DLSU RESEARCH CONGRESS 2020
"Building Resilient, Innovative, and Sustainable Societies"
June 17-19, 2020

An Application of Dynamic Bayesian Networks in the Context of Philippine Rice Food Security

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Abstract: Food security is the state where the physical, social and economic access of all people at all times to adequate, safe and nutritious food to meet their dietary needs and preferences in order to attain an active and healthy lifestyle. In the past 15 years (2003 to 2018), the number of Filipino families who rated themselves as hungry rose from 7.0% to 13.3%. In the aim of determining if changes in rice production and rice price in the Philippines cause food insecurity, the degree of impact of factors affecting Philippine rice production and Philippine rice retail price were forecasted. This study uses dynamic Bayesian network to determine the decision support for food security in connection with possible fluctuation in rice industry. Results show that a tremendous number of typhoons in the Philippines and insufficient area for rice to be harvested are the causes of the downfall in rice production which prevent the Philippines from achieving a hundred percent rice self-sufficiency. Furthermore, world rice price, world rice supply and the integration of Philippine rice consumption and Philippine total supply bring about an increase in the retail price of rice in the while the high amount of rice imports in the Philippines impact the rice industry by causing a decrease in the Philippine rice retail price.

Key Words: Rice Food Security; Dynamic Bayesian Networks; Rice Production; Retail Price

1. INTRODUCTION

The elevated price of food leads to costly food items that prevent poor Filipino families to meet their daily food and dietary needs. Rice is considered as the staple food in the Philippines. Filipinos spend more on rice than any other food items, regardless of income bracket as examined by the Bureau of Agricultural Statistics. According to the National Statistician Dennis S. Mapa (2015), food items including rice account for 70% of the household budget of Filipinos earning less than average and about 39% of an average Filipino household (Business Mirror, 2018). Philippines' rice consumption has been continuously increasing from 13.25 million metric ton (MMT) in 2017 to 14.1 MMT (6.42% growth increase) in 2018 and 14.4 MMT

(2.13% growth rate) in 2019 (USDA, 2019). Rice has become more expensive over the years, which caused a downfall in the ability of the poor household to meet their daily food and dietary needs. The Philippines was ranked 69th worldwide with its hunger incident categorized as "serious" having a Global Hunger Index (GHI) of 20.2 in 2018 (Global Hunger Index, 2018). From 2003 to 2018, a great number of Filipino families who considered themselves under the situation of hungry or someone had nothing to eat only once to a few times during the past quarter or the last three months rose from 7.0% to 13.3% (Social Weather Station, 2019). The price of rice has continued to increase despite the rice imports inject. Based on the World Rice Statistics in 2008, the Philippines were recorded as the biggest rice importer in the world. The country has been importing around 1.8 million tons of rice. Consequently, the demand of rice in the Philippines increased while supply decreased.

As the nationwide demand for rice increases, finding ways to grow more rice to make sure that every Filipino family has enough supply of rice is essential to help ensure food security. Food security is the state where the physical, social and economic access of all people at all times to adequate, safe and nutritious food to meet their dietary needs and preferences in order to attain an active and healthy lifestyle (FAO, 2006). In order to attain food security of rice in the Philippines, the country needs to be self-sufficient in producing its local rice. Being self-sufficient in food is defined as the ability to meet and provide the country's consumption needs (especially for staple food) from their own production rather than purchasing or importing (Minot & Pelijor, 2010). The Philippines has been struggling in developing self-sufficiency specifically in rice production given the cases of deteriorating yields, loss of agricultural land and farmers fighting for their rights and position in the rice industry. According to the Philippine Statistical Authority, the area harvested for rice in 2018 dropped to 939,790 hectares from 947,190 hectares in 2017. Similarly, rice yields remained low at 4.38 tons per hectare in 2018.

In line with the second sustainable development goal (SDG) which aims to end hunger, achieve food security, improve nutrition and promote sustainable agriculture, this paper aims to forecast the degree of impact of factors such as the number of tropical cyclones that made landfall in the Philippines, the number of rice tractors in use in the Philippines, rice area harvested in the Philippines, rice yield in the Philippines, Philippine rice consumption, Philippine population, total rice supply in the Philippines, rice imports of Philippines, world rice price and world rice supply on Philippine rice production and Philippine rice retail price using dynamic Bayesian network (DBN). Changes in the levels of such factors associated with rice self-sufficiency and rice food security are helpful for the government in order to formulate necessary policies and effective strategies to prevent rice food insecurity and to mitigate rice self-insufficiency.

