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RELEVANCE OF FUZZY CAUSAL NETWORK APPLICATION TO HEALTH WARNING ON SMOKERS' QUITTING BEHAVIOURS

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Abstract

Linear regression and logistic regression are very popular statistical techniques for modelling and analysing complex data in tobacco control systems. However, these techniques have fundamental limitations due to their inability to deal with complex non-linear data relationships, which may characterise many aspects of tobacco domain. In this paper, we explore fuzzy causal network (FCN) as a new methodology for modelling and analysing complex data in tobacco control systems. After introducing briefly the basic concepts of an FCN and its possible applications in tobacco control, three sample data relating to warning labels on cigarette packs are selected from the International Tobacco Control Policy Evaluation Survey (ITCPES) project. An FCN-based model is constructed to evaluate and compare the effect of health warnings on cigarette packs in influencing smokers' quitting behaviours in two countries over time. Our research outcomes demonstrate that FCN has potential to become a useful framework for causal discovery and decision support in tobacco control systems, especially in the cases where intensive interaction among many attributes and non-linear data relationships are involved.

RELEVANCE OF FUZZY CAUSAL NETWORK APPLICATION TO HEALTH WARNING ON SMOKERS' QUITTING BEHAVIOURS

BACKGROUND

Cigarette smoking has been recognised as the second leading cause of death in the world [David, 2000]. Accordingly controlling tobacco smoking has become a social imperative [Boyle, 2004]. Governments in many countries have attempted to influence behaviour of smokers by regulating and implementing diverse tobacco control policies, such as warning labels on cigarette packs, increasing the price of cigarettes and anti-smoking advertisements. However controlling tobacco smoking and determining effective policies is difficult because of the complexity of human nature and behaviours. Policy makers need feedback from the field to adopt more fruitful policies. This feedback is usually obtained from ground level surveys. For example, the ITCPES project is a recent coordinate international research and evaluation effort [ITCEPS, 2002]. It aims to evaluate the psychosocial and behavioural impact of key national-level tobacco control policies over the years. That project provides massive survey data, which are collected from many countries including Australia and UK, for studying the impact of diverse tobacco control policies across these countries. A problem arsing from survey data is that, such a survey data cannot directly provide the overall picture of the effect of the policies. In the literature, there have been numerous attempts to describe and understand the effect of tobacco control policies to smokers' quitting behaviour. Most of them are based on traditional statistical techniques such as linear regression and logistic regression [Hammond et al, 2006 and 2007]. However, these techniques assume a linear sequence between research evidence outlining the need for action, the optimal forms of action, policy development, and the subsequent effectiveness of policies. Interestingly, even simple analyses [Hocking, 1991] have already demonstrated for example that smoke-free rules feedback in a non-linear way on attitudes to smoker-free places. Similarly, when evaluating behavioural changes of smokers in response to policy initiatives, such relations are often non-linear. Further, regression approaches do not adequately address the potential influence of policies that cannot be directly measured by such models. As a result, significant gaps in tobacco control policy planning and development remain.

FCN is a popular soft computing methodology and widely used in decision support systems to model complex and intelligent systems, decision analysis as well as intelligent graph behaviour analysis [Zhang, 2006 & Zhou, 2006]. It can be used to describe the behaviour of complex systems in terms of concepts and represent the systems graphically. FCN stores the causal knowledge of the dynamic behaviour of the complex systems in its graphical structure. This approach displays the causal relationship among the concepts in an easily recognisable manner and helps to analyse the inference patterns quickly.

In this paper, we explore FCN to model and analyse complex data in tobacco control systems. After briefly introducing the basic concepts of an FCN and its possible applications in tobacco control, three sample data relating to warning labels on cigarette packs are selected from the ITCPES project. FCN is constructed in order to evaluate the effect of health warnings on cigarette packs in influencing smokers' quitting behaviours in two countries over time. Then the causal inference mechanism proposed in any FCN is applied to evaluate and compare the effect of warning labels on cigarette packs in influencing smokers' quitting behaviours in two countries over time. We aim to work out a global picture, which provides comprehensive information about interrelated relationships among many variables; relative importance of each variable in predicting the rate of make a quit attempt; direct, indirect and total effect of one variable on another one along all possible directed paths from the former to the latter; and data flow for the quitting behaviour of all smokers over time.

FUZZY CAUSAL NETWORK AND ITS POSSIBLE APPLICATION IN TOBACCO CONTROL

The topological structure of an FCN is a directed graph Ω = (V, A), where V is the set of vertices and A is the set of directed arcs of Ω. We use $v_i \in V$ to denote the vertices of Ω, where $i = 1, 2, \ldots, n$, and n = |V| is the number of vertices of Ω. Each vertex v_i stands for a concept of the FCN. If v_i has some causal influence on v_j at time t then a directed arc (v_i, v_j) is drawn from v_i to v_j. The weight (strength) of such an influence is usually given by a real number w_{ij}, which after normalisation if necessary, can be assumed between -1 and 1. If $w_{ij} > 0$, then v_i has a positive influence on v_j ; if $w_{ij} < 0$, then v_i has a negative influence on v_j ; and if $w_{ij} = 0$, then v_i has no influence on v_j . Associated with each v_i is a vertex state value $x_i(t) \in [0, 1]$, which specifies the degree that the fuzzy event occurs at a discrete time t. The state of the FCN at time t can then be represented conveniently by the vector function: $\Psi_\Omega(t)$ =

$(x_1(t); \cdots, x_n(t))$. At each vertex there is also a vertex function *fi* that transforms the total inputs received by this vertex into its next state value $x_n(t + 1) \in [0, 1]$. At any time, when a vertex receives a series of external stimuli, its state value will be updated at next time according to a state transition function. This process is iterated until the system converges to a stable state or identifies a limit cycle [Zhang, 2006 & Zhou, 2006].

