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Enhancing Meteorological Drought Risk Management in Regional Italy

A strategic approach through SPI forecasting

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Executive Summary

This policy brief proposes a structured approach to mitigating meteorological drought risks in regions of central Italy using the Standardized Precipitation Index (SPI). It is suggested that by leveraging advanced forecasting models, such as the Vector Autoregressive with Dynamic Conditional Correlations (VAR-DCC-GARCH) model, it is possible to enhance early warning systems for central Italian regions and improve water resource management. The suggested strategy emphasizes proactive monitoring, stakeholder coordination, and adaptive response measures to build resilience against the increasing frequency of droughts.

A technical **Working Paper** with extensive explanations of methodology, data, and empirical results (part of which are summarized below) will be also available on Amelia, including the **Matlab code** used to produce and automate SPI forecasting.

Introduction

Drought is an increasingly severe issue in Italy, exacerbated by climate change and regional variability. Romano et al. (2022) provide evidence of an increase in drought events during the last 20 years, with a rise in extreme events such as heat waves and intense droughts in central Italy.

Traditional reactive approaches to drought management have led to delays and economic losses, particularly in agriculture and hydroelectric production. Existing policies, which rely on historical precipitation patterns and reactive interventions, have proven insufficient to deal with the increasing unpredictability of drought events. See, e.g., Mishra and Singh (2011) and Fung et al. (2017) for extensive reviews.

While regional and national water management regulations are currently in place, they lack sufficient integration of predictive modeling and coordinated early warning systems. Academic research has made significant strides in developing statistical models for drought forecasting, from the early empirical studies of Hayes et al. (1999) and Cancelliere et al. (2007) to the more recent work of Modarres and Ouarda (2014). However, the implementation of these models into policy remains limited.

The suggested contribution aims to bridge the existing gap by introducing a scientifically grounded framework to stimulate proactive drought risk management. Our research highlights the importance of a multivariate modeling approach to accurately assess regional drought trends and improve decision-making.

Improving drought monitoring

The increasing frequency and severity of drought events across Italian regions necessitates a proactive monitoring and forecasting framework. A science-based, predictive model is crucial for agriculture, energy, and public health. Prolonged droughts have impacted agriculture, causing economic losses, while water availability is essential for hydroelectric power. Climate change adds complexity by altering precipitation patterns.

We analysed a commonly applied drought index called the Standardized Precipitation Index over a 24-month period (SPI24) monthly time series from January 1953 to December 2024 for three regions: Tyrrhenian coast, Apennine ridge, and Adriatic coast. The SPI24 helps quantify the long-term drought conditions by assessing cumulative precipitation over a 24-month timeframe. By using this index, we could better understand extended periods of drought, which are crucial for water resource management. See WMO (2011) and our working paper for further details on the SPI.

The three-monthly time series span from January 1953 to December 2024 (864 monthly observations), as shown in Figure 1.

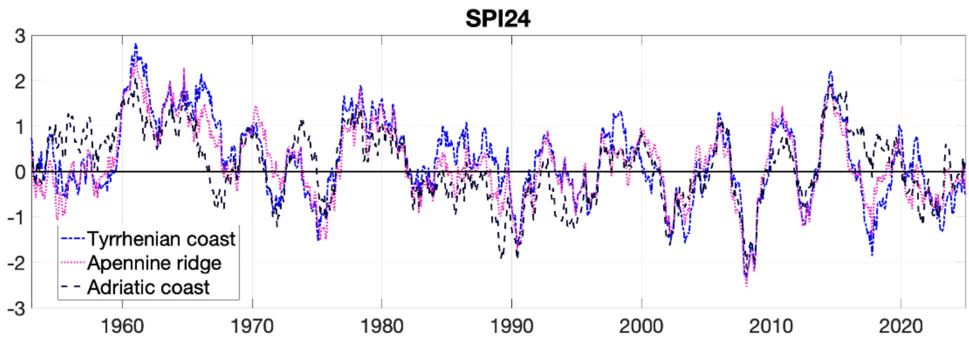

Figure 1: SPI24 time series averaged over the three reference areas. The time series spans from January 1953 to December 2024.

Rolling window estimates of correlation coefficients using a 12-month window (Figure 2) provide insights into the temporal dynamics of the correlations among the regions. The figure shows how correlations vary over time, reflecting potential shifts in climate dynamics and shared climatic influences. These rolling window correlations allow us to observe periods of high or low inter-regional synchronization.

