A Study on Constructing Bayesian Causal Maps and Methods of Breaking their Loops

Wang Ying 1, Liu Guoji 2

1 Laboratory of Logistics Industry Economy and Intelligent Logistics
Yatai School of Business Administration
Jilin University of Finance and Economics
Changchun, Jilin, China
2 College of Physics
Jilin University
Changchun, Jilin, China
citichys_liuguoji@126.com

Abstract — The Bayesian network and the causal map are both effective tools used to decision-making and reference-making. A Bayesian causal map (BCM) integrates their advantages in expressing knowledge of expert. And it could be used to factor analysis and decision. But the causal loop brought by the causal map’s construction is a problem which has to be solved. This paper discusses the feasibility of constructing Bayesian causal map (BCM) and the construction method. At the base of that, it comprehensively analyses the existing methods of breaking loop proposed by domestic and foreign scholars—the method of breaking loop by time frame and the method of breaking loop by logic. At last, this paper proved the method of time frame is more reasonable.

Keywords - Bayesian network; Causal map; Bayesian causal map (BCM); the method of breaking the loop

I. INTRODUCTION

The method of constructing the Bayesian causal map (BCM) was proposed by American scholar Nadkarni and Shenoy (2001) [1]. Bayesian network (BN) with independent causal relationship is called Bayesian causal map. It has been known as causal belief network or causal probabilistic networks too. BCM combine the BN and causal map (CM). BN can be used to analyze the uncertain, ambiguous, and incomplete CM. It can also use the evidential reasoning algorithm of BN to analyse the sensitive rate of variables. Then we can find other variables. CM also is a useful tool in many fields [3-7]. CM will be an effective technology to construct the qualitative structure of BN[2,8,9,10]. Since then, domestic and foreign scholars start to study the construction of BCM and its application problems. Zhan (2003) [11] proposed the construction case of BCM. Li Guozhi(2009)[12] proposed the method of conversion from BN to causal map which at the base of Wang’s (2004) [13] means of the conversion from causal map to belief network. That further improved the construction theory of BCM. The BCM methodology has been successfully used in various areas of economic and business including the analysis of complex and dynamic structure of inflation (Onsel-Sahin et al. 2006)[14], environmental economics (Ulengthin et al. 2010)[15], venture capital decision making (Kemmerer and Shenoy 2007)[16], and services (health care) management (Aktas et al. 2005)[17], enterprise ethic action(Ahmet Ekici et al.)[18].

BCM is a combination of Bayesian network and causal map. The appearance probability of the causal loop is higher in the process of construction of causal map. Because of that using BCM to probabilistic reasoning and breaking the causal loop have become the bottleneck of BCM’s application. For the causal map, effective algorithm hasn’t been developed to deal with causal feedback loop until now (Jensen, 2002) [19]. Nadkarni and Shenoy (2001, 2004) [1,20] proposed the method of breaking the causal loop according to the different time frames t1, t2; Zhang Qin (1994) [21] proposed the logical method of breaking the causal loop; Zhan Yuanrui (2003) [11] put forward the method of breaking the causal loop in accordance with the time frame. All of the above results have referred to the problem of breaking the loop in the causal map.

II. THE BCM TECHNIQUE AND THE ANALYSIS OF THE RELATED RESEARCH

A. The analysis of constructing the BCM

To construct the BCM need to go through two stages: the shaping stage and the quantitative stage. Firstly, constructing the causal map in which the elements are conditional independent. And then, transforming the
causal map into bayesian network. Finally, constructing the BCM. Revising the chart according to the common characteristics of the causal map and bayesian networks. The process of the construction requires several steps as below.

The steps of constructing the BCM:
1. Correcting the causal map into the network diagram with the character of (dependence map) D-map or (independence map) I-map[22]. That using the BCM to probabilistic reasoning demands for the elements without arrow being conditional independent. The process leading to the causal map is often exploratory analysis. The lack of arcs from one to another element represents that there is no causality related. This does not mean that the expert believes the nodes being independent. So it should be added with the possible of conditional dependent at the base of causal map.

2. Determining the causal relationship reasoning. Individuals reason by accumulating possibly significant pieces of information and organizing them in relation to each other so as to be able to combine them into a conclusion and decision[23]. BCM use such reasoning processes to predict future’s courses of events. The process of causal reasoning contains two types of reasoning: deductive and abductive[23]. A reasoning process is called deductive when we reason from causes to effects, and a reasoning process is called abductive when we reason from effects to causes. It should be distinguished correctly. In Figure 1, the direction of the arrow is the reasoning direction. There are also some literature marked with "+" or "-" on the arrow.

