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REVIEW OF COMBINING FORECASTS APPROACHES

Aline Castello Branco Mancuso
Federal University of Rio Grande do Sul (UFRGS) - Brasil
E-mail: aline.mancuso@gmail.com

Liane Werner
Federal University of Rio Grande do Sul (UFRGS) - Brasil
E-mail: liane@producao.ufrgs.br

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ABSTRACT

The first review of the literature on the subject combination of forecasts was made in the twentieth century by Robert Clemen. After more than twenty years, several other papers have been published with new theories and applications, but no other similar review was performed. Faced with this placement, this paper aimed to review the literature on the approaches of combining forecast after the survey conducted by Clemen (1989), covering the various areas of knowledge. Thus, this paper presents the classification and analysis of 174 articles collected on the subject, describing their main characteristics. As main contributions, this paper offers: a summary of current literature on the topic; a classification of articles according to the approaches; a subdivision of items within each approach; analysis of classification and identification of the most common methods, new methods, and future research.

Keywords: combining forecasts, review of the literature, forecasting.

1. INTRODUCTION

The market is constantly changing and evolving, with local actions depending on global phenomena in addition to increasingly fierce competition. Faced with this scenario, formulation and strategic planning become vital to organizational survival and growth, both in theoretical and practical areas. Attentive to the new world order, as well as to business needs, search for optimization of the quantity of products to be produced with as minimal waste as possible has become the main topic of many studies.

Industries need accurate demand forecasts, since any significant deviation of the actual demand can cause several types of negative impacts, especially to the economic performance of the company. Besides the storage cost and risk of product obsolescence, some business sectors, such as food, for example, need to consider the short duration of perishable products, among many other variables that influence the volume and quality of production. However, it is essential to find a balance to avoid overproduction being wasted or else disadvantage caused by low productivity (CASAGRANDE & HOSS, 2010).

Due to this increasing need of greater control over the storage level, a mechanism has been designed to connect budget and actual demand. Demand forecasting is a process for making statements about events whose results have not yet been observed; after all, the future is unknown, but not unpredictable. Consequently, forecasting became an indispensable activity in planning, setting strategy and making business decisions.

Initially, the prediction process was based on a single technique, among the various options available. However, in many situations, single results may not be sufficient for decision making, due to the market complexity. Aiming at increasingly reliable forecasts along with the lowest error prospect, a procedure to add and adjust various forecasting techniques was developed, namely the integration of forecasts (WEBBY & O´CONNOR, 1996). Among different integrated structures, this study is limited to a method known as combining forecasts. It is a method that uses some objective or subjective mechanism to compose forecasts to obtain a final forecast (combined). According to Clemen (1989), among many ways developed to perform combining forecasts, so far, the results have been unanimous: combining forecasts lead to increased accuracy.

In the twentieth century, Clemen (1989) conducted the first review of the literature on the subject combining forecasts, listing 209 broad aspect publications. After more than twenty years, several other studies have been published with new theories and applications. However, none of those works compares to the one published by that author. Faced with this situation, the purpose of this paper is to review the literature on the approaches of combining forecasts, following the survey conducted in 1989 by Robert Clemen, state of the art in the area up to that date.

This article is divided into five sections, the first being this introduction. Section two presents the methodological procedures for the development of this article. Section three presents a theoretical combination of forecasts. The classification and analysis of mapped items are presented in section four. Finally, section five presents the main conclusions of this study.

2. METHODOLOGICAL PROCEDURES

Revision of specific literature review aims to survey and analyze material published on a particular topic, identifying the gaps and the main theoretical or methodological obstacles. This research provides a mapping of what has been written and by whom (SILVA & MENEZES, 2001). By synthesizing primary similar studies, the secondary ones serve as support for the targeted search, summarizing the volume of literature.

Hence, this section provides detailed steps of the literature review procedure. The project design ensures research reproducibility, besides allowing comments, suggestions and criticisms to the method used.

2.1 Research Question

The realization of the review initiates with the formulation and definition of the problem, enclosing the material to be analyzed. The completion of the review starts with the formulation and problem definition, which enclose the material to be analyzed. In this work, we want to obtain information about the current state of the literature of combining forecasts, as well as its use. For that reason, the theoretical framework should clarify the issue, providing a better definition of the subject studied.

2.2 Research Project

The search for studies was conducted online during the year 2012. Through the exploration of the ten areas of knowledge recorded in Journal Portal Capes, 83

databases were filtered to be searched in full-text journals. Consulting databases from such periodicals, the articles selected were the ones which mentioned the words "combining" and "forecast" or "combine" and "forecasting" in their title or keywords. Since the main objective of this work is to examine studies on combination of forecasts, continuing the review by Clemen (1989), only studies published from 1989 on were compiled. The search resulted in 256 articles, except for the work already covered by Clemen (1989), and the studies on the combination of models and inference combinations (combination of intervals and densities), considered outside the scope of the search. The final number of identified articles was reduced to 174. The total figure resulting from the search, as the strategies used for each database, can be seen in Table 1.