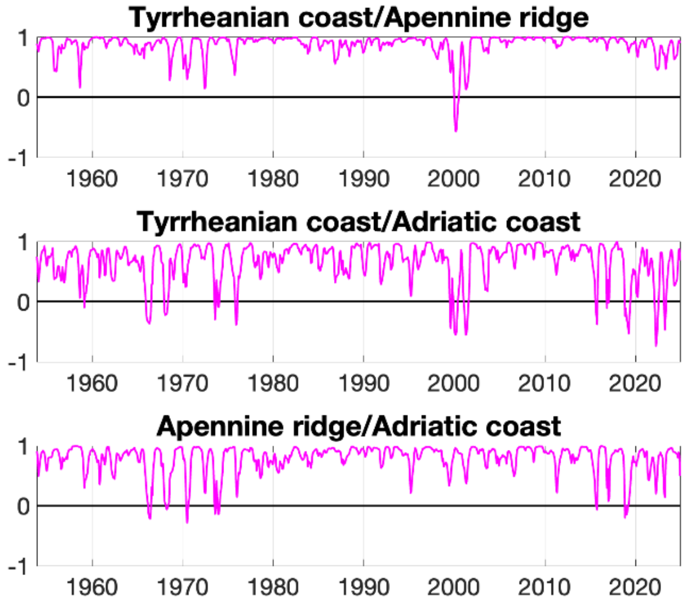

Figure 2: Empirical correlation on a rolling window of 12 months of the monthly SPI24 series.

Our analysis aims to move towards predictive modelling, using advanced statistical models that capture the dynamic relationships between drought conditions in different regions to monitor and forecast drought conditions accurately. The VAR-DCC-GARCH model allows for real-time monitoring and forecasting, ensuring more effective early warning systems. The GARCH and DCC models were introduced in the econometric literature by Bollerslev (1986) and Engle (2002).[1]

The suggested data-driven approach enhances the ability of policymakers to allocate resources efficiently and mitigate the socio-economic impacts of droughts, and implement timely measures to mitigate drought impacts, fostering resilience and protecting key economic sectors. Coordinated stakeholder engagement is essential for an effective response to drought challenges.

Out-of-Sample Forecasting Analysis

To validate the effectiveness of the proposed approach, an out-of-sample forecasting exercise was conducted. Using an expanding window evaluation, the

[1] See also Lütkepol (2005) for technical details on the VAR model.

model was tested for 12 up to 24-month forecasting horizons. The entire dataset has been divided into an in-sample period, spanning from January 1953 to December 2000, and an out-of-sample period, covering January 2001 to December 2024.

Results indicate that the VAR-DCC-GARCH model performs well in predicting drought trends across different regions, though with varying degrees of accuracy. The forecasting results are displayed in Figure 3.

