequential Super Learner is a meta-algorithm that learns the mean conditional cost θ^* from $(\bar{O}_t)_{t \geq 1}$ by aggregating the estimators of θ^* provided by a user-supplied collection of J algorithms $\hat{\theta}_1, \dots, \hat{\theta}_J$. At each time $t \geq 1$, every algorithm $\hat{\theta}_j$ trained on $\bar{O}_1, \dots, \bar{O}_t$ outputs an estimator $\theta_{j,t}$ of θ^* . The one-step ahead sequential Super Learner selects the best algorithm indexed by \hat{j}_t defined as the minimizer of the empirical average cumulative risks,

$$\hat{j}_t \in \arg \min_{1 \leq j \leq J} \hat{R}_{j,t}, \quad (1)$$

where

$$\hat{R}_{j,t} := \frac{1}{t|\mathcal{A}|} \sum_{\tau=1}^t \sum_{\alpha \in \mathcal{A}} [Y_{\alpha,\tau} - \theta_{j,\tau-1}(X_{\alpha,\tau}, Z_{\alpha,\tau})]^2. \quad (2)$$

Interestingly, the one-step ahead sequential Super Learner is an online algorithm if each of the J algorithms $\hat{\theta}_1, \dots, \hat{\theta}_J$ is online, that is, such that the making of $\theta_{j,t}$ consists in an update of $\theta_{j,t-1}$ based on newly accrued data \bar{O}_t .

The (unknown) t -specific measure of performance of each $\hat{\theta}_j$ is

$$\tilde{R}_{j,t} := \frac{1}{t|\mathcal{A}|} \sum_{\tau=1}^t \sum_{\alpha \in \mathcal{A}} \mathbb{E} \left\{ [Y_{\alpha,\tau} - \theta_{j,\tau-1}(X_{\alpha,\tau}, Z_{\alpha,\tau})]^2 \middle| \bar{Z}_\tau, F_{\tau-1} \right\} \quad (3)$$

where F_t is the history generated by $\bar{O}_1, \dots, \bar{O}_t$ (by convention, $F_0 = \emptyset$). It takes the form of an average cumulative risk conditioned on the observed sequence $(\bar{Z}_t)_{t \geq 1}$ with $\bar{Z}_t = (Z_{\alpha,t})_{\alpha \in \mathcal{A}}$. The (unknown) t -specific oracular meta-algorithm is indexed by the oracular \tilde{j}_t defined as the minimizer

$$\tilde{j}_t \in \arg \min_{1 \leq j \leq J} \tilde{R}_{j,t}. \quad (4)$$

Note that $\widehat{R}_{j,t}$ estimates $\tilde{R}_{j,t}$ and that (1) mimicks (4).

The theoretical analysis hinges on a key-assumption about the dependence structure in the time-series $(\bar{O}_t)_{t \geq 1}$. We rely on conditional dependency graphs to model the amount of conditional independence. Specifically, we assume that there exists a graph \mathcal{G} with vertex set \mathcal{A} such that if $\alpha \in \mathcal{A}$ is not connected by any edge to any vertex in $\mathcal{A}' \subset \mathcal{A}$, then $O_{\alpha,t}$ is conditionally independent of $(O_{\alpha',t})_{\alpha' \in \mathcal{A}'}$ given F_{t-1} and \bar{Z}_t . Then what matters is how much connected is the graph, as reflected by its degree, $\deg(\mathcal{G})$, which equals 1 plus the largest number of edges that are incident to a vertex in \mathcal{G} . Finally, let us emphasize that the dependency graph \mathcal{G} plays no role in the one-step ahead sequential Super Learner's characterization and training. However, it is pivotal in the algorithm's theoretical analysis.