Table 1. Articles identified in Databases.

Databases	Publisher	URL	Articles
ACM Digital Library	Association for Computing Machinery	http://dl.acm.org	23
IEEE Xplore	IEEE	http://ieeexplore.ieee.org	07
Cambridge Journals Online	Cambridge University Press	http://journals.cambridge.org	02
OECD iLibrary: Periodicals	Organization for Economic Co-operation and Development	http://www.oecd-ilibrary.org	01
American Physical Society	American Physical Society	http://publish.aps.org	01
SciElo	Bireme	http://www.scielo.org	02
AIP Scitation	The American Institute of Physics	http://scitation.aip.org	01
Central Online and Open Access Library	Copernicus Systems + Technology GmbH	http://sref.org	01
Academic Search Premier	EBSCO	http://ebscohost.com	03
Social Sciences Full-Text	HW Wilson	http://hwwilsonweb.com	02
High Wire: Free Online Full Text Articles	High Wire Press	http://highwire.stanford.edu	03
Maney Publishing		http://ingentaconnect.com	52
Wiley Online Library	Wiley Inter Science	http://onlinelibrary.wiley.com	33
Cell Press Collection	Cell Press (Elsevier)	http://sciencedirect.com	44

After defining the research question (stage I), and mapping available literature (stage II), approaches were identified (stage III), following the classification of articles in approaches (stage IV) and the analysis of the classification of approaches (stage V). However, before the mapping, a theoretical framework on the subject must be presented.

3. COMBINATION OF FORECASTS

In the production of goods, demand forecasting can be understood as a function related to predicting the consumption of products, so that they can be appropriately manufactured to meet demand. However, this function can be described by several methods, ranging from informal judgment, intuition and expert opinion, through macro-economic factors, and even forecasting techniques based on historic data.

Most of the methods employed analyze information using only a single forecasting technique; as a consequence, some information from other techniques end up disregarded (WERNER & RIBEIRO, 2006). As previously mentioned, the complexity of the market demands all available information for forecasting, and a single technique cannot make efficient use of such great deal of information. Since Bates and Granger (1969), the fact that forecasting techniques can become more accurate when performing combination has been studied. Regardless of how the combination is obtained, its result is intended to cause an increase in the accuracy of the individual estimates. This happens because individual forecasting techniques are based on different approaches, and can therefore capture distinctive characteristics of the series as well as allow the combination to benefit from such characteristics (ARMSTRONG, 2001).

The idea of combining forecasts is simple, as described in Figure 1. Based on a set of information, the forecasting models are generated based on different techniques (technique 1, technique 2, …, technique n), providing n forecasts. Such forecasts are then combined, generating a single final forecast. Armstrong (2001) discusses the number of techniques to be considered in combination, concluding that, with respect to efficiency, five would be suitable. The author bases his suggestion on the exponential behavior of the combination gains. The combination of five forecasts reduces the amount of errors, but when more than five techniques are combined, gains get smaller and smaller at each addition.

However, the question is: How should such techniques be combined? Two combination approaches are defined in the literature: one involving an objective approach and another involving a subjective one. The objective approach represents methods which use a mathematical function, so that results can be repeated. The

subjective approach includes intuitive efforts to combine forecasts, by means of knowledge and opinion.

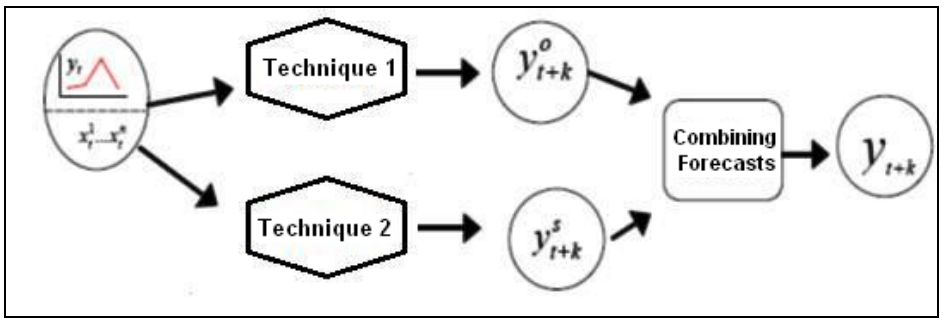

Figure 1. Combination of Forecasts
Source: adapted from Webby and O'Connor (1996, p. 100).

3.1 Objective Combining Methods

Objective methods of combination originated with Bates and Granger (1969), considered the forerunners of this subject. They proposed the method to combine the forecasts through a linear combination of two non-biased objective forecasts (or properly corrected) considering a weight k for the first, and (1 – k) for the second, as depicted in Equation (1).

$$C = kf_1 + (1-k)f_2 \quad (1)$$

Where: C is the value of the combination, f_1 the value of forecast one, f_2 the value of forecast two and k is the factor that minimizes the error variance of the combined forecast.