3. Distinguishing between direct and indirect relationships. It is helpful for the final BCM’s probabilistic reasoning that clearly distinguishing between the direct and indirect relationship. One factor affects another factor in the system scope set in the causal map, that may be the direct effects or the indirect effects [24,25]. But they can't coexist in BCM. It can reduce unnecessary arrows which distinguishing it between direct or indirect.

4. Determining the causal loop. BCM is direct graph. That means that if it has a hierarchical (or acyclic) structure, it can be used to probabilistic reasoning. But when the two factors are reciprocal causation or they cycle to a loop with other factors, the probabilistic reasoning will become to an endless loop [24, 26, 27]. There are two kinds of causal loop in the objective world. As shown in Fig.1.

The first case is that the two factors are reciprocal causation, the second case is several factors forming a causal ring. The existence of a causal loop makes the sensitivity reasoning, and the decisions haven’t been finished. For the reason of that, the problem of breaking the loop becomes the key of constructing a BCM. Domestic and foreign scholars have proved a causal loop can’t appear at the same time. To break the loop, many

different methods of breaking the loop.

Figure1. Two kinds of causal loop

(5) The process of probability evaluating or probability assignment. Probability assignment can use the following three scale method [28]: Cumulative probability (e.g. 0.3, 0.6, 0.9); Quantile method (e.g.1, 2, 3, 4, 5); Linguistic annotation method (e.g. High, middle, low). Assign the value of the initial probability and condition probability with the method which is easy to be understood. And then we can expand the probability reasoning and other operations.

Either the transformation methods from the casual map to the BCM, or the transformation methods from the BN to BCM, it generally need to go through the following steps: At first individual domain experts is interviewed using qualitative interview to elicit his/her domain knowledge and the experts’ response to the interview is transcribed to get a text, this process we call a ‘narrative’. And then the casual map is modified through eliminating biases and errors, and its structure is compatible with BN. In the final step, the parameters of the BCM are derived.

B. The analysis about the research conclusion of the method of breaking the loop.

When an factor X leads to Y, and Y leads to the occurrence of X conversely. Or Y leads to the occurrence of X indirectly through other factors. This constitutes a causal loop. Causal loop is a closed causal chain with forward and reverse causality links (David Lewis, 1986) [29]. For the closed causal chain, it is either logically or physically impossible that a causal map have both forward and reverse causal relationships (Richard Hanley, 2004) [30].

(1) The method of breaking loop by time frame. An American scholar (Sucheta Nadkarni) put forward two kinds of method to break the causal loop. One is distinguishing direct or indirect relations. Event is either directly or indirectly, so redundant arrow can be eliminated, because that causes and effects can’t happen at the same time. Another method is put forward. That is breaking the loop according to the two connected different time frame (t1 and t2). It has the same principle as the theory of breaking the loop by time frame proposed by
Zhan Yuan-rui and Xie Qiu-ping etc.(2003)[8]. That is dividing the variable into two events which happened in two connected time frames. As shown below in Fig.2.

The event X leads to the event Y after t1, and then leads to event X’ after t2. X’ is the same event of X at different time frame and in different states. This method has the rationality. Opening the causal loop can make the probabilities’ transmission to proceed.

(2) The method of breaking loop by logic. Zhang Qin put forward the theory of Dynamic Causality Diagram (1994), and put forward the method of breaking loop by logic in 1995 before and after. The premise of applying this method is that two reciprocal causation factors couldn’t happen at the same time. Select a node as the center point, and enumerating all the events and their relationships which lead to the node event. Break the loop in the map, and transform it into several sub graphs without loop. At last probabilistic computation by BN could be completed. As shown in Fig.3, respectively take the X, Y, Z as the center point. And then enumerate all the relationships which lead to these center point.

Because the factors in the objective world can’t be indeed reciprocal causations that happened at the same time, the application of the premise of this approach is logical and reasonable. This method can be used to unlock the arbitrary complex loop of causality diagram, and it is easy to understand and operate.