The performance of \widehat{j}_t as an estimator of \tilde{j}_t is expressed in terms of a comparison of the excess risk of the former to the excess risk of the latter. Under additional mild assumptions [Ecoto et al., 2021, corollary 2] there exists a decreasing function $C : \mathbb{R}_+^* \rightarrow \mathbb{R}_+^*$ such that, for any $\varepsilon > 0$,

$$\mathbb{E} \left[\underbrace{\widehat{R}_{\widehat{j}_t,t} - \tilde{R}_t(\theta^*)}_{\text{excess risk of } \widehat{j}_t} - (1 + \varepsilon) \underbrace{\left(\tilde{R}_{\tilde{j}_t,t} - \tilde{R}_t(\theta^*) \right)}_{\text{excess risk of } \tilde{j}_t} \right] \leq C(\varepsilon) \frac{\log(J \log(\mathcal{I}^2))}{\mathcal{I}^2} \quad (5)$$

where \mathcal{I} grows like the amount of information available and can be equal to either t or $|\mathcal{A}|/(t \deg(\mathcal{G}))$. If the ratio $|\mathcal{A}|/\deg(\mathcal{G})$ is sufficiently large (both in absolute terms and relative to t), then the oracular inequality (5) is sharper when $\mathcal{I} = |\mathcal{A}|/(t \deg(\mathcal{G}))$ than when $\mathcal{I} = t$. This reveals that the one-step ahead sequential Super Learner can leverage a large ratio $|\mathcal{A}|/\deg(\mathcal{G})$ in the face of a small t .

In the application, $t \approx 25$, $|\mathcal{A}| \approx 36,000$. As for $\deg(\mathcal{G})$, it is much harder to assess a meaningful value. In this regard, it is relevant to recall that there were around 1,000 federations of municipalities in France in 2019, each regrouping 30 cities on average. Furthermore, we computed the number of neighboring cities for each city. The quantiles and mean of these numbers are reported in Table 1. In particular, the city with the largest number of neighboring cities (Paris) has 29 of

min.	1st qu.	median	mean	3rd qu.	99%-qu.	max
0	5	6	5.96	7	11	29

Table 1: Quartiles, 99%-quantile and mean of the numbers of neighboring cities in France in 2019. Although the maximum cannot be interpreted literally as $\deg(\mathcal{G}) - 1$, it nevertheless gives a sense of what a meaningful value of $\deg(\mathcal{G})$ can be.

them.

3.2 Anticipating the cost of drought events

The one-step ahead sequential Super Learner presented in Section 3.1 is designed to learn the mean conditional cost θ^* from $(\bar{O}_t)_{t \geq 1}$. At each time $t \geq 1$, it outputs the t -specific estimator $\theta_{\hat{j}_t, t}$. This estimator can be evaluated at every $(X_{\alpha, t+1}, Z_{\alpha, t+1})$ ($\alpha \in \mathcal{A}$) and we use the sum

$$\sum_{\alpha \in \mathcal{A}} \theta_{\hat{j}_t, t}(X_{\alpha, t+1}, Z_{\alpha, t+1})$$

to predict the cost of the drought event at time $(t + 1)$, that is, $\sum_{\alpha \in \mathcal{A}} Y_{\alpha, t+1}$.

4 Application

This section discusses the practical implementation, training and exploitation of the one-step ahead sequential Super Learner presented and studied in Section 3. Section 4.1 describes the collection of J algorithms $\hat{\theta}_1, \dots, \hat{\theta}_J$; Section 4.2 explains how the one-step ahead sequential Super Learner is trained; Section 4.3 presents the results and comments upon them.

4.1 Implementing two one-step ahead sequential Super Learners

In fact, we deploy two meta-algorithms taking the form of one-step ahead sequential Super Learners, the so-called discrete and continuous overarching Super Learners. Both rely on the same library of J algorithms $\hat{\theta}_1, \dots, \hat{\theta}_J$. These J algorithms are themselves one-step ahead sequential Super Learners either in the strict or in a loose sense – more details to follow.