Subsequently, other authors adhered to the method and studies advanced in the area. The combination of forecasts was extended from two to "n", and combined techniques began to be interpreted as a structured form of regression (NEWBOLD & GRANGER, 1974). Since then, several authors have suggested new considerations and more sophisticated methods have been compared. However, the arithmetic mean is still one of the most commonly used methods (MENEZES et al., 2000).

An example of arithmetic mean performance compared to other methods of combination can be seen in Marques (2005). The author considers the simple average, the average weighted by the inverse of the mean square error (equivalent to the minimum variance method), the optimization with weight restriction and without constant (which is the estimated weights by the method of least squares, with weight

restriction and without constant) and the optimization without weight restriction, with constant.

Various forms of combination forecasts have been developed since the publication of the article by Bates and Granger (1969), extending from the simple arithmetic mean to more sophisticated methods such as neural networks to nonlinear combinations or studies using Bayesian analysis for the combining forecast, which in general weighs each forecast based on the expected value. Chan et al. (1999) listed some classic works in this approach. However, there is no consensus in the literature that a sophisticated combination method might be superior to simpler ones, as the average of individual forecasts. Like Clemen (1989), Werner (2005) emphasizes the combination via simple average which, despite lacking optimal weights, can provide better results compared to more sophisticated methods. Nonetheless, Martins (2011), for example, discusses the superior performance of the combination via minimum variance.

Moreover, to establish the accuracy of a forecast in the objective approach, it is essential to estimate error. Paliwal and Kumar (2009) observed the use of MAPE (Mean Absolute Error Perceptual), MSE (Mean Square Error) and MAE (Mean Absolute Error) as the main measures to evaluate model performance in several studies. However, variations as the Root Mean Square Error (RMSE), among others, are also commonly applied.

3.2 Subjective Combining Methods

The subjective approach of combination is still considered unexplored, given that intuition can hardly be repeated (WERNER & RIBEIRO, 2006). It is usually used with scarce data, while launching a new product, for example. Using only intuition and acquired knowledge, as the consensus practices of a group, the Delphi method and the selection of the best experts are distinguished for combining forecasts subjectively. For Armstrong (2001), in most situations, the first step should be the opinion of experts.

The combination of models (objective techniques) with human judgment (subjective techniques) follows the same principle of combination mentioned above, and illustrated by Figure 1. However, this method is best seen in. Based on historical data, the model is generated at the same time as human judgment is executed,

adding contextual information to yield two forecasts (objective and subjective). These forecasts are combined and, based on contextual information, one single final forecast is generated (WEBBY & O'CONNOR, 1996; WERNER, 2005).

Werner (2005) discusses some publications based on subjective combining, concluding that combining forecasts are influenced by the individual characteristics of predictors, as well as by the aspects of the forecasting context.

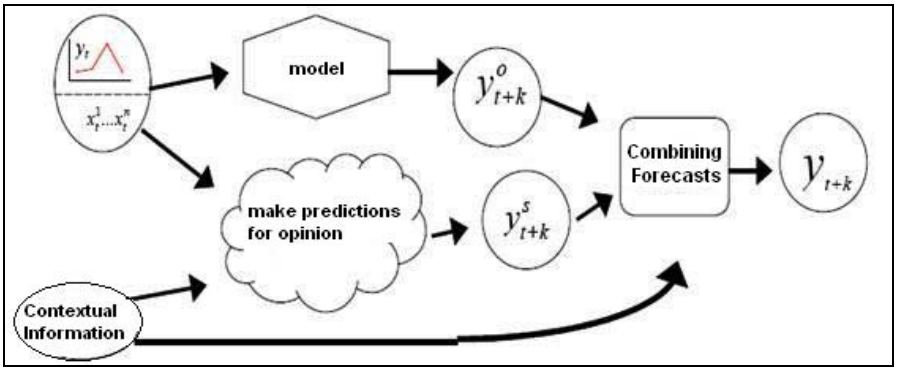

Figure 2. Subjective Combining Method
Source: Webby and O'Connor (1996, p. 100).

There are many studies on combining forecasts in the literature, as represented in the mapping. Moreover, this popularity of combination is due to the fact that, instead of attempting to choose the best technique, the problem is formulated by asking which techniques could improve accuracy (WERNER, 2005; WERNER & RIBEIRO, 2006). Armstrong (2001) recommends combining forecasts when there is no assurance about the situation and/or technique precision, so as to avoid significant mistakes.

4. MAPPED ARTICLES

In an analysis preceding the identification of the approaches, obtained data were described according to year of publication and journal. Table 2 presents the number of articles per journal, being the category "others" the group of journals that presented only one publication during the period surveyed.