The main causal inferences of FCN that will be used in our study follow the method described by Liu and Zhang [2003]. That is, for any two distinct vertices $u, v \in V$, if we use $\rho = \rho(u, v)$ to represent a directed path from u to v, then the directed path is defined as a sequence $v_1, v_2, \cdots, v_r$ of distinct vertices of Ω, such that $v_1 = u$, $v_r = v$ and (v_i, v_{i+1}) is a directed arc of Ω for each $i = 1, 2, \cdots, r-1$. If we use $I_\rho = I_\rho(u, v)$ to represent the indirect effect u influences v along the directed path $\rho = \rho(u, v)$, then

$$I_\rho = \prod_{(y,z)\in A(p)} X_y(t) \cdot W_{yz}(t) \qquad (1)$$

where $A(p)$ is the set of directed arcs on the directed path $\rho(u, v)$, $X_y(t)$ is the state of vertex y at time t, and $W_{yz}(t)$ is the weight associated with the directed arc (y, z) on the path $\rho(u, v)$. If the directed path $\rho = \rho(u, v)$ consists of two vertices only, then $I_\rho = I_\rho(u, v)$ =

$X_y(t) \cdot W_{yz}(t)$ represents the direct effect u influences v. If we use $\Phi = \Phi(u, v)$ to represent the set of all directed paths $\rho = \rho(u, v)$ from u to v, $T_\rho = T_{\rho(u, v)}$ to represent the total effect u influences v along all possible directed paths from u to v, then

$$T_\rho = \sum_{u_i \in N_-(v)} \max_{\rho \in \Phi(u, u_i, v)} I\rho(t) \qquad (2)$$

where $N\text{-}(v)$ is the set of all existing vertices u_i such that there exists a directed arc of Ω from u_i to v. $\Phi = \Phi(u, u_i, v)$ represents the set of all directed paths $\rho = \rho(u, u_i, v)$ from u to v which passes u_i.

A CASE STUDY OF FUZZY CAUSAL NETWORK IN TOBACCO CONTROL

Selection of Three Sample Data and Four Representative Variables

Warning labels on cigarette packs in UK were firstly enhanced in 2003, in order to meet the minimum Framework Convention on Tobacco Control (FCTC) -- the first international treaty devoted to public health [WHO, 2008]. We take this as a case study with the purpose to evaluate and compare the effect of warning labels on cigarette packs in influencing smokers' quitting behaviours in both Australia and UK, including the impact of new health warnings implemented in UK.

First, as some questions we choose in this study are asked on wave 2 to wave 5 but not asked on wave 1, we select three sample data from W_{2-3} (n = 2485; 1269 from Australia, 1216 from UK); W_{3-4} (n = 2057; 1084 from Australia, 973 from UK); W_{4-5} (n = 1895; 1011 from Australia, 884 from UK) respectively. Here W_i ($i = 2, 3, 4, 5$) represents four surveys wave (from 2003 to 2005) within the ITCPES project, $W_{2-i} = W_2 + W_3 + \cdots + W_i$ ($i = 3, 4, 5$). The three sample data are selected from both Australia and UK. Each sample data represents the smokers who participated in survey in three waves (the previous wave, this wave and the next wave).

Second, three representative questions from W_i are asked as the input attributes in this study. The three questions, after recoding, are represented by the following variables:

v_1 ("noticed warning labels", 3-point scales: never or rarely, sometimes, very often);

v_2 ("warning labels make you to think about the health risks of smoking", 3-point scales: not at all or a little, somewhat, a lot); v_3 ("warning labels make you more likely to quit smoking", 3-point scales: not at all or a little, somewhat, a lot). At the same time, we use v_4 to represent the status of make a quit attempt (binary values: no, yes) chosen from W_{i+1}. The possible values of v_1, v_2, v_3 at W_i and v_4 at W_{i+1} are as follows:

$v_1 \in \{1,2,3\}$ = {never or rarely, sometimes, very often}
$v_2 \in \{1,2,3\}$ = {not at all or a little, somewhat, a lot}
$v_3 \in \{1,2,3\}$ = {not at all or a little, somewhat, a lot}
$v_4 \in \{1, 2\}$ = {yes, no}

Construction of a Fuzzy Causal Network-Based Model

For the three sample data selected from Australia and UK, we use statistical software SPSS to work out the possible response association (row %) among v_1, v_2 and v_3 at W_i and v_3 at W_{i+1} ($i = 2, 3, 4$), which are summarised in Tables 1 and 2. The information shown in Table 1 informs us that the row associations between v_1 (1,2,3) at W_{2-4} and v_4 (1) at W_{3-5} are "42.4%/44.2%/44% vs. 28.4%/35.2%/36.9%"; "38.8%/37%/45.9% vs. 31.3%/45%/44.4%; 41.4%/41%/43.6% vs. 31.6%/25.4%/36.4%" respectively. This implies that in both countries when smokers' consciousness relating to v_1 (noticed warning labels) increases at W_{2-4}, the probability that the smoker will make a quit attempt at W_{3-5} increases over the four years. In this case we interpret that the responses as showing that there is positive causal relationship from v_1 to v_4 over the four years. For Tables 1 and 2, if we follow the same procedures above, we can obtain that in both countries there are positive causal relationships from v_1 to v_2, v_1 to v_3, v_2 to v_3, v_2 to v_4, v_3 to v_4 over the four years. Accordingly, we can construct an FCN-based model to monitor and evaluate the effect of warning labels on cigarette packs in influencing smokers' quitting behaviours over four years, which is shown in Figure 1 below.

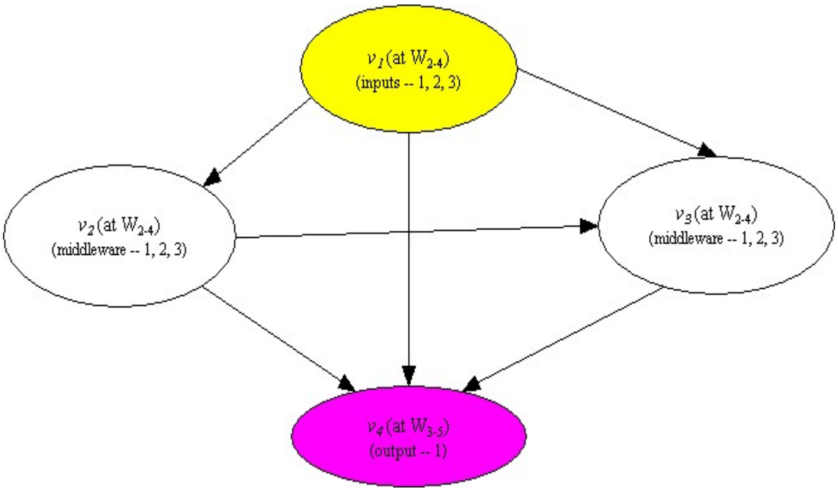

Figure 1. FCN based on four significant questions and three sample data at W2-5 selected from Australia and UK