Penalization. Because our ultimate goal is to anticipate the cost of the latest drought event, we made the decision to rely on a penalized version of $\widehat{R}_{j,t}$ (2), by substituting

$$\widehat{R}_{j,t} + \frac{0.05}{t} \sum_{\tau=1}^t \left(\underbrace{\sum_{\alpha \in \mathcal{A}} Y_{\alpha,\tau}}_{\text{actual cost}} - \underbrace{\sum_{\alpha \in \mathcal{A}} \theta_{\widehat{j}_{\tau-1,\tau-1}}(X_{\alpha,\tau}, Z_{\alpha,\tau})}_{\text{predicted cost}} \right)^2 \quad (6)$$

for $\widehat{R}_{j,t}$ (we recall that $\theta_{j,t}$ is the output of $\widehat{\theta}_j$ trained on $\bar{O}_1, \dots, \bar{O}_t$ and that \widehat{j}_t is defined in (1)). Observe that each t -specific penalization term equals 0.05 times the average over $1 \leq \tau \leq t$ of the τ -specific squared difference between the actual cost of the drought event (left-hand side summand) and the predicted cost made by the (penalized) one-step ahead sequential Super Learner trained on $\bar{O}_1, \dots, \bar{O}_{\tau-1}$ (right-hand side summand). The factor 0.05 was chosen somewhat arbitrarily.

By adding this penalization term, the one-step ahead sequential Super Learner favors the algorithms that better predict not only the *city-specific* costs but also the *overall* cost of the next drought event. In addition, the penalization term slightly dilutes the importance of the city-specific costs and, on the contrary, reinforces the importance of the overall cost, the latter being more dependable than the formers as we explained in Section 2.3.

The discrete and continuous overarching Super Learners. Called the *discrete* overarching Super Learner, the first one-step ahead sequential Super Learner is the algorithm that, at time $t \geq 1$, outputs $\theta_{\widehat{j}_t,t}$ (using (6) instead of (2) as an empirical measure of the risk).

We also consider a second one-step ahead sequential Super Learner which is defined as a regular one-step ahead sequential Super Learner based on a library derived from $\widehat{\theta}_1, \dots, \widehat{\theta}_J$ and comprising $J' = O(\varepsilon^{1-J})$ algorithms where $\varepsilon > 0$ is a small positive number ($J' = O(\varepsilon^{1-J})$ means that J' is upper-bounded by a constant times ε^{1-J}). Specifically, these J' algorithms are denoted by $\widehat{\theta}_\pi$ where the index π ranges in an ε -net over the simplex $\{x \in (\mathbb{R}_+)^J : \sum_{j=1}^J x_j = 1\}$ (an ε -net whose cardinality is J' , *i.e.*, a finite subset of J' elements of the simplex which “approximates” the simplex). For each π in the ε -net, $\widehat{\theta}_\pi$ trained on $\bar{O}_1, \dots, \bar{O}_t$ outputs the π -specific convex combination $\sum_{j=1}^J \pi_j \theta_{j,t}$. The bound in (5) is still meaningful when $\varepsilon = O(\mathcal{I}^{-1})$. We refer to this second one-step ahead sequential Super Learner as the *continuous* overarching Super Learner.

Their library of algorithms. We now turn to the description of the J algorithms $\widehat{\theta}_1, \dots, \widehat{\theta}_J$. All of them rely on a collection of base learners $\widehat{\mathcal{L}}_1, \dots, \widehat{\mathcal{L}}_K$. Some of the base learners rely on linear models and their extensions (lasso, ridge, elastic net, multivariate adaptive regression splines, support vector regression). Others are tree-based algorithms (CART, random forest, gradient boosting), or rely on neural networks. Others fall in the category of k -nearest-neighbors algorithms tailored to our study so that the dissimilarity between observations is a convex combination of the Kolmogorov-Smirnov distances between the empirical cumulative distribution functions mentioned in Section 2.3. Finally, some are regular Super Learners themselves, based on a selection of the aforementioned base learners and oblivious to the temporal ordering (*i.e.*, they rely on vanilla inner cross-validation).

Moreover, some of these base learners are combined (upstream) with so-called screening algorithms. A screening algorithm is merely an algorithm that selects a subset of the covariates deemed relevant to feed the base learners. In general, the selection can be either deterministic or data-driven. In our study, we only use deterministic screening algorithms based on expert knowledge.