Table 2 shows that the periodicals International Journal of Forecasting and Journal of Forecasting concentrated approximately 37% of the publications relating to combining forecasts in that period. Still, yearly publications are better analyzed in. Additionally, Figure 3 shows a positive trend over the years, especially 2007 and 2008, both with 14 publications. The culmination of the work in this area was year 2011, with 23 publications.

Table 2. Number of articles per journal and year of publication.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total (%)
Applied Economics									1									1					1		3 (1,72)
Applied Economics Letters																	1		1						2 (1,15)
Computers and Industrial Engineering									1		1														2 (1,15)
Conference											1					1		1	4	1	1		2		11 (6,32)
Decision Sciences	1																								2 (1,15)
European Journal of Operational Research								1			1	1	1		1										6 (3,45)
Expert Systems with Applications											1												2	1	4 (2,30)
Hydrological Processes																					1			1	2 (1,15)
International Journal of Forecasting	6	1			1		1	3	1	3	2	1		2	1	2	1	1	2	3		1	7	1	45 (25,86)
International J. of Production Economics			1																				2		2 (1,15)
J. Computational Statistics & Data Analysis				1																1			1		2 (1,15)
Journal Decision Analysis																1							1		2 (1,15)
Journal Management Science		1		1							1							1							4 (2,30)
Journal of Applied Statistics													1				1	1	1						4 (2,30)
Journal of Forecasting				2	2	3	2	1	1								1		1	3	1		2		19 (10,92)
Journal of Hydrology													1								1				2 (1,15)
Journal of the Operational Research Society											1	2													3 (1,72)
Journal of Time Series Analysis																							1	1	2 (1,15)
Management Science							1			1															2 (1,15)
Mathematical and Computer Modeling											1			1											2 (1,15)
Meteorological Applications								1								1									2 (1,15)
Oxford Bulletin of Economics and Statistics																					2			1	3 (1,72)
Technological Forecasting and Social Change																			1				1		2 (1,15)
Tourism Management																			1		1				2 (1,15)
Others	1	1		1	1		3	1	1	1	3	1	2	1	1	2	3		3	6	3	5	3	1	44 (25,29)
Total (%)	8 (4,60)	4 (2,30)	2 (1,15)	8 (4,60)	4 (2,30)	3 (1,72)	7 (4,02)	7 (4,02)	5 (2,87)	5 (2,87)	12 (6,90)	5 (2,87)	5 (2,87)	4 (2,30)	3 (1,72)	7 (4,02)	7 (4,02)	5 (2,87)	14 (8,05)	14 (8,05)	10 (5,75)	6 (3,45)	23 (13,22)	6 (3,45)	**174**

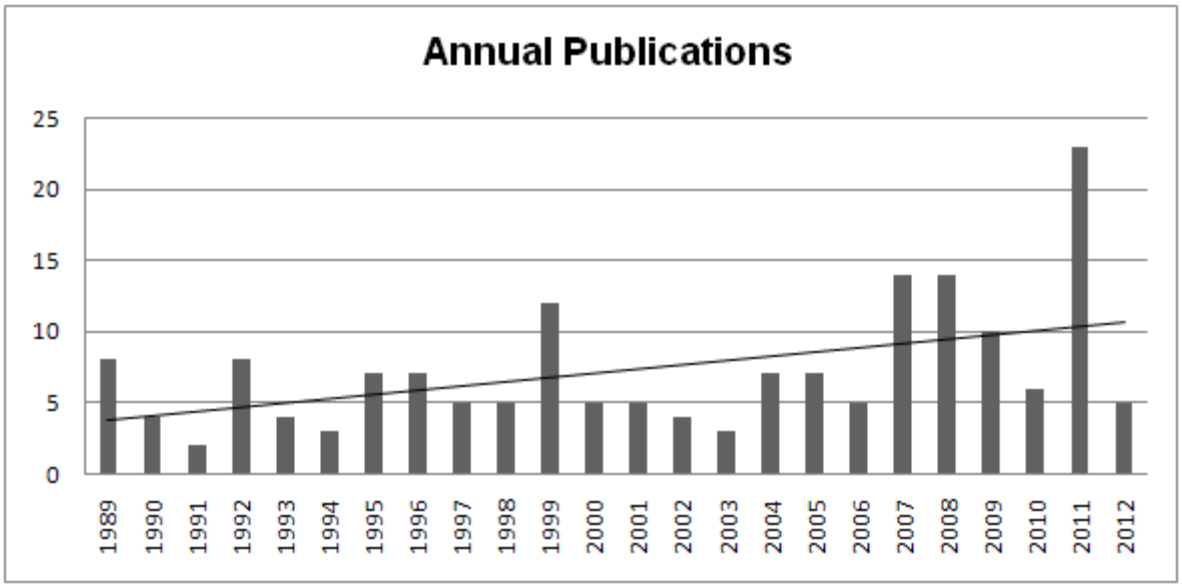

Figure 3. Temporal evolution of publications
Source: prepared by the author

4.1 Classification

Regarding approaches, we identified four major groups: a summary or review of the literature, comparison of methods, application and exploration.