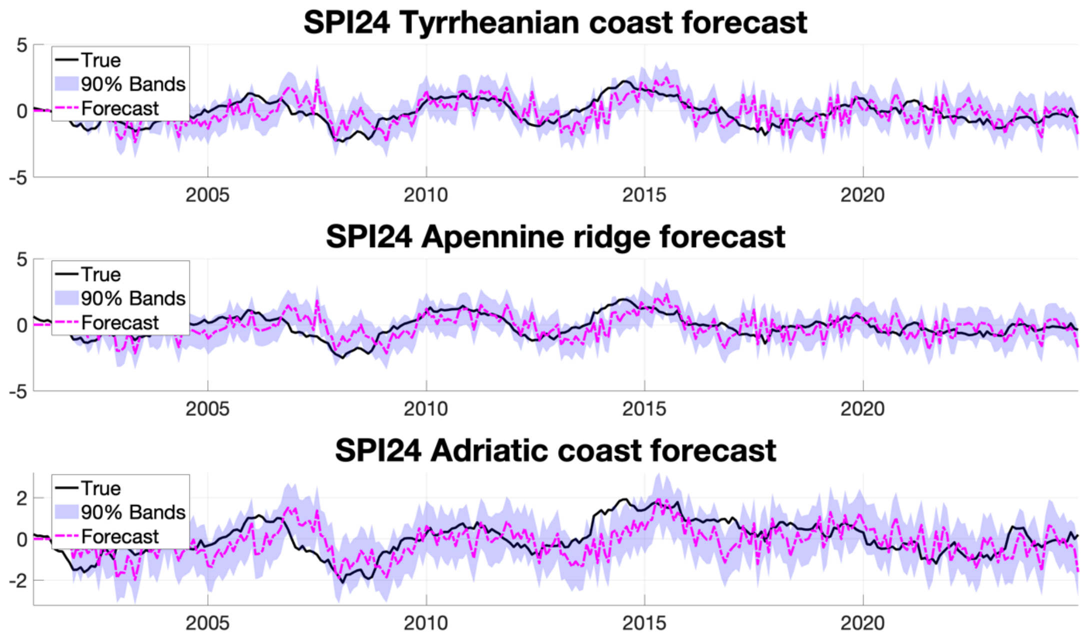

Figure 3: 12 step-ahead forecast of the monthly SPI24 time series. The out-of-sample period covers from January 2001 to December 2024.

For the **Tyrrhenian and Apennine regions**, the model provides strong predictive power, capturing long-term trends and maintaining alignment with actual SPI24 values. These results suggest the model is highly effective for these regions, supporting immediate drought response planning and long-term resource allocation. However, for the **Adriatic region**, the forecast results exhibit greater variability, with more pronounced deviations from observed values. The 90% confidence bands indicate moderate to high uncertainty in some periods, particularly after 2015, where the model struggles to capture extreme fluctuations. This suggests that additional localized modeling efforts or supplementary variables may be necessary to enhance forecasting precision in this region.

Overall, while the predictive framework successfully captures general drought trends, improvements are needed to better address short-term extreme events, particularly in regions with high climate variability. These findings reinforce the need for dynamic, data-driven drought management policies that incorporate real-time monitoring and localized adjustments.

Risk Management Framework

From a risk management perspective, evaluating a forecasting method by solely relying on statistical methods can be challenging. Risk managers often analyze a "confusion matrix", which summarizes correct and incorrect predictions by class. The results for the three different regions are reported in Figure 4.

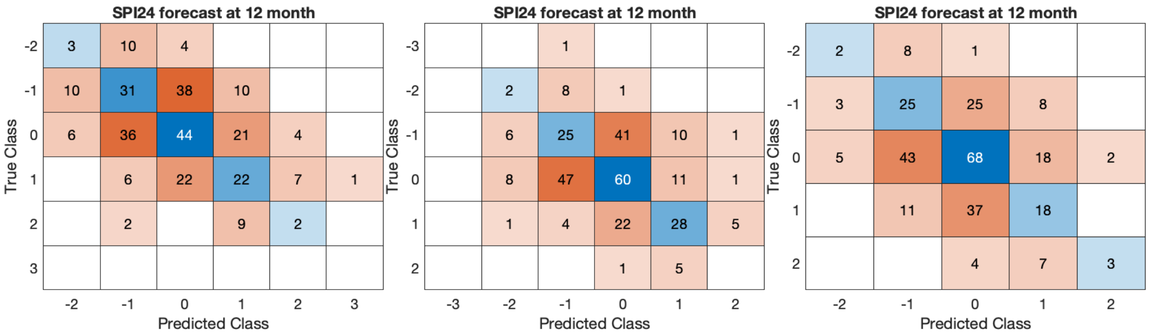

Figure 4: Confusion matrices of the 12 step-ahead forecast of the monthly SPI24 time series for the three different regions: Tyrrenian coast (left matrix), Apenine ridge (center matrix), Adriatic coast (left matrix).

The confusion matrices plotted in Figure 4 demonstrate a strong forecasting performance of the VAR-DCC-GARCH model, with high accuracy across regions and no evident systematic biases. The model reliably distinguishes different classes, supporting effective risk management decisions in water resources, agriculture, and disaster preparedness.

This robustness remarks that the focus should shift to optimizing decision frameworks by refining early warning systems and resource allocation strategies to fully leverage the model's accuracy.

Discussion

1. **Monitoring and Forecasting Meteorological Drought:** Our results from the VAR-DCC-GARCH model highlight significant interregional correlations, particularly between the Tyrrhenian coast and the Apennine ridge. These findings emphasize the interconnected nature of drought conditions across regions, necessitating a coordinated response strategy. Additionally, rolling window correlation analysis reveals that drought conditions are not static but evolve over time, reinforcing the need for adaptable policies. By leveraging this predictive model, policymakers can better anticipate drought risks and allocate resources more efficiently.