Overall, we implement a collection of $K = 27$ base learners (including the variants obtained by combining with different screening algorithms). The collection is shared by the J algorithms $\widehat{\theta}_1, \dots, \widehat{\theta}_J$ which differ in the methods they rely on to exploit the base learners.

One of the methods yields a one-step ahead sequential Super Learner precisely as defined in (1) and (2)/(6) where we substitute K for J and $\ell_{j,\tau-1}$ for $\theta_{j,\tau-1}$, with $\ell_{j,t}$ the output of $\widehat{\mathcal{L}}_j$ trained on $\bar{O}_1, \dots, \bar{O}_t$. The resulting one-step ahead sequential Super Learner is an instance of discrete Super Learner as previously described when introducing the first overarching Super Learner. As we already explained, the library of base learners $\widehat{\mathcal{L}}_1, \dots, \widehat{\mathcal{L}}_K$ can be extended using an ε -net over the simplex $\{x \in (\mathbb{R}_+)^K : \sum_{k=1}^K x_k = 1\}$. For each π in the ε -net, $\widehat{\mathcal{L}}_\pi$ trained on $\bar{O}_1, \dots, \bar{O}_t$ outputs the π -specific convex combination $\sum_{k=1}^K \pi_k \ell_{k,t}$. Using the extended collection of base learners, the same method then yields an instance of continuous Super Learner as previously described when introducing the second overarching Super Learner.

In a similar fashion, we consider several methods to exploit the base learners $\widehat{\mathcal{L}}_1, \dots, \widehat{\mathcal{L}}_K$. Heuristically, the principle is to learn to produce a single prediction based on the multiple predictions made by the base learners once they have been trained, just like we described in the previous paragraph. Some methods rely on the same method as above with an extra penalization term in

the definition of the risk (similar to the one used to define (6) based on (2)). The other methods rely on the lasso, ridge and elastic net algorithms, or on the random forests, gradient boosting and support vector regression algorithms. Finally, some of the methods can exploit the covariates. Overall, we implement a collection $J = 48$ algorithms $\hat{\theta}_1, \dots, \hat{\theta}_J$.

4.2 Training

At each time $t \geq 1$ we define a summary of the past based on observations made during the five previous years. This is very relevant for two reasons. First, a drought-related claim can be the by-product of repeated shrinkage-swelling episodes over the years. Second, a city-level cost of a drought event is expected to be high when the city did not benefit recently from a declaration of natural disaster (because of the possible accumulation of damages over the years); on the contrary, it is expected to be low otherwise (because damages may already have been compensated). To do so, we reserve the data from year 1990 to year 1994.

For each $t \in \{1995, \dots, 1999\}$, we derive $\ell_{1,t-1994}, \dots, \ell_{K,t-1994}$. For each $t \in \{2000, \dots, 2005\}$, we derive $\theta_{1,t-1994}, \dots, \theta_{J,t-1994}$ using $\ell_{1,(t-1)-1994}, \dots, \ell_{K,(t-1)-1994}$, and also $\ell_{1,t-1994}, \dots, \ell_{K,t-1994}$. For each $t \in \{2006, \dots, 2017\}$, we derive the discrete overarching Super Learner \hat{j}_{t-1994} using $\theta_{1,(t-1)-1994}, \dots, \theta_{J,(t-1)-1994}$ (which rely themselves on $\ell_{1,(t-2)-1994}, \dots, \ell_{K,(t-2)-1994}$), and also $\theta_{1,t-1994}, \dots, \theta_{J,t-1994}$ and $\ell_{1,t-1994}, \dots, \ell_{K,t-1994}$. For each $t \in \{2006, \dots, 2017\}$, the continuous overarching Super Learner is derived too.

We cannot train our algorithms beyond the year 2017 because, to this day, the real costs and city-level costs are still too uncertain.

The numerical analysis was conducted in R [R Core Team, 2022]. We adapted the R package SuperLearner [Polley et al., 2021] in a package called SequentialSuperLearner [Chambaz and Ecoto, 2021].