From a total of 174 articles compiled, 80 were considered exploratory, 73 were applicative, 15 were selected for the comparison of methods and 6 are abstracts or reviews. What follows is the importance to emphasize that these ratings are suggestive. Many publications do not present an exact definition of attributes; some articles, for example, use both application and comparison in the discussion of combining methods. However, in such cases, the suggested classification was based on the content of these studies: summary and review of the literature studies that prioritize the review of the subject; comparison of methods and works confronting methods; applications to compare or explore the use of combination applied to a specific topic; and exploratory, which are designated to the theoretical analysis.

4.2 Summary or Literature Review

During the mapped period, four review articles and two abstracts were found. Clemen (1989) provided an annotative bibliography of the literature so far, including the contributions of psychology, statistics and other areas of knowledge, in addition to highlighting some suggestions for further studies. Smith (1997) reviewed and discussed the performance of simple models compared to more complex ones. Yet, in the study of model precision, Menezes et al. (2000) have also revised the

guidelines for the use of the combination and analyze data on the performance of different combining methods, aiming to provide practical guidance based on three properties of forecast errors: variance, asymmetry and correlation. More recently, Jorgensen (2007) examined subjective combining.

Nevertheless, Armstrong (2006) and Wallis (2011) defined that work as a summary. While Armstrong (2006) summarizes the progress made during the past 25 years, regarding methods to reduce forecast error. Wallis (2011) dedicates his review to the memory of Clive W. J. Granger (1934 - 2009), resuming some of the themes approached in the article of Bates and Granger (1969).

4.3 Comparison of Methods

Several authors compare their results with results of other authors in an attempt to suggest a new method or justify the proposed one. However, this kind of approach lists works that assign a larger space between the comparison techniques and models. In Table 3, 15 publications classified in this area are identified (first column) along with the methods compared (second column). Columns three and four distinguish the focus of comparison (context), when it is set, and the specific application area, respectively.

Despite the comparative content of these works, some authors focus on the application areas. Such principle of comparison and application highlights the prominent comprehensiveness of economy. In the macroeconomic area, more specifically, Walz and Walz (1989) confront a Bayesian method of combination with multiple regressions. Moreover, applied to exchange rates, Tsangari (2007) analyzes different methods of combining forecasts and proposes an alternative methodology. Yet, Jing-Rong (2007) and Jing-Rong (2008) compares the combining forecast model proposed with the individual forecasts and the combination of methods. In both works the author uses forecasts of stock market volatility; the difference resides in the Bayesian interpretation of the combining forecast suggested by the author in 2008. Furthermore, currently, in the field of macroeconomics, Poncela et al. (2011) compare the use of four combination methods: most important components, dynamic factor models, partial least squares and sliced inverse regression. In tourism, Shen et al. (2008) analyze three combining methods: simple mean, variance-covariance (minimum variance) and the discounted mean square forecast error method.

Table 3. Articles mapped in attribute Comparison of Methods.

	Methods Compared	Context	Application
Walz e Walz (1989)	- multiple regression - Bayesian method	Bayesian method	macroeconomic
Lobo e Nair (1990)	- individual forecasts - objective methods - subjective methods	equal weights versus unequal ones	annual profit accounting
Aksu e Gunter (1992)	Four combination methods		
Ming Shi *et al*. (1999)	- individual forecasts - linear methods - nonlinear methods	ANN (artificial neural networks)	
Taylor e Bunn (1999)	- theoretical methods - empirical methods	nonparametric for accurate measurements	
Goodwin (2000)	Three integration methods subjective		
Jing-Rong (2002)	- individual forecasts - conventional methods - nonlinear methods	FNN (Fuzzy Neural Network)	
Jing-Rong (2007)	- individual forecasts - combining forecast - combination of methods		forecasts of stock market volatility
Tsangari (2007)	Several		exchange rates
Jing-Rong (2008)	- individual forecasts - combining forecast - combination of methods	Bayesian method	forecasts of stock market volatility
Shen *et al*. (2008)	- individual forecasts - three combining methods		tourism
Jeong e Kim (2009)	Eight combination methods		
Hsiao e Wan (2011)	Two combination methods	scenarios prone to structural breakage	
Poncela *et al*. (2011)	Four combination methods		macroeconomics
Martins e Werner (2012)	- individual forecasts - Three combination methods	orrelation between the errors	industrial series

Besides comparing methods, several authors compare combining with individual forecasts. Shi et al. (1999) discuss the use of artificial neural networks (ANN) in relation to methods of linear combination and Jing-Rong (2002) compares fuzzy neural networks (FNN) with conventional methods. Yet, applied to the forecast annual profit accounting, Lobo and Nair (1990) also compare combining with individual forecast, and discuss objective in opposition to subjective methods. Additionally, they analyze the use of equal weights versus unequal ones.