Among four vertices "v_1 (at W_{2-4}), v_2 (at W_{2-4}), v_3 (at W_{2-4}) and v_4 (at W_{3-5})" shown in this FCN, v_1 (at W_{2-4}) is the most significant initial vertex, which can be regarded as the input of a simplified tobacco control system that consists of the four vertices; v_4 (at W_{3-5}) is the outcomes we study, which can be regarded as the output of the same system; while v_2 (at W_{2-4}) and v_3 (at W_{2-4}) can be regarded as the middleware, which implies that the responses for the two questions are dependent on the responses for v_1 (at W_{2-4}), and at the same time, the responses for the two questions influence the responses for v_4 (at W_{3-5}). For the initial vertex v_1 (at W_{2-4}), its state value is determined by some external policy stimulus, such as the warning labels on cigarette packs. We aim to investigate whether when the responses for v_1 (at W_{2-4}) increase from lower to higher level (*i.e., never→ sometimes→ very often*) over the four years (from W_2 to W_5), affects the responses for v_2 (at W_{2-4}), v_3 (at W_{2-4}) and v_4 (at W_{3-5}) directly and indirectly; how v_1 (at W_{2-4}), v_2 (at W_{2-4}) and v_3 (at W_{2-4}) have been interacting each other and working together to affect v_4 (at W_{3-5}) over the four years; the overall impact of v_1 (at W_{2-4}), v_2 (at W_{2-4}) and v_3 (at W_{2-4}) on v_4 (at W_{3-5}) over the four years; and the direct, indirect and total impact of v_1 (at W_{2-4}) on v_4 (at W_{3-5}) along all possible directed paths from the former to the latter over the four years. Such investigations can provide invaluable information about the effect of warning labels on cigarette packs in influencing smokers' quitting behaviour (quit attempt) over time, and thus provide decision support for decision-makers on modifying existing policies or developing new policies in order to achieve better results. We provide our solutions to these questions as follows.

First, we use Ω = (V, E) to represent FCN, where V = {v_1, v_2, v_3, v_4}, E is the set of directed arcs between any two vertices. For v_1, v_2 and v_3, we use a simple linear fuzzy membership function to scale three levels of responses to 0.33, 0.66, 1, which represents the degree of that fuzzy event at any time *t*. As a result, the possible state values of the three input vertices can be specified as follows:

$x_1(t) = \{x_{11}(t), x_{12}(t), x_{13}(t)\} = \{0.33, 0.66, 1\}$
$x_2(t) = \{x_{21}(t), x_{22}(t), x_{23}(t)\} = \{0.33, 0.66, 1\}$
$x_3(t) = \{x_{31}(t), x_{32}(t), x_{33}(t)\} = \{0.33, 0.66, 1\}$

Second, for two distinct vertices $v_i = \{v_{i1}, v_{i2}, \cdots v_{ik}\}$ and $v_j = \{v_{j1}, v_{j2}, \cdots v_{jk}\}$ (i, j= 1, 2, $\cdots$, n+1), any participant at any time t will give answers $l_i \in \{v_{i1}, v_{i2}, \cdots v_{ik}\}$ and $l_j \in \{v_{j1}, v_{j2}, \cdots v_{jk}\}$ to them. We accept the real number $w_{ij} \in [-1,1]$, which is transferred from the row % located in l_i^{th} row and l_j^{th} column, as the weight of v_i influences v_j for that specific participant at time t. For example, from the upper part of Table 2 we can see that in Australia, for v_2 and v_3, if a smoker at W_{2-4} gives responses 1 (not at all) to v_2 and 1 (not at all) / 2 (somewhat) / 3 (a lot) to v_3, then we can find out that the row % located in 1^{th} row and $1^{th}/2^{th}/3^{th}$ column for that specific smoker are 96%/95.9%/94.4%, 3.8%/3.8%/5.4%, 0.2%/0.3%/0.1% respectively. Then we can transfer such row associations to real numbers, which are 0.96/0.959/0.944, 0,038/0.038/0.054, 0,002/0.003/0.001, as the weights of v_2 influence v_3 for that specific smoker at W_{2-4} respectively. From Section 3.1 we can see that, there are 3 responses for v_1, 3 responses for v_2 and 3 responses for v_3. Then, there are 27 (3 · 3 · 3 = 27) cases (combination of responses) with which smokers are associated. According to all information for both Australia and UK shown in Tables 2 and 4 and repeating the same procedure above, we can estimate all weights of the influence of one vertex on another one for all possible cases with which smokers are associated. In different cases with which smokers are associated, the weight of the influence of an initial vertex on another terminal vertex at a different time t can be quite different.

Second, according to the causal inference mechanism proposed in any FCN [Zhang, 2006, Zhou, 2006], the direct impact of v_1 (at W_{2-4}) on v_2 (at W_{2-4}), v_3 (at W_{2-4}) and v_4 (at W_{3-5}) at any time t can be measured by $x_1 \cdot w_{1j}$ ($j = 2, 3, 4$).

Third, from Figure 1 we can see that there are four directed paths from v_1 to v_4: $\rho_1 = (v_1, v_4)$, $\rho_2 = (v_1, v_2, v_4)$, $\rho_3 = (v_1, v_3, v_4)$, $\rho_4 = (v_1, v_2, v_3, v_4)$. Based on the dynamic causal algebra proposed in any FCN [Liu and Zhang, 2003], the indirect and total impacts of v_1 (at W_{2-4}) on v_4 (at W_{3-5}) along the four directed paths above at any time t can be measured as follows:

$I_1 = x_{1i} \cdot w_{14}$
$I_2 = (x_{1i} \cdot w_{12}) \cdot (x_{2j} \cdot w_{24})$
$I_3 = (x_{1i} \cdot w_{13}) \cdot (x_{3k} \cdot w_{34})$
$I_4 = (x_{1i} \cdot w_{12}) \cdot (x_{2j} \cdot w_{23}) \cdot (x_{3k} \cdot w_{34})$
$T = I_1 + I_2 + \max\{I_3, I_4\}$, where i, j, k = 1, 2, 3.

For all possible cases with which smokers are associated, we can estimate the direct, indirect and total impacts of v_1 at W_{2-5} on v_5 at W_{3-6} along the above four directed paths.