2. **Early Warning System and Response Measures:** Our study underscores the importance of dynamic correlations in forecasting regional drought risks. Temporal variations in correlation strength suggest that real-time monitoring is crucial for effective drought management. A structured early warning system based on climate data can improve response times, ensuring that local governments and stakeholders take timely and appropriate actions. Immediate measures, such as water use restrictions during peak drought periods, should be combined with long-term investments in sustainable water management infrastructure.

3. **Regional Climate Dynamics and Adaptive Strategies:** Our findings indicate that the Adriatic coast experiences greater variability in drought conditions compared to other regions, highlighting the need for localized strategies. The shifting nature of interregional drought dependencies suggests that static policy approaches may be insufficient. Policymakers should develop flexible drought mitigation strategies that incorporate real-time data and allow for regional customization. These strategies should include both short-term emergency measures and long-term initiatives, such as improved irrigation practices and water storage solutions.

4. **Research Findings and Interpretation:** The research findings demonstrate the effectiveness of multivariate drought modeling in improving forecasting accuracy. While SPI is a well-established index for monitoring drought,

integrating VAR-DCC-GARCH enhances predictive capabilities by capturing dynamic dependencies among different climatic regions.

Potential counterarguments include concerns about the complexity of these models, which require technical expertise for implementation. Policymakers may also question the adaptability of the model across all Italian regions, particularly those with highly localized climate variations. However, the robustness of the suggested approach is supported by extensive historical data spanning over 70 years.

Other potential limitations in our findings stem from data limitations, including the reliance on standardized indices that may not always fully capture regional microclimatic variations. In this respect, our ongoing research aims to refine these models for enhanced accuracy.

Policy implications and recommendations

- Data-Driven Decision-Making: Policymakers must integrate ecometric modeling into drought management strategies to improve accuracy and efficiency.
- Investment in Infrastructure: Funding for improved water storage, irrigation systems, and conservation technologies is critical to long-term resilience.
- Legislative and Regulatory Support: Clear guidelines and enforcement mechanisms are required to ensure compliance with water use regulations and drought response measures.
- Public Awareness and Engagement: Community participation and education on water conservation can enhance the effectiveness of drought management policies.

Our analyses suggest that to enhance drought risk management, policymakers should:

- Expand Forecasting Capabilities: Integrate additional climatic variables and refine regional models to improve predictive accuracy, especially for regions with high climate variability, such as the Adriatic coast.

- **Strengthen Early Warning Systems:** Develop real-time monitoring platforms to provide timely alerts to stakeholders, ensuring proactive drought mitigation measures.
- **Improve Water Resource Management:** Implement sustainable water storage and conservation infrastructure to mitigate long-term drought impacts.
- **Enhance Policy Coordination:** Foster collaboration between national, regional, and local authorities to ensure unified drought response strategies.
- **Increase Public Engagement:** Raise awareness and encourage community participation in water conservation efforts to support sustainable drought management practices.

Implementation considerations

While these recommendations provide a strong foundation for improved drought management, successful implementation depends on several key factors:

- **Institutional Capacity:** Government agencies and research institutions must be equipped with the technical expertise and resources necessary to implement advanced forecasting models and early warning systems.
- **Funding and Investment:** Adequate financial resources must be allocated to improve water infrastructure, enhance forecasting technology, and develop educational campaigns on water conservation.
- **Legislative Support:** Clear regulatory frameworks are required to enforce drought mitigation measures, including water use restrictions and incentive programs for efficient water usage.
- **Data Sharing and Integration:** Collaboration among meteorological agencies, research institutions, and policymakers, and contribution to national repositories, like the AMELIA platform, is critical for real-time data collection and sharing to optimize drought response strategies.
- **Adaptability to Climate Change:** Policies must be flexible and adaptive to evolving climate conditions, ensuring that drought management strategies remain effective in the long term.

Concluding remarks

This study provides a robust, comprehensive approach to managing meteorological drought risk in Italy.

The empirical findings highlight that the suggested dynamic multivariate approach effectively captures regional dependencies and temporal variations, offering valuable insights for informed drought management and policy development.

The results emphasize the need for region-specific drought management strategies that leverage the observed correlations and variability in SPI dynamics.

By integrating advanced forecasting models, enhancing early warning systems, and fostering stakeholder collaboration, Italy can strengthen its resilience against drought impacts.

Regular policy evaluations and updates will ensure continued effectiveness in addressing climate challenges.

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