4.3 Results

In Figure 2 we present the evolution of the weights that characterize the continuous overarching Super Learner through the years 2007 to 2017. The figure reveals that only four of the $J = 48$ algorithms $\hat{\theta}_1, \dots, \hat{\theta}_J$ get a positive weight, and that only two of them do in 2016 and 2017. Moreover, one of the algorithms dominates the others during the whole training. It does not come as a

surprise that this algorithm (whose method is a variant of gradient boosting with linear boosters) is constantly selected by the discrete overarching Super Learner.

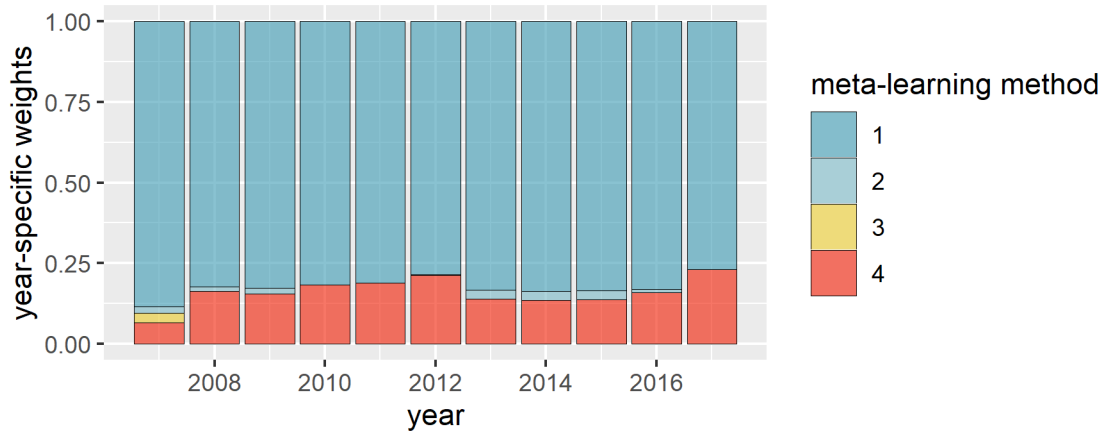


Figure 2: Evolution (from 2007 onward) of the weights attributed in the overarching Super Learner to four of the algorithms $\hat{\theta}_1, \dots, \hat{\theta}_J$. The others get no weight at all.

For confidentiality reasons, we were not given the authorization to discuss how the overarching Super Learners fare compared to the algorithm currently deployed at CCR to predict the overall costs of drought events in France from 2007 to 2017. However, we were authorized to make a comparison for the sole year 2017. That particular year, the discrete and continuous overarching Super Learners outperform the algorithm currently deployed at CCR, with a precision of 96% (discrete overarching Super Learner), 94% (continuous overarching Super Learners) versus 83% (currently deployed algorithm).

In Figure 3 we present three sequences of predictions from 2007 to 2017: those from the discrete and continuous overarching Super Learners and those obtained by averaging all the base learners' predictions (for comparison). Note that the two sequences of predictions from the Super Learners are quite similar. Overall, the Super Learners' predictions are generally accurate and better than the averaged predictions. In Table 2 we report the averages and standard deviations (over the years) of the ratios of the predicted costs to the real costs for the predictors. Both in terms of mean and standard deviation, the discrete overarching Super Learner outperforms its continuous counterpart, which itself outperforms the predictor that averages all the base learners' predictions. Furthermore, the two Super Learners' predictions are quite good for all years except 2012 and 2016. The poorer predictions in 2016 are more problematic because the real cost in 2016 is much higher

than in 2012.

predictions	mean	standard deviation
average of the base learners' predictions	1.21	0.42
continuous overarching Super Learner's	1.10	0.32
discrete overarching Super Learner's	1.04	0.28

Table 2: Averages and standard deviations (over the years) of the ratios of the predicted costs to the real costs. The predictions are either those made by the discrete and continuous overarching Super Learners or obtained by averaging all the base learners' predictions.