Table 3 provides detailed information about total impacts of v_1 at W_{2-4} on v_4 at W_{3-5} along the above four directed paths, which are based on three sample data selected from Australia and UK.

Table 4 provides detailed information about the percentage of smokers who are associated with each case; and the rate of *make a quit attempt* for each case, which are based on three sample data selected from Australia and UK as well.

PERFORMANCE EVALUATION

In this section, we investigate for different case with which smokers are associated, how the total impact that v_4 received at W_{2-4} affect the rate of quit attempt (v_4) at W_{3-5}. First of all, we notice that there are three classifications of data patterns, which may provide us very important information about smoker' quitting behaviours in both countries in different ways.

Three classifications of data patterns in Australia are as follows:

(a) the highest proportion of smokers at W_{2-4} are associated with the case (1,1,1) (33.9%/31.6%/31.6%), indicating that over the four years, about one third of smokers (with a slightly decreasing trend) never or rarely notice the warning labels and thus any warning labels had not caused them to think about risk of smoking and to be more likely to make a quit attempt. There are second highest proportion of smokers at W_{2-4} are associated with the case (3,1,1) (13.1%/17.8%/17.9%), indicating that although another group of smokers (with slightly increasing trend) notice the warning labels very often over the four years, these warning labels did not cause them to think about risk of smoking or be more likely to make a quit attempt at all. The third highest proportion of smokers at W_{2-4} is the case (2,1,1) (9.7%/8.9%/10.6%), and the forth highest proportion of smokers at $W_{2\text{-}4}$ is the case (3,2,1) (5.3%/6.4%/6.1%). The above data indicates that over the four years, although the number of smokers who never or rarely noticed warning labels decreased slightly, the number of smokers who noticed warning labels sometimes or very often increased slightly, the total proportion of smokers who are associated with the four cases above, comparing all 27 cases, was very high (62%/64.7%/66.2%) and increased over the four years! The four top cases, even if the total effect that v_4 received at $W_{2\text{-}4}$ increased steadily (i.e., 0.22/0.20/0.21→0.41/0.37/0.43→0.59/0.61/0.75→0.61/0.62/0.76) when the state value of v_4 increased (i.e., *never or rarely →sometimes→ very often*), the corresponding rate of quit attempt v_4 at $W_{3\text{-}5}$ in the four top cases are almost the same and comparable to the lowest ranges of rate of quit attempt among all 27 cases (i.e., 41.4%/39.6%/42.5%→38.4%/30.3/35.2%→32%/36.9/35.2%%→36.2%/42/40.6%).

(b) for five other cases – (3,2,2), (3,2,3), (3,3,1) (3,3,2), (3,3,3), the total effect that v_4 received at $W_{2\text{-}4}$ are obviously higher than that for the four top cases mentioned above; and compared with the rate of quit attempt v_4 at $W_{3\text{-}5}$ for the four top cases, the corresponding rate of quit attempt v_4 at $W_{3\text{-}5}$ for the five cases almost doubles. This suggests that increasing consciousness relating to the noticed warning labels may stimulate smokers to think about the risk of smoking and make them more likely to quit smoking, so that the chance of make a quit attempt increased significantly. However, the total proportion of smokers at $W_{2\text{-}4}$ are associated with the five cases, compared with all 27 cases, is relatively low (20.2%/21.1%/18.4%) and decreased slightly in the last year.

(c) there are many extremely cases, like (1,1,2), (1,1,3), (1,2,3), (1,3,1), (1,3,3), (2,1,3), (2,3,1), where the proportion of smokers associated with them was extremely low, such as 0.2%/0.0%/0.0% for the case (1,2,3). This provides us two layers of information – one is that, these extremely low cases, like the case (1,2,3), indicate that if a smoker has not noticed a warning, then the chance of thinking about risk of smoking and making a quit attempt is almost zero. This implies that warning labels really had an impact on smokers' behaviours. Also in these very unlikely cases, the row %, similar to the outlier appeared in traditional statistical analysis, did not have representative meaning and may provide misleading information about the relationship between total effect and rate of quit attempt. For example, for the case (1,2,3) that participants are associated with, the total effects v_4 at $W_{3\text{-}5}$ received are 0.19/0.18/0.19, but the corresponding rate of quit attempt with this case are100%/—/— - these are unstable and unreasonable relationships! In order to improve the accuracy of our analysis, these extremely low cases should be removed.

Three classifications of data patterns in UK are as follows:

(a) the highest proportion of smokers at $W_{2\text{-}4}$ is the case (3, 1,1) (29.2%/27.1%/25.8%), indicating that a considerable proportion of smokers (with a little bit decreasing trend) notice the warning labels very often over the four years, but these warning labels had not caused them to think about risk of smoking or be likely to make a quit attempt at all. The second highest proportion of smokers at $W_{2\text{-}4}$ is the case (3, 2, 1) (12.6%/11.1%/11.1%), indicating that although many smokers (with slightly decreasing trend) noticed the warning labels very often and these warning labels make some what to think about the risk of smoking, but never made them more likely to make a quit attempt. The proportions of smokers at $W_{2\text{-}4}$ in the cases (2,1,1) and (1,1,1) were (5.1%/12.1%/5.4%) and (5.3%/7.7%/11.1%) respectively. The total proportion of smokers associated with the four cases, compared with all 27 cases, is still relatively high (52.2%/58%/53.5%). Also for the four cases, even if the total effect that v_4 received at $W_{2\text{-}4}$ increased steadily (i.e., 0.15/0.18/0.16→0.34/0.43/0.26→0.49/0.59/0.48→0.50/0.62/0.49) when the state value of v_4 increased (i.e., *never or rarely →sometimes→ very often*), the corresponding rate of quit attempt v_4 at $W_{3\text{-}5}$ for the four cases are fluctuating but still with the lowest range of rate of quit attempt among all 27 cases (i.e., 25.8%/28.1%/25.8%→29.3%/47.2/20%→28.4%/35.3/29.3%%→37.9%/45.1/31.4%).