And in the scope of exploration, Aksu and Gunter (1992) comment on the efficiency of the simple mean, of the OLS (Ordinary Least Squares) model, ERLS - Equality Restricted Least Squares (also Restricted Least Squares) and NRLS - Restricted Non Negative least Squares. Taylor and Bunn (1999) compare the ability of theoretical and empirical methods, and a nonparametric proposal for accurate measurements. In the field of subjectivity, Goodwin (2000) compares the accuracy of combined forecasts with two other integration methods. Jeong and Kim (2009), from

theoretical angles, contrast the two most popular combining methods, simple average and weighted average, with six others. The authors also develop a guideline for the choice of combining method using analytical derivations.

In a more contemporary context, some authors use the comparison between methods as an exploration basis. Martins and Werner (2012) intend to identify differences in the accuracy of forecasts obtained with and without considering the correlation between the errors, comparing individual forecasts to the combination by simple average and minimum variance with and without correlations. Hsiao and Wan (2011), however, suggest two corrections for the combination via simple average, comparing models in scenarios prone to structural breakage.

Moreover, this class includes an extremely well-known forecast competition: M-Competition (MAKRIDAKIS et al., 1982) and its subsequent versions, the M2-Competition (MAKRIDAKIS et al., 1993) and M3-Competition (MAKRIDAKIS & HIBON, 2000). The main idea of the authors is to hold a competition with the largest possible number of sets and models. A set of 1001 series is used in the M-Competition, with interest models forecasting these series (24 different models). Later versions include new series and new models in the competition. However, these three publications of the Competition series do not take part of the group of papers screened, as they go beyond the scope of this study. Addressing them, however, is essential in any reference work on combining forecasts.

4.4 Application

In the application criterion, there are 73 papers that analyze and/or use the combination of forecasts as a forecasting method for a particular field. Table 4 identifies such field and their references.

According to Table 4, in this attribute there is a significant amount of work from the field of economy, with 26 publications. Weather has the second highest rate, with 12 publications.

As in the previous attribute, applied works are not necessarily unique. Many authors have used comparisons and engaged in an exploration. Among the references identified as application stand out Xiong et al. (2001), Dreger and Schumacher (2005) and Rapach and Strauss (2008), on a criterion of comparisons. Menezes and Bunn (1993), Volkov and Gladkov (1995), Terregrossa (2005), and

Moreno and Lopez (2007) and Moreno and Lopez (2011) and Christodoulos et al. (2011) also have works distinguished by the level of exploratory application. Lubecke et al. (1998) are prominent as well in the exploration of neural networks.

Table 4. Articles mapped in attribute Application.

Field	References	Context
Economy and Finance	Spiro (1989)	Macroeconomic / Canada
	Lobo (1991)	Net business
	Collopy e Armstrong (1992)	Economic and demographic Series
	Klein e Park (1993)	USA
	Menezes e Bunn (1993)	Annual inflation / UK
	Macdonald e Marsh (1994)	Exchange Rates
	Volkov e Gladkov (1995)	Exchange Rates
	Donaldson e Kamstra (1996)	Stock market volatility
	Shen (1996)	Macroeconomic / Taiwan
	Lubecke *et al*. (1998)	Exchange rate volatility
	Hu e Tsoukalas (1999)	European Monetary System (EMS)
	Leung *et al*. (2001)	Financial trading
	Dreger e Schumacher (2005)	Economic Indicators / Germany
	Greer (2005)	Interest Rates
	Ramnath *et al*. (2005)	Cash Flow
	Terregrossa (2005)	
	Poncela e Senra (2006)	Inflation / USA
	Moreno e López (2007)	Economic Growth / Spain
	Hollauer *et al*. (2008)	Brazilian industrial GDP
	Wang e Nie (2008)	Indexes / Shanghai
	Wang e Nie (2008b)	Indexes / Shanghai
	Rapach *et al*. (2009)	
	Drechsel e Scheufele (2011)	Indicators of industrial production / Germany
	Bjornland *et al*. (2012)	Inflation / Norway
	Gmez *et al*. (2012)	Food inflation / Colombia
	Moreno e López (2011)	Macroeconomics / Spain
Industrial demand	Gardner (1993)	Component failure in computer systems
	Thomas (1996)	Service sector
	Chan *et al*. (1999)	Ordering and stocking of bank printed forms
	Chan *et al*. (1999b)	Inventory management banking
	Strijbosch *et al*. (2000)	Inventory control procedure for spare parts
	Taylor *et al*. (2000)	Electricity demand
	Cox e Popken (2002)	Telecommunications
	Caiado (2010)	Water consumption / Spain
	Lin *et al*. (2010)	Third-generation (3G) telecommunication industry
Electoral market	Berg *et al*. (2008)	
	Jones (2008)	Presidential elections / USA

(continuation)

Table 4. Articles mapped in attribute Application (continuation).