The year 2016 is known in the French insurance market as particularly challenging. Unfortunately, as far as we know, this fact is undocumented in the literature. However, we can report two facts to uphold this statement. First, the year-specific average cost (understood as the ratio of the total cost of the year's drought event to the corresponding number of declarations of natural disaster delivered that year) is particularly large in 2016 compared to the global average cost (understood as the ratio of the total cost of the drought events between 2007 and 2017 to the total number of declarations of natural disaster delivered these years): 797,000 EUROS versus 482,000 EUROS. Second, we can quote [Charpentier et al. \[2021\]](#) who say of their predictions for the year 2016 that they are "severely underestimated". Judging by their Figure 7, the underestimation by the discrete and continuous overarching Super Learners for the year 2016 is less pronounced than the underestimation by their algorithms (but we recall that they tackle a more challenging problem than us because we focus on the city-specific costs for those cities that have obtained the government declaration of natural disaster whereas they consider all French cities).

In Figure 4 we present (Gaussian) kernel density estimates of the conditional laws of the residual error (defined as the real cost minus the prediction made by the continuous overarching Super Learner – the figure is very similar when substituting the discrete overarching Super Learner for the continuous one) in ten strata characterized by the deciles of the city-level costs. We note that the higher the city-level costs, the higher the residuals. Moreover, the overarching Super Learner tends to overestimate the costs in cities with lower city-level costs and, on the contrary, it tends to underestimate them in cities with higher city-level costs.

In Figure 5 we present two maps that provide insight into the geographical distribution of the residual errors (of the predictions made by the continuous overarching Super Learner – the maps are very similar when considering its discrete counterpart). In the left-hand side map, a

city contributes as many points as the number of times it benefited from a declaration of natural disaster between 2007 and 2017. In the right-hand side map, a city contributes a point if and only if it benefited from a declaration of natural disaster in 2016, the year considered as particularly challenging. In both maps, the color reflects the quartile of the residual error to which the city- and time-specific residual error belongs. Moreover, in the left-hand side map the transparency reflects the number of times the city benefited from a declaration of natural disaster between 2007 and 2017, a larger number leading to less transparency. By comparing the two maps, we notice (i) that the 2016 drought episode impacted very strongly the South of France and (ii) that, in this region, the residual errors tend to be higher, leading to the underestimation of the local cost.

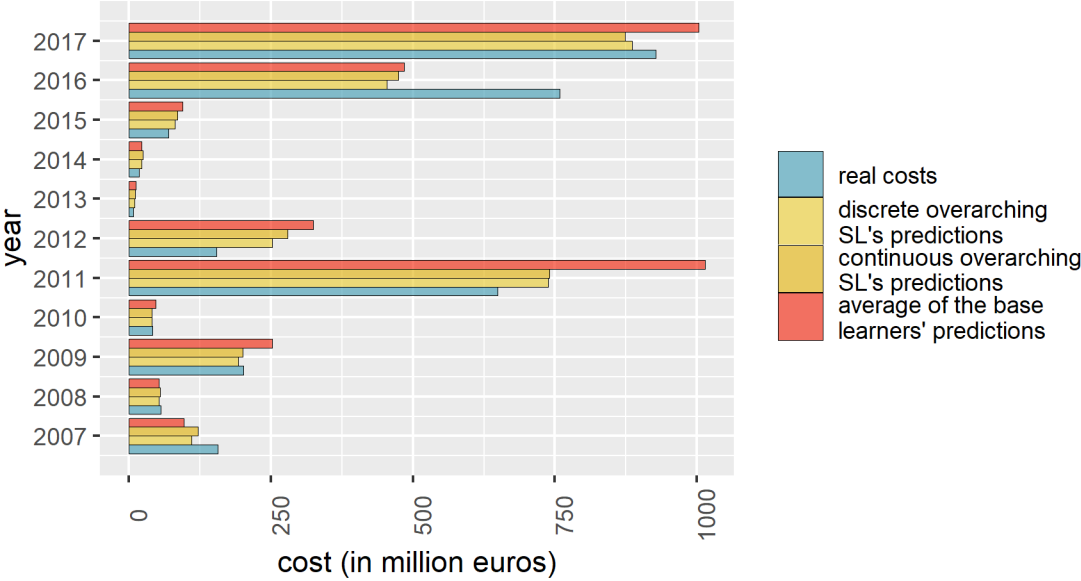


Figure 3: Presentation (from 2007 onward) of the real costs of drought events and their predictions. The predictions are either those made by the discrete and continuous overarching Super Learners or obtained by averaging all the base learners' predictions.