(b) for five other cases – (3,2,2), (3,2,3), (3,3,1) (3,3,2), (3,3,3), the total effect that v_4 received at $W_{2\text{-}4}$ was obviously higher than that at four top cases mentioned above; and compared with the rate of quit attempt v_4 at $W_{3\text{-}5}$ for the four top cases mentioned above, the corresponding rate of quit attempt v_4 at $W_{3\text{-}5}$ for the five cases almost doubles. This implies that if increasing consciousness about noticed warning labels could stimulate smokers to think about the risk of smoking and make them more likely to quit smoking, then the chance of making a real quit attempt increased significantly. However, the total proportions of smokers at $W_{2\text{-}4}$ who are associated with the five cases, compared with all 27 cases, was still relatively low (38.6%/31.9%/31.5%).

(c) for the remaining cases - (1,1,2), (1,1,3), (1,2,3), (1,3,1), (1,3,3), (2,1,3), (2,3,1), the data patterns are very similar as that we discussed in classification (c) of data patterns in Australia.

From three classifications of data patterns in both countries, we can see that compared with smokers in Australia, more smokers in UK noticed the warning labels, thus warning labels in UK played a more active role in influencing smokers to think about risk of smoking and making a quit attempt. This implies that over the four years, UK smokers reported greater levels of awareness of and impact for health warnings on cigarette packages. Thus, implementation of new UK warning at W_2 has improved the effectiveness of warning label policy on changing smokers' behaviours.

Next, we conduct further analysis for the data patterns above. We remove all extreme cases for the three sample data selected from both countries, where a case is defined as a extremely low case if it satisfies the condition: max {Column %} over four years in both countries <2.4%. In total, 16 extremely cases are removed; the remain 11 representative cases with which the majority of smokers were associated among the 27 cases. For these representative cases, we use three diagrams to describe the possible relationships between the total effect that v_4 received at $W_{2\text{-}4}$ from v_1 to v_4 along four directed paths and the rate of quit attempt (v_4) at $W_{3\text{-}5}$ in both countries.

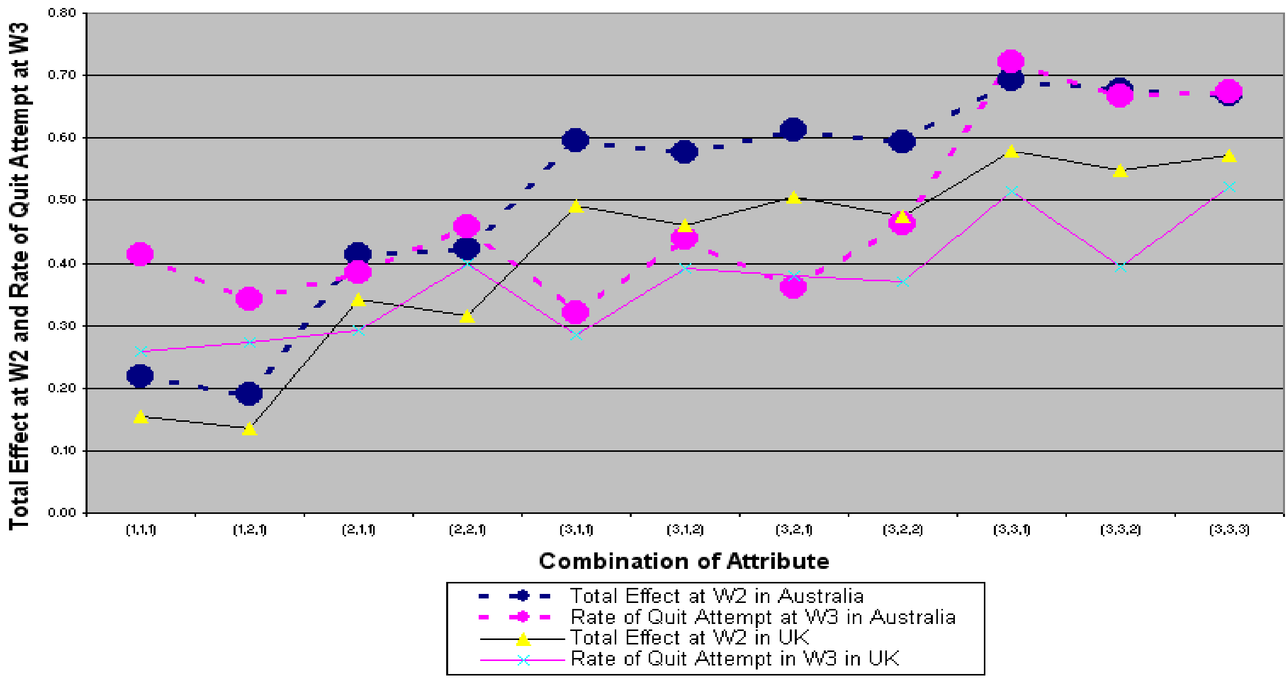

Figure 2. Possible relationship between total effect at W_2 and rate of quit attempt at W_3 in Australia and UK, which is based on top 11 representative cases among 27 combinations of attributes