Field	References	Context
Meteorology	Garand e Grassotti (1995)	Rain Rate
	Brown e Murphy (1996)	Temperature road surface
	Xiong *et al*. (2001)	Precipitation and runoff
	Klopper e Landman (2004)	South African Weather Service (SAWS)
	Metzger *et al*. (2004)	El Niño - Southern Oscillation (ENSO)
	Doblas-Reyes *et al*. (2005)	DEMETER multi-model ensemble system
	Lucio *et al*. (2007)	Standardized Precipitation Index (SPI)
	Nielsen *et al*. (2007)	Wind energy
	Bezerra *et al*. (2008)	Climate Forecast
	Zhang *et al*. (2009)	Hydrological processes
	Sumi *et al*. (2011)	Index precipitation
	He *et al*. (2012)	Hydrological processes
Commercial Sector	McIntyre *et al*. (1993)	Retailers who plan periodic promotions
	Gong *et al*. (2011)	Foreign trade forecasting system
	Mukhopadhyay *et al*. (2011)	Information sharing
	Zhu *et al*. (2011)	Information sharing
Business Sector	Mahmoud (1989)	Managerial issues
	Öller (1990)	Business cycle
	Kamstra *et al*. (2001)	Bond ratings in the transportation and industrial sectors
	Jiang e Yuan (2007)	Personal credit
	Yufang e Minghui (2007)	Personal credit
	Rapach e Strauss (2008)	Employment growth / USA
	Rapach e Strauss (2012)	Employment growth / USA
Tourism	Wong et al. (2007)	Tourism demand
	Coshall (2009)	Tourism demand
	Chen (2011)	Tourism demand / Taiwan
Other	Perry e Euler (1990)	Situations where time is a scarce resource
	White *et al*. (1992)	Thoroughbred horse race outcomes
	Meade e Islam (1998)	Technological forecasting
	Cho e Wüthrich (1999)	Information available on the World Wide Web
	Host *et al*. (2007)	Laboratory experiments
	Stathopoulos *et al*. (2008)	Urban traffic
	Spann e Skiera (2009)	Betting market
	Zhang *et al*. (2010)	Semiarid mountains
	Christodoulos *et al*. (2011)	Propagation of a successful innovation
	Green e Armstrong (2011)	Decisions in conflict situations

4.5 Exploration

Most of the articles mapped point at an exploratory nature. In this class, authors study and analyze various different criteria of combining forecasts. The 80 selected articles in this attribute were classified into two Tables, according to the focus of exploration. Table 5 identifies the studies that explore subjective models, neural networks, Bayesian statistics and theories for the selection of models. In Table 6

works that focus on the combined weighting of forecasts, forecast errors and a variety of fields are listed.

Table 5 presents the scope of subjective methods in relation to others, despite the bias they may establish (WERNER, 2005). Studies on the model selection and the use of neurotic networks have also played a major advance over the last decade. However, the use of Bayesian methods in combination of predictions is still scarce. Table 6 displays a growing concern about the weighting of forecasts and the accuracy of the models. Whereas in the "other" category, still in Table 6, exploration is widespread, studies address different combining topics, sometimes repeating the context of antithetical forecasts.

Table 5. Articles mapped in attribute Exploration: subjective models, neural networks, Bayesian statistics and selection of models.

Exploration		
Subjective Models	Hogarth (1989) McNees (1992) Sanders e Ritzman (1995) Maines (1996) Vokurka *et al*. (1996) Kamstra e Kennedy (1998) Fischer e Harvey (1999) Zhou *et al*. (1999)	Harries *et al*. (2004) Harvey e Harries (2004) Winkler e Clemen (2004) Richard e Soll (2006) Franses (2011) Franses e Legerstee (2011) Wang (2011)
Neural Networks	Aussem e Murtagh (1997) Fromm *et al*. (1998) Donaldson e Kamstra (1999) Jing-Rong (2000) Magalhaes *et al*. (2004)	Szupiluk *et al*. (2006) Shi (2009) Aladag *et al*. (2010) Ranjan e Gneiting (2010) Wichard (2011)
Bayesian Statistics	Palm e Zellner (1992) Tibiletti (1994) Faria e Souza (1995)	Félix e Rodríguez (2008) Cai *et al*. (2012)
Selection of Models	Clemen *et al.* (1995) Zou e Yang (2004) Costantini e Pappalardo (2010)	Costantini e Kunst (2011) Franses (2011b)

Table 6. Articles mapped in attribute Exploration: combined weighting of forecasts, forecast errors and a variety of theme are listed.