5 Discussion

The legal framework of the French natural disasters compensation scheme was created in 1982. Drought events were included in 1989 and have been since then the second most expensive type of natural disaster. In recent years, drought events have been remarkable in their extent and intensity. The problem is worsening and not limited to France, as was predicted in the technical report [Wüest

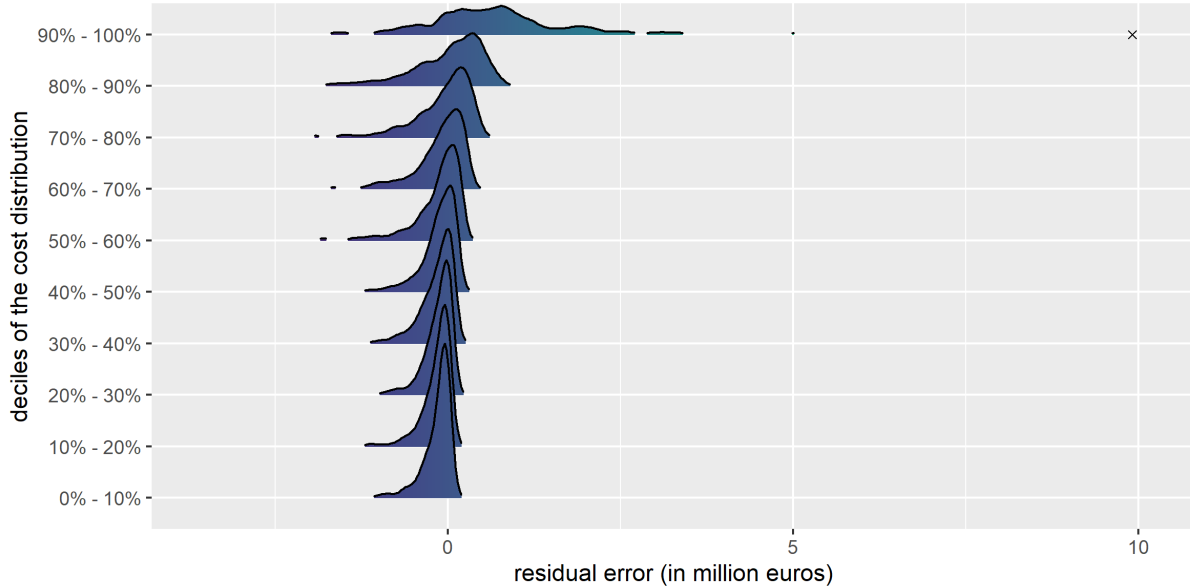


Figure 4: Kernel density estimates of the conditional laws of the residual error (of the predictions made by the continuous overarching Super Learner) in ten strata characterized by the deciles of the city-level costs. The cross at the upper right-hand side of the plot indicates the maximum residual error, made for a city belonging to the last decile of the cost distribution.

et al., 2011, page 7]: “as our climate continues to change, the risk of property damage from soil subsidence [*i.e.*, drought events] is not only increasing but also spreading to new regions across Europe”.

Anticipating the cost of a drought event is important actuarial problem. To tackle this challenge, we develop a new methodology that builds upon super learning. Our so-called overarching Super Learner blends predictions made by a collection of one-step ahead sequential Super Learners which, themselves, blend the predictions made by a variety of machine-learning algorithms.

In [Ecoto et al., 2021] we studied the theoretical properties of the overarching Super Learner. We showed that it can learn despite the complex dependence structure induced in the data by the spatial and temporal nature of the phenomenon of drought, making up for the shortness of the time-series thanks to the manyness of each time-specific observation because the latter are only slightly dependent. In this article, we focus on its application.