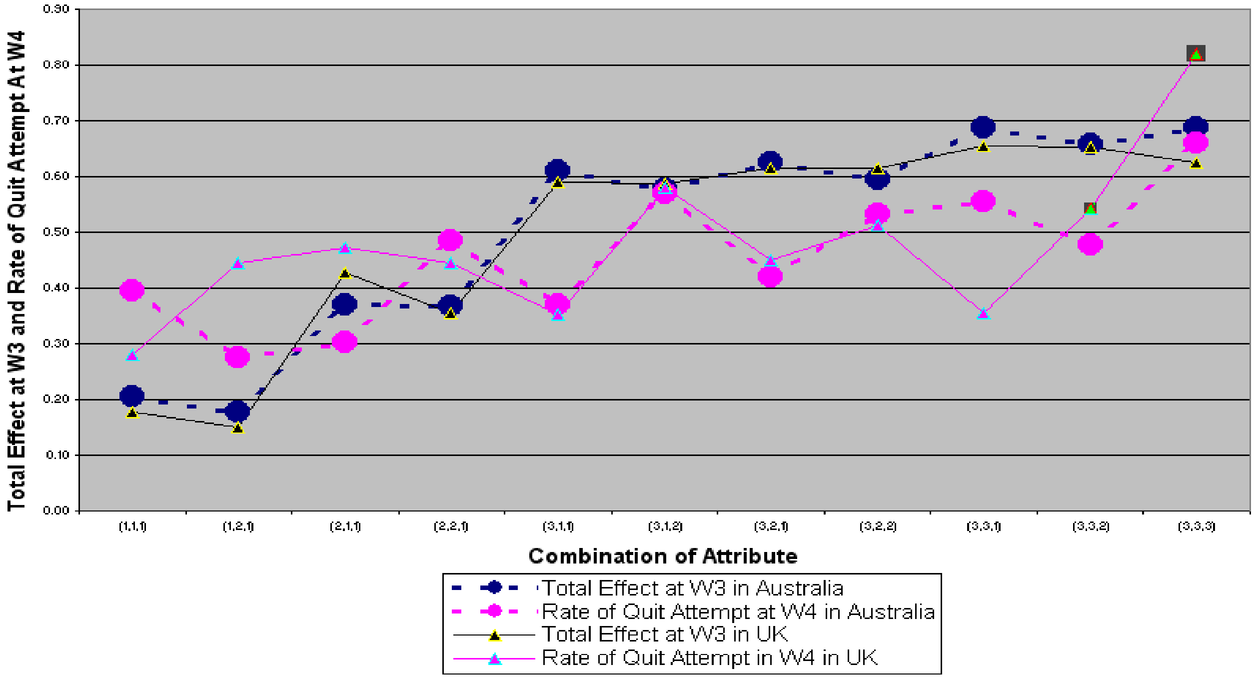

Figure 3. Possible relationship between total effect at W_3 and rate of quit attempt at W_4 in Australia and UK, which is based on top 11 representative cases among 27 combinations of attributes

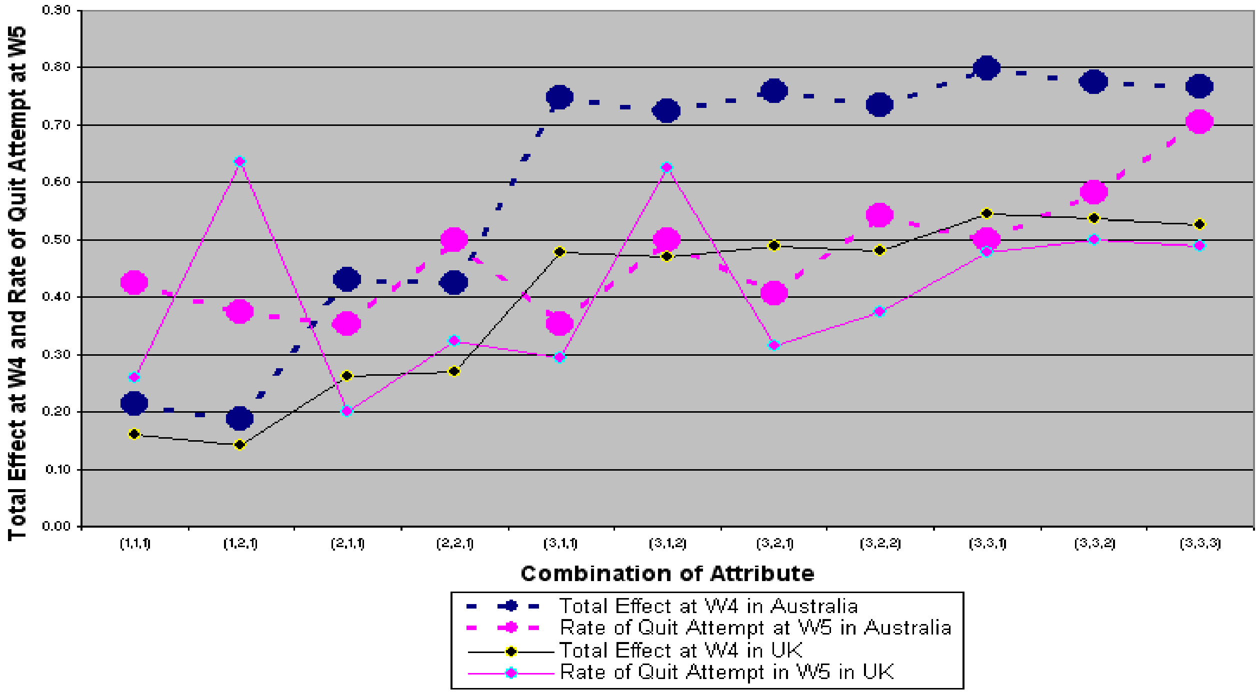

Figure 4. Possible relationship between total effect at W_4 and rate of quit attempt at W_5 in Australia and UK, which is based on top 11 representative cases among 27 combinations of attributes

From Figures 2, 3 and 4 we can see that in general, when response for v_1 at $W_{2\text{-}4}$ increases from lower to higher level (i.e., *never or rarely* →*sometimes*→ *very often*), the impact of v_1 at $W_{2\text{-}4}$ on v_4 at $W_{3\text{-}5}$ for participants associated with each case along four directed paths from the former to the latter in Australia were higher than in UK; the actual rate of quit attempt at $W_{3\text{-}5}$ for participants with each case in Australia were also higher than in UK; both impacts increase steadily over the four years, and the corresponding rates of quit attempt in both countries fluctuated with an increasing trend.

If we combine the information from Tables 3 and 4 and Figures 2, 3 and 4, we can find out an interesting and conflicting phenomenon – the actual rate of quit attempt for smokers associated with each case in Australia is higher than in UK, but the warning labels on cigarette packs in UK have stronger impact on quit attempt, since more smokers in UK are associated with the classification of data patterns (b). The possible reasons for this phenomenon may be that -- other key policies in Australia, like "the noticed information of smoking risk/encouraging quitting", "banning smoking in public places", "provision of smoking cessation information and services", and "price of cigarettes", compared with the same key policies in UK, play more important roles in pushing smokers to think about the risk of smoking and making a quit attempt.

Based on all information above, we can conclude that the simplified tobacco control system described in this case study is a dynamic system. That is, for both countries, the quitting behaviour of all smokers involved in this system is very depended on each case with which how many smokers are associated. There is a very positive relationship between the total effect of smokers receive from the external stimulus and the rate of making a quitting attempts. But the data relationship is clearly non-linear. If more smokers are associated with classification of data pattern (a), then the rate of quit attempt will not increase dramatically even if the total increases. However, if the implementation of new warning labels can push more smokers switch from the classification of data patterns (a) to the classification of data patterns (b), then a dramatic increase in the rate of quit attempt is likely to happen suddenly.