III. NUMERICAL VERIFICATION

We can draw a conclusion that both interest rate and exchange rate have an effect on inflation by influencing inflation directly or influencing inflation expectation to affect inflation indirectly through investigating the relationship between interest rate, exchange rate inflation and inflation expectation. Don’t consider other relevant factors for the present and structure the casual map only according to the relationship between these four factors that are as shown in the following Fig.4

The symbol “+” in the figure 4 stands for the positive causal relationship between factors, that is, the high interest rate may curb inflation. On the contrary, the low interest rates may promote inflation. The relationship between exchange rate and inflation expectation is in the same way. The relationship between inflation and inflation expectation is the causal relationship of positive correlation, that is, the two are mutually reinforcing relationship. To identify causal parameters, which including the initial probability, conditional probability and total probability, should accord to the statistical data and experts’ investigation. As it shown in the Table.1

<table>
<thead>
<tr>
<th></th>
<th>Value of Parameters in Figure 4.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P(IR)</td>
</tr>
<tr>
<td>0.46</td>
<td>0.54</td>
</tr>
<tr>
<td>0.54</td>
<td>0.68</td>
</tr>
<tr>
<td>0.77</td>
<td>0.38</td>
</tr>
<tr>
<td>0.23</td>
<td>0.62</td>
</tr>
</tbody>
</table>

In order to compare the method of breaking loop by the time frame with the method of breaking loop by logic which scholars put forward before, we analyse of contrast sensitivity as following. Choose the interest rate (IR) as the reference value and calculate the sensitivity of the inflation when interest rate changing. When IR=[0.5,0.5],
interest rate is IR\[0.5,0.5\], there is no influence of the interest rate on the system. And inflation is recorded as I\[0.5,0.5\]=\[x_1[0.5,0.5], x_2[0.5,0.5]\]. When interest rate change to an extreme value, it is recorded as IR\[1,0\] and IR\[0,1\], and I\[1,0\]=\[x_1[1,0], x_2[1,0]\], I\[0,1\]=\[x_1[0,1], x_2[0,1]\]. The absolute difference between I\[1,0\] and I\[0.5,0.5\] can reflect the impact of interest rate changes on inflation. Under the different circumstances of breaking loop method, here we call the relative effect that one factor causes another factor changes as action rate. For example, the action rate can be recorded as 
\[
\Delta[1,0]=\left| x_1[1,0] - x_1[0.5,0.5] \right|, \left| x_2[1,0] - x_2[0.5,0.5] \right|
\]
If open the causal loop according to the time frame, the assignment is shown in Fig.5, we can come to the conclusion through calculating that I=[0.5891, 0.4108] when IR=[0.5,0.5]; I=[0.5647, 0.4353] when IR=[1,0]; I=[0.6174, 0.3825] when IR=[0,1]. Therefore, calculating the action rate is \(\triangle[1,0]=0.0244, 0.0244\) and \(\triangle[0,1]=0.0283, 0.0283\). From the data we can see that the effect of rising the inflation which arising from reducing interest rate is slightly obvious than the effect of curbing the inflation which arising from increasing the interest rate. The sketch map of opening the loop by time frame method is shown in Fig.5.

If open the causal loop by logic, the assignment is also as shown in Fig.4, we can come to the conclusion through calculating that I=[0.6157,0.3843] when IR=[1,0] ; I=[0.63857,0.36143] when IR=[0,1]; I=[0.6271,0.3729] when IR=[0.5,0.5]. And calculating the action rate equal to \(\Delta[1,0]=0.0114, 0.0114\), \(\Delta[0,1]=0.0115, 0.0115\). Using the state probability which only calculating the inflation as an example, breaking the loop by logic is shown as Figure 6.

Comparing the two results from different breaking loop method, we will find that the two results are approximate but the action rate of breaking the loop by the time frame is the most remarkable. Therefore, the method of breaking the loop by the time frame is the most accurate method. And its sensitivity is the most prominent.

IV. CONCLUSION

The construction of the Bayesian causal map is operational and necessary. It has the dual advantage of BN and causal map. The construction method and its steps and the applications of BCM has been recognized by many domestic and international scholars. But the problem is challenge of opening the causal loop which bringing by causal diagram. Under the precondition of the assumption that elements and their relations are not changed in the abstract time, it is feasible to achieve factors’ probability. It is easy to understand and to be operated.

But at present, the method of opening the loop have failed to be fully discussed and extended in the literature. There are also problems existing. First, in the abstract short time whether all the elements will not change, especially continuous variable such as the share price, economic indicators and so on, all will changes in real-time. In addition, the factors in causal loop sometimes spend long causal interaction time, which may cause other changes of influence factors. Such as learning effort and achievement, or between infrastructure and economic growth, the mutual influence of change is not the instant result, but the need for a period of time. Second, the initial probability and condition probability in causal loop rely too much on the judgments of the experts, and also more known conditions are required. In some cases, the application of the two methods may be limited.

REFERENCES


