Technological Forecasting & Social Change 118 (2017) 128–133

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Technology forecasting using time series intervention based trend impact analysis for wheat yield scenario in India

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ARTICLE INFO

Article history:
Received 29 April 2016
Received in revised form 4 February 2017
Accepted 6 February 2017
Available online 15 February 2017

Keywords:
Trend impact analysis
Intervention model
ARIMA

ABSTRACT

In conventional Trend Impact Analysis (TIA), a baseline model based forecast is generated using historical data. Also, a set of future events and their impacts are identified utilizing prior knowledge. Further, these impacts and events are combined with baseline to generate possible future scenarios through simulation. One of the main drawback of this approach is that it cannot deal with unprecedented future technologies or rare events. Further, it cannot answer about expected future, if some specific event occurs at a particular period in future. Intervention analysis has been traditionally used to assess the impact of any unprecedented event occurring at known times on any time series. It consists of a single impact parameter and a slope parameter for a particular event. Hence, a new TIA method has been developed by combining conventional TIA with the intervention model instead of simulation, The traditional interventional model were modified as per the requirement of TIA to incorporate three impact parameters for any number of events. For the unprecedented future event, impact of the event is known while time at which event will occur is not known in advance. A formula for estimating slope parameter has been derived. The proposed TIA approach is capable to handle the influence of any unusual occurrences on the structure of the fitted model while providing forecasts of future values. The data requirements in this proposed new TIA is less as compared to conventional TIA approach. It can also answer about expected future if some particular event occur in particular time. The proposed TIA approach has been empirically illustrated for wheat yield scenario at All-India level. For this, three events each with three degrees of severity have been considered. All possible scenarios were generated from which preferable futures can be chosen.

1. Introduction

Forecasting in a systematic and scientific way can play a crucial role for providing timely information to policy makers on food shortages and/or surpluses for timely management of food supplies. This is more important in case of adverse environmental conditions.

Wheat is the second most important food-grain crop after rice in India. It is the staple food of millions of Indians. Therefore, not only forecasting of wheat yield but also technology forecasting related to this crop is very important for policy makers of the country. The applications of quantitative technique i.e. statistical model particularly ARIMA model were used extensively for forecasting crop are, yields or production data have been reported for pigeon pea production (Sarika et al., 2011), sugarcane area, production and productivity (Suresh and Priya, 2011), maize area and production (Badmus and Ariyo, 2011), rice area and production (Prabakaran and Sivapragasam, 2014) etc. The approach of employing ARIMA modeling for forecasting provides better result for short period but for longer period this approach may not produce a reliable forecast as it does not consider the effects of unprecedented future events or technologies that could cause deviation from the model.

The domain of technology forecasting not only incorporates, the benefits of quantitative approaches but also takes care of unprecedented future events. Therefore, efforts are often made to fuse qualitative approaches with them to better predict the future values. One such important hybrid forecasting approach is the Trend Impact Analysis (TIA) (Gordon, 2003; Glenn, 2003; Firat et al., 2008). TIA consists of two steps. In the first step, a baseline forecast is generated using a suitable statistical model based on historical data. In the second step, a set of future events and their impacts are identified utilizing prior knowledge which are elicited/validated from/by experts or by collecting information employing qualitative forecasting approaches like Environmental Scanning, Delphi Survey etc. This is further followed by application of Monte Carlo simulation in the TIA algorithm which combines the impact and event probability judgments with the outcomes of the baseline

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http://dx.doi.org/10.1016/j.techfore.2017.02.012
0040-1625/

scenario (model based forecasts) to generate a fan of possible future scenarios. Based on these scenarios, the median, 5th and 95th percentile scenarios are computed thus specifying three divergent scenarios.

There are several instances of application of TIA in industry and other divergent domains like aviation, energy, transportation etc. (Gordon, 2003; Winkless, 2004). TIA approach has been applied in the field of agriculture as well, for predicting future fruit consumption of Netherland (Hennen and Benninga, 2009) and for projections of Eucalyptus cultivation in Brazil (Lotfi and Pela, 2009).

There are instances of modifying the TIA approach. An enhanced TIA approach by considering three degrees of severity; low, medium and high was developed for each unprecedented future event to generate fan of possible future scenarios (Agami et al., 2008). Attention was paid to surprise-free forecast aspects of TIA by employing neural network based approach for forecasting the base-line scenario to enhance the prediction ability of TIA (Agami et al., 2009). Further, an advanced mechanism was proposed to generate more valid estimates to the probability of occurrence of an unprecedented event as a function of time with divergent degrees of severity employing fuzzy logic (Agami et al., 2010).