CONCLUSION

In this paper we have proposed FCNs as a new methodology to model and analyse complex tobacco control systems. The new methodology has been applied to a simple tobacco control system. This system consists of three concepts "v_1 (noticed warning labels), v_2 (warning labels make you think about the health risk of smoking), v_3 (warning labels make you more likely to quit smoking) selected from one wave survey and one concept v_4 (quit attempt)" selected from next wave survey within the ITCPES project. Four wave surveys and three sample data collected from Australia and UK are selected from the ITCPES project. FCN is constructed to evaluate and compare the effect of health warnings on cigarette packs in influencing smokers' quitting behaviours in two countries over time. We have worked out interrelated relationships among v_1 (noticed warning labels), v_2 (warning labels make you think about the health risk of smoking), v_3 (warning labels make you more likely to quit smoking) and v_4 (quit attempt); relative importance of v_1 (noticed warning labels), v_2 (warning labels make you think about the health risk of smoking), v_3 (warning labels make you more likely to quit smoking) in predicting the response to v_4 (quit attempt); direct, indirect and total effect of v_1 (noticed warning labels) on v_4 (quit attempt) along all possible directed paths from the former to the latter; and data flow for the quitting behaviour of all smokers over four years. The research outcomes clearly demonstrated not only the effect of new warning labels on cigarette packs implemented in UK in influencing smokers' quitting behaviour, but also the complexity of tobacco control systems. It has also demonstrated that FCNs has potential to be a useful framework for knowledge discovery and decision support in tobacco control systems, especially in the cases where intensive interaction and non-linear data relationships among many attributes are involved.

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Table 1: The associations between v_1, v_2, v_3 at $W_{2\text{-}4}$ and v_4 at $W_{3\text{-}5}$

Case	Row % for v_4											
v_1	Yes						No					
	Australia			UK			Australia			UK		
1	42.4%	38.8%	41.4%	28.4%	31.3%	31.6%	57.6%	61.2%	58.6%	71.6%	68.7%	68.4%
2	44.2%	37%	41%	35.2%	45%	25.4%	55.8%	63%	59%	64.8%	55%	74.6%
3	44%	45.9%	43.6%	36.9%	44.4%	36.4%	56%	54.1%	56.4%	63.1%	55.6%	63.6%
v_2												
1	38.8%	37.7%	39%	29%	37.2%	28.5%	61.2%	62.3%	61%	71%	62.8%	71.5%
2	43.6%	44.5%	45.4%	39.5%	47.8%	35.5%	56.4%	55.5%	54.6%	61%	52.2%	64.5%
3	68.4%	58.6%	58.8%	48.8%	54.8%	48.6%	31.6%	41.4%	41.2%	51%	45.2%	51.4%
v_3												
1	40.1%	38.6%	39.4%	32.7%	37.6%	29.6%	59.9%	61.4%	60.6%	67.3%	62.4%	70.4%
2	53.8%	48.2%	49.3%	38.9%	51.5%	45%	46.2%	51.8%	50.7%	61.1%	48.5%	55%
3	71.9%	67.2%	68.1%	53.8%	75%	51.6%	28.1%	32.8%	31.9%	46.2%	25%	48.4%

Table 2: The associations between v_1 and v_2, v_3 at $W_{2\text{-}4}$; v_2 and v_3 at $W_{2\text{-}4}$

Case	Australia								
v_1	Row % for v_2								
	1			2			3		
1	87.4%	88.5%	88.2%	9.5%	9.8%	9.9%	3%	1.7%	1.9%
2	60.7%	67.5%	68.8%	32.2%	28%	27.3%	7%	4.5%	3.9%
3	48.8%	50%	53.3%	27.5%	26%	26.5%	23.7%	24%	20.2%
v_1	Row % for v_3								
1	94.3%	94%	92%	5%	6%	7.2%	0.8%	0%	0.8%
2	79.8%	83%	83.3%	17.8%	15%	13.8%	2.5%	2%	3%
3	69.7%	69.1%	70.3%	20.8%	18%	20.8%	9.4%	12.9%	8.9%
v_2	Row % for v_3								
1	96%	95.9%	94.4%	3.8%	3.8%	5.4%	0.2%	0.3%	0.1%
2	62.4%	60.1%	61.5%	33.5%	37.6%	36.1%	4.1%	2.3%	2.4%
3	36.8%	32.8%	27%	34.2%	22.7%	32%	28.9%	44.5%	41%
Case	UK								
	Row % for v_2								
v_1	1			2			3		
1	84.3%	88.1%	84.5%	10.2%	8.2%	11%	5.6%	3.7%	4.5%
2	79%	76.7%	64.9%	13.3%	20%	31.3%	7.6%	4.5%	3.7%
3	49%	49.4%	47.7%	23.3%	27%	29.6%	27.6%	23%	23%
v_1	Row % for v_3								
1	94.5%	93.3%	91%	4.6%	4.5%	7.1%	0.9%	2.2%	1.9%
2	83.8%	84.1%	84.3%	10.5%	13.9%	11.9%	5.7%	2%	3.7%
3	69.6%	68.3%	69.8%	17.8%	24.4%	20.7%	12.6%	7.3%	9.5%
v_2	Row % for v_3								
1	92.2%	94.1%	94.6%	4.7%	4.9%	5%	3.2%	1%	0.4%
2	64.6%	56.1%	62.8%	29.6%	60%	33.3%	5.8%	3.9%	3.8%
3	36.4%	31.1%	32.7%	30.1%	44.3%	31.3%	33.6%	24.6%	36.1%

Table 3: Total effects of v_1 at $W_{2\text{-}4}$ on v_4 at $W_{3\text{-}5}$ along four directed paths $\{\rho_1, \rho_2, \rho_3, \rho_4\}$, where $\rho_1 = (v_1, v_4)$, $\rho_2 = (v_1, v_2, v_4)$, $\rho_3 = (v_1, v_3, v_4)$, $\rho_4 = (v_1, v_2, v_3, v_4)$