We present two implementations of overarching Super Learners, called the discrete and continuous overarching Super Learners. Their predictions are generally accurate and better than those obtained (for comparison) by averaging all the predictions made by the base machine-learning al-

all drought events

drought event of year 2016

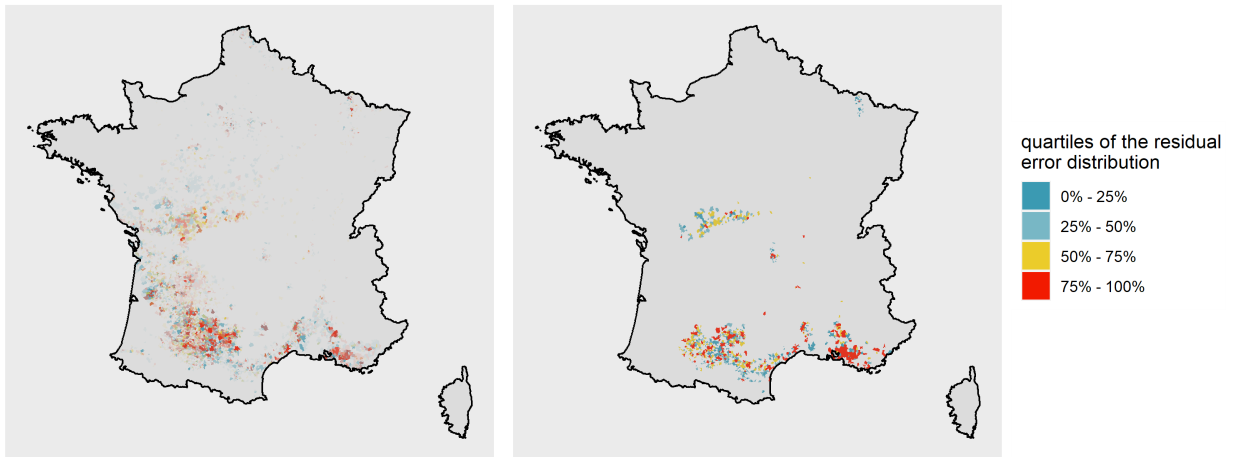


Figure 5: Geographical distribution of the residual errors (of the predictions made by the continuous overarching Super Learner). Left-hand side map: a city contributes as many points as the number of times it benefited from a declaration of natural disaster between 2007 and 2017. Right-hand side map: a city contributes a point if and only if it benefited from a declaration of natural disaster in 2016. The color reflects the quartile of the residual error to which the city- and time-specific residual error belongs (based on all the errors). In the left-hand side map, the transparency reflects the number of times the city benefited from a declaration of natural disaster between 2007 and 2017, a larger number leading to less transparency.

gorithms. Specifically, the two Super Learners' predictions are quite good for all years except 2012 and 2016. The poorer predictions in 2016, a year known in the French insurance market to be particularly challenging, are more problematic because the real cost in 2016 is much higher than in 2012. Moreover, we were given the authorization to compare the predictions of the discrete and continuous overarching Super Learners with that of the algorithm currently deployed at CCR for the sole year 2017: the precisions are respectively 96% (discrete overarching Super Learner), 94% (continuous overarching Super Learners) and 83% (currently deployed algorithm).

In conclusion, the quality of the predictions made by the overarching Super Learners strongly depends on the quality of the local description of the drought event. It would probably benefit from a refined version of the city-level SWI that, contrary to the one we rely on, does not assume that the nature of the soil is the same all over France. In addition, the local description would also be considerably enhanced if it included information such as the distribution of proximity between a house and a tree at the city-level, or the distribution of the depth of house foundations at the city-level. Such pieces of information are proxies to the soil shrinkage and swelling. The local description could also be considerably enhanced by including direct measurements of soil shrinkage and swelling which can be obtained by radar interferometry.

In this work, we anticipate the cost of drought events in France by super learning for those cities that have obtained the government declaration of natural disaster. The next step will be to predict which cities will obtain the government declaration of natural disaster. Tackling this difficult challenge will allow anticipating the cost of drought events earlier.

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