The intervention modeling and analysis are used for adjustments of impact of any unprecedented events in the time series data. First applications of intervention model was done to study impact of air pollution controls, economic controls on the consumer price index (Box and Tiao, 1975). A good account on intervention modeling is given in Box et al. (1994), Madsen (2008), Yaffee and McGee (2000) etc. Intervention model was also applied to study impact of interventions in an experimental design (Krishnamurthi et al., 1989), to quantify the impact of sales promotional data (Shao, 1997), to improve methods for forecasting in telemarketing centers (Bianchi et al., 1998), to analyze the epidemiological situation in England and Wales for the period of 1940–1990 (Girard, 2000), to evaluate the policies (Mcleod and Vingilis, 2005), to forecast five star hotels' occupancy (Ismail et al., 2009), to measure the business process reengineering (Lam et al., 2009), to study survey redesign (Brakel and Roels, 2010) and for modeling and forecasting cotton yield of India considering the introduction of Bt cotton as unprecedented technology (Ray et al., 2014).

In this study, new TIA approach has been proposed and it was used for predicting Wheat yield scenario for India. As crop yield of a future year shall depend on future unprecedented technologies (say, new variety and other inputs such as nano-chemicals and fertilizers, new cultivation procedure, better management practice etc.) and rare events (say, extreme weather conditions like drought, flood, high temperature, water logging, etc.) which are unprecedented events. Apart from this, other events could also be introduced/occurs such as new environmental regulations, economic policy changes, employee strikes, bomb blasts, special promotion campaigns, natural disasters etc. In all these cases, there is a strong need for further modification of existing or modified TIA approach (Hennen and Benninga, 2009; Lotfi and Pela, 2009; Agami et al., 2008, 2009, 2010). Therefore, in this proposed methodology, an intervention analysis based time series model has been used to generate all-possible scenarios instead of Monte Carlo simulations when future events are considered as introduction of new technologies or occurrence of rare events.

With this intervention analysis, the proposed TIA approach is capable to handle the influence of any unusual occurrences on the structure of the fitted model and adjusts for estimates of model parameters through adopting such patterns while providing forecasts of future values. Further, in this study, the conventional intervention model has been modified to accommodate the parameters of TIA. Also, this newly proposed TIA techniques has been used in the analysis of Wheat yield in India under different unprecedented events.

The rest of the paper is organized in different sections. In Section 2, a brief overview of intervention model is given. In Section 3, modified intervention model has been explained. Then Section 4, the proposed methodology for TIA has been explained in detail. Finally, in Section 5, the proposed approach has been empirically illustrated for various wheat yield scenarios at All-India level considering three situations: two unprecedented future wheat variety breeding technologies (heat tolerant and rust resistant) and occurrence of one rare event (increase in temperature) followed by conclusions in Section 6.

2. Intervention model

The conventional intervention model can be represented as follows:

$$Y_t = \frac{\omega(B)}{1-\delta(B)} B^b I_t + N_t \tag{1}$$

where, Y_t is the dependent (time series) variable, I_t is the indicator variable coded according to the type of intervention, $\delta(B) = 1 + \delta_1 B + \ldots + \delta_r B^r$ i.e. slope parameter, $\omega(B) = \omega_0 + \omega_1 B + \ldots + \omega_s B^s$ i.e. impact parameter, b is delay parameter; B represents Backshift operator i.e. $B^a Y_t = Y_{t-a}$, N_t is the noise series, which represents the background observed series Y_t but without intervention effects i.e. N_t is nothing but the ARIMA model. The parameters of Intervention model is represented graphically in Fig. 1.

In general, the values an intervention variable can depends on types of interventions such as pulse (one time occurrence), ramp, step etc. In this study, only step intervention is used which is given by

$$S_t = \begin{cases} 0 & t<T' \\ 1 & t \geq T' \end{cases}$$

With T' is the time at which intervention has occurred and S_t represents the indicator variable for such intervention. Divergent response patterns are possible through different choices of intervention components. Different intervention components with their output responses are given in (p. 464 Box et al., 1994).

Intervention analysis has been traditionally used to assess the impact of any unprecedented event occurring at a known point of time (i.e. already occurred event in a recent time period but not in a future time period) on any time series of interest. On the other hand, in TIA, it is assumed that for the unprecedented event (or set of events) that will occur in future, the estimated impact(s) of the event (or set of events) are elicited/validated from/ by experts. Another issue in TIA is that, the time point at which event will occur is also not known in advance. Hence, the parameter which has to be estimated in intervention analysis is known in TIA, but the time point is unknown. Therefore, by varying the time points, generation of different scenarios is possible through this analysis.

3. Modified intervention model for new TIA approach

In traditional TIA algorithm, it is assumed that when any unprecedented event occurs, it will have some initial impact and after some time, the impact will be maximum (maximum impact) and finally, after a time period, the impact will be constant (Steady-State impact). Moreover, there are two time parameters in TIA viz., time to maximum impact and time to steady-state impact respectively. The parameters of TIA is represented graphically Fig. 2 (Agami et al., 2008).

It may be noted that instead of a single event and single impact parameter as is the case with traditional intervention modeling, TIA has three impact parameters viz., initial impact, maximum impact and steady-state impact for each event. Let the TIA parameters be defined as follows:

ω_0 = initial impact
ω_m = maximum impact
ω_s = steady-state impact
t_m = time to maximum impact
t_s = time to steady state impact
n = number of events
k = degree of severity