		Focus of Exploitation
Weighting	Gunter (1992)	Theoretical properties
	Winkler e Clemen (1992)	Instability of weights
	Chandrasekharan *et al*. (1994)	Weights and covariance matrix
	Mostaghimi (1996)	Sensitivity of weights
	Chan *et al*. (2003)	Variable weights
	Tang (2003)	Ideal matrix
	Elliott e Timmermann (2005)	Regime change
	Liang *et al*. (2006)	Linear combination
	Fan e Deng (2007)	Forecast error to variable weights
	Kim (2008)	Generalized autoregression
	Smith e Wallis (2009)	Finite-sample error in estimating the combining weights
	Kolassa (2011)	Akaike weights
Errors	Batchelor e Dua (1995)	Expected error variance
	Liu *et al*. (1998)	Distribution of errors
	Lam *et al*. (2001)	Approaches to minimizing the error
	Wenzel (2001)	Alternative measures to compare
	Tang (2002)	Error bounds of optimal combined forecasting (OCF)
	Riedel (2009)	Pooling
Other	Schmittlein *et al*. (1990)	Winkler method for combining
	Ridley (1995)	Global Antithetic Forecasts
	Gunter e Aksu (1997)	Non-negativity Restricted Least Squares – N(E)RLS
	Ridley (1997)	Optimal weights for combining antithetic forecasts
	Gardner (1999)	Rule-based forecasting vs. damped-trend exponential smoothing
	Ridley (1999)	Heteroscedastic antithetic forecasts
	He e Xu (2005)	Self-organizing algorithms
	Preminger *et al*. (2007)	Extended switching regression model
	Jose e Winkler (2008)	Average Trimmed e Winsorized
	Clark e McCracken (2009)	Nested models
	Clements e Harvey (2011)	Probability forecasts
	Armstrong (1989)	Rules to combine
	Ringuest e Tang (1989)	Discussion of combinations of Makridakis *et al*. (1982)
	Winkler (1989)	Forms and rules to combine
	Reeves e Lawrence (1991)	Accuracy and direction of change
	Miller *et al*. (1992)	Effects of nonstationarity
	Holden e Thompson (1997)	Combinations, forecast encompassing and efficiency tests
	Johnston *et al*. (1999)	Series with negligible growth and seasonality
	Terui e Dijk (2002)	Nonlinear time series
	Fang (2003)	Encompassing tests
	Armstrong (2007)	Significance tests
	Wang e Lan (2007)	Scenario analysis and the technological substitution model
	Amendola e Storti (2008)	Volatility forecasts
	Sancetta (2009)	Dependent heterogeneous data
	Hyndman *et al*. (2011)	Hierarchical time series
	Theodosiou (2011)	STL decomposition

4.6 Analysis

Besides the approaches, there is the interest of analyzing the data collected according to authors. Table 7 lists the number of publications by author, considering all the authorship of the same work.

According to Table 7, there are not many papers published by the same author. Of the 321 registered authors, R. L. Winkler leads the ranking with six publications, followed by R. T. Clemen and J. S. Armstrong, with five publications. As for the other authors, not included in Table 3, 29 had two publications and 273 had only one.

Table 7. Number of publications by author.

Author	nº	Author	nº	Author	nº
Winkler, R. L.	6	Chan, C. K.	3	Ridley, D.	3
Clemen, R. T.	5	Franses, P. H.	3	Shi, Y.	3
Armstrong, J. S.	5	Gunter, S. I.	3	Strauss, J. K.	3
Bunn, D. W.	4	Harvey, N.	3	Taylor, J. W.	3
Kamstra, M.	4	Kingsman, B. G.	3	Wong, H.	3
Jing-Rong, D.	4	Menezes, L. M.	3	Zhou, Z.	3
		Rapach, D. E.	3		

5. FINAL CONSIDERATIONS

The use of forecasts has become an important activity in today's market. Regardless of the mode in which forecasts are obtained, their outcomes affect decision making. Hence, combining forecasts emerged as a way to gather available information and increase accuracy of the final forecast. Nevertheless, there are several methods to combine forecasts. This work presents a literature review on the approaches of combining forecasts. Aiming to continue the revision proposed by Clemen (1989), 174 papers published between 1989 and 2012 were collected.

An overall analysis identified the year 2011 as the peak of the publications of combining methods, followed by 2007 and 2008 as second in contributions. During this period Robert L. Winkler stands out with the greatest number of publications on the subject matter.

Within the current market framework, combining forecasts is already a widely spread method in various branches of knowledge. Economy stands out as the field that invested most in the study of the subject. In the exploratory approach, however, combining forecast is still a growing method, as literature proves constant development of new techniques and comprehensive improvement of previously known models. Among such new techniques, it is noticeable that, in addition to the artificial neural network models, different and varied conjectures are proposed for the combination, along with speculation about the weighting of forecasts and their accuracy measures. Another highlight is the scarce literature on the use of Bayesian methods in combining forecasts, indicative of future research.

As for the comparison scope, many works still confront combining with individual forecasts, ensuring the accuracy of the models. However, works devoted to review the matter are still only a few.

The main contribution of this paper follows the classification and subdivision of publications in approaches, identifying areas of exploration and the latest contributions. The analysis of this classification seeks to summarize the knowledge on the subject so far, and is useful both for researchers in this and other areas. At last, this work stands as a reference for all those who wish to combine forecasts.

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