	Total Effect					
Cases	**Australia**			**UK**		
(1,1,1)	0.22	0.20	0.21	0.15	0.18	0.16
(1,1,2)	0.19	0.18	0.19	0.13	0.15	0.14
(1,1,3)	0.19	0.18	0.18	0.13	0.15	0.14
(1,2,1)	0.19	0.18	0.19	0.14	0.15	0.14
(1,2,2)	0.16	0.15	0.16	0.11	0.12	0.12
(1,2,3)	0.16	0.15	0.16	0.11	0.12	0.12
(1,3,1)	0.19	0.17	0.18	0.14	0.15	0.14
(1,3,2)	0.16	0.14	0.15	0.11	0.12	0.12
(1,3,3)	0.16	0.14	0.15	0.11	0.12	0.12
(2,1,1)	0.41	0.37	0.43	0.34	0.43	0.26
(2,1,2)	0.38	0.33	0.39	0.30	0.34	0.23
(2,1,3)	0.36	0.31	0.37	0.30	0.32	0.22
(2,2,1)	0.42	0.37	0.43	0.31	0.35	0.27
(2,2,2)	0.39	0.33	0.38	0.27	0.32	0.24
(2,2,3)	0.36	0.31	0.37	0.28	0.30	0.23
(2,3,1)	0.39	0.33	0.39	0.32	0.32	0.23
(2,3,2)	0.37	0.29	0.34	0.27	0.29	0.20
(2,3,3)	0.34	0.27	0.33	0.28	0.27	0.19
(3,1,1)	0.59	0.61	0.75	0.49	0.59	0.48
(3,1,2)	0.58	0.58	0.72	0.46	0.59	0.47
(3,1,3)	0.57	0.61	0.72	0.48	0.56	0.46
(3,2,1)	0.61	0.62	0.76	0.50	0.62	0.49
(3,2,2)	0.59	0.59	0.74	0.48	0.61	0.48
(3,2,3)	0.59	0.62	0.73	0.50	0.59	0.47
(3,3,1)	0.69	0.69	0.80	0.58	0.65	0.54
(3,3,2)	0.68	0.66	0.77	0.55	0.65	0.54
(3,3,3)	0.67	0.69	0.77	0.57	0.62	0.52

Table 4: Percentage of smokers and rate of make a quit attempt at W_{3-5} for 27 cases with which smokers are associated, where "—" represents no smokers are associated with that case

Cases	Australia						UK					
	Column %			Row %			Column %			Row %		
(1,1,1)	33.9%	31.6%	31.6%	41.4%	39.6%	42.5%	5.3%	7.7%	11.1%	25.8%	28.1%	25.8%
(1,1,2)	0.7%	0.9%	0.9%	57.1%	36.4%	28.6%	0.0%	0.5%	0.7%	—	100%	100%
(1,1,3)	0.2%	0.0%	0.0%	100%	—	—	0.2%	0.2%	0.3%	100%	50%	100%
(1,2,1)	2.4%	1.8%	2.1%	34.2%	27.6%	37.5%	0.7%	1.0%	2.3%	27.3%	44.4%	63.6%
(1,2,2)	0.7%	0.9%	1.2%	36.4%	33.3%	41.7%	0.0%	0.2%	0.7%	0.0%/	50%	33.3%
(1,2,3)	0.2%	0.0%	0.0%	100%	—	—	0.0%	0.0%	0.0%	—	—	—
(1,3,1)	0.9%	0.9%	0.2%	83.3%	80%	25%	0.5%	0.2%	0.0%	100%	50%	—
(1,3,2)	1.1%	0.0%	0.2%	75.0%	—	100%	0.5%	0.2%	1.0%	50.0%	50%	100%
(1,3,3)	0.4%	0.0%	0.2%	100%	—	50%	0.0%	0.0%	0.3%	—	—	50%
(2,1,1)	9.7%	8.9%	10.6%	38.4%	30.3%	35.2%	5.1%	12.1%	5.4%	29.3%	47.2%	20%
(2,1,2)	0.9%	0.4%	1.4%	55.6%	66.7%	50%	0.5%	0.2%	1.0%	28.6%	14.3%	42.9%
(2,1,3)	0.0%	0.0%	0.0%	—	—	—	0.2%	0.2%	0.0%	100%	50%	—
(2,2,1)	4.0%	3.6%	4.5%	45.8%	48.5%	50%	0.9%	1.9%	3.4%	40.0%	44.4%	32.3%
(2,2,2)	2.7%	2.4%	1.4%	57.7%	47.8%	37.5%	0.7%	1.5%	0.7%	100%	50%	25%
(2,2,3)	0.5%	0.0%	0.2%	75.0%	—	100%	0.0%	0.0%	0.3%	—	—	33.3%
(2,3,1)	0.7%	0.2%	0.2%	57.1%	100%	33.3%	0.5%	0.2%	0.3%	66.7%	50%	50%
(2,3,2)	0.7%	0.4%	0.0%	50.0%	50%	—	0.0%	0.0%	0.0%	—	—	—
(2,3,3)	0.2%	0.4%	0.9%	50.0%	50%	80%	0.7%	0.2%	0.3%	75.0%	100%	/50%
(3,1,1)	13.1%	17.8%	17.9%	32.0%	36.9%	35.2%	29.2%	27.1%	25.8%	28.4%	35.3%	29.3%
(3,1,2)	1.3%	1.8%	1.4%	43.8%	57.1%	50%	2.1%	2.7%	3.4%	39.1%	57.9%	62.5%
(3,1,3)	0.2%	0.4%	0.2%	100%	100%	100%	1.8%	0.5%	0.3%	42.1%	100%	100%
(3,2,1)	5.3%	6.4%	6.1%	36.2%	42%	40.6%	12.6%	11.1%	11.1%	37.9%	45.1%	31.4%
(3,2,2)	4.4%	5.6%	5.9%	46.2%	53.2%	54.3%	6.2%	9.7%	8.1%	37.0%	51.3%	37.5%
(3,2,3)	0.9%	0.9%	0.2%	83.3%	80%	33.3%	2.3%	1.2%	1.3%	71.4%	55.6%	66.7%
(3,3,1)	5.6%	4.4%	2.4%	72.1%	55.6%	50%	11.7%	4.1%	7.0%	51.5%	35.4%	47.7%
(3,3,2)	4.4%	2.4%	4.2%	66.7%	47.8%	58.1%	7.4%	9.2%	7.0%	39.5%	54.3%	50%
(3,3,3)	4.9%	7.8%	5.7%	67.5%	66%	70.6%	11.0%	7.7%	8.1%	52.2%	82.1%	49%