2. METHODOLOGY

2.1 Data

The data utilized came from four different sources. The following data were obtained from the United States Department of Agriculture (USDA): Philippine (PH) Rice Production, PH Area Harvested for Rice, PH Rice Imports, PH Rice Consumption, PH Total Supply for Rice, World Rice Price and World Rice Supply. The World Rice Price is based on rice prices of Thailand (Mapa et al, 2015). Data on PH Rice Retail Price were retrieved from Philippine Statistics Authority (PSA). PH Population and PH Tractors were collected from Food and Agriculture Organization of the United Nations (FAOSTAT). Lastly, data on Typhoons in the Philippines were obtained through the Freedom of Information (FOI) website by Philippine Atmospheric, Geophysical and Astronomical Service Administration (PAGASA). According to FAOSTAT, rice yield is calculated by dividing the rice production by area harvested. The time frame of the data is from year 1990 to 2017. Table 1 shows the list of variables and descriptions.

Table 1. Variables and Descriptions

Variable	Descriptions
PH Rice Production (*Production*)	PH milled rice production in tons yearly
PH Rice Retail Price (*RetailPrice*)	PH retail price for regular milled rice in PH pesos per kilo, yearly
PH Population (*PopulationPH*)	PH Annual total population
PH Area Harvested for Rice (*AreaHarvested*)	PH area harvested for rice in hectares yearly
PH Rice Imports (*Imports*)	PH milled rice imports in tons yearly
PH Total Rice Supply (*TotalSupply*)	PH total rice supply in tons yearly
Number of Rice Tractors (*Tractor*)	PH number of rice tractors in use yearly
Typhoons in the Philippines (*Typhoon*)	Number of tropical cyclones that made landfall in PH yearly
PH Rice Yield (*Yield*)	PH computed rice yield in hectograms per hectare yearly
PH Rice Consumption (*DomesticConsumption*)	PH rice domestic consumption per capita in tons yearly
World Rice Supply (*WorldSupply*)	World supply of rice in tons yearly
World Rice Price (*WorldPrice*)	World price of rice in US dollars monthly (converted to PH peso)

World rice price is based on monthly rice prices in Thailand which was converted by averaging the prices of rice in 12 months into average price in a year. The continuous variables have been discretized similar to the process used by Barons, Zhong, and Smith (2014) which used a benchmark by attaining the average annual growth of all the variables excluding typhoons. The average annual growth of a variable was categorized into 'very high', 'high' and 'moderate' which correspond to 100%, 50% and 10% increase, respectively, while category 'low' corresponds to a decrease of 10% in average annual growth.

2.2 Dynamic Bayesian Network

Bayesian network (BN) is defined as a type of graphical model represented as a directed acyclic graph (DAG) where the nodes in the DAG represent variables or states (Mihajlovic & Petkovic, 2001). It is a causal network that represents conditional dependencies among variables using directed edges. Figure 1 shows a DAG where V_c is the child of V_p and V_p is the parent of V_c since there is a directed edge from node V_p to node V_c. Nodes V_{p1} and V_{p2} are the parents of node V_c , while node V_a , V_{p1} and V_{p2} are the ancestors of V_c . Node V_d is the child of V_c and also regarded as the descendant (Jensen & Graven-Nielson, 2007).

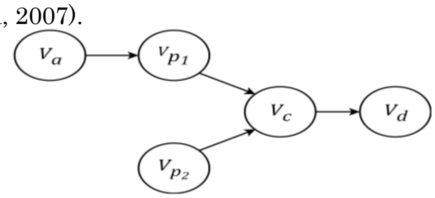

Fig.1. Directed Acyclic Graph

According to Jensen & Graven-Nielsen (2007), the following must be found in a BN:

1. A set of variables and a set of directed links between variables.
2. Every variable has a finite set of states which are mutually exclusive.
3. A directed acyclic graph wherein it constructed by variables together with the directed links.
4. For every variable B with parents $A_1,\ldots,A_n$, a conditional probability table $P(B|A_1,\ldots,A_n)$.
5. If B has no parents, then the table reduces to the unconditional probability table $P(B)$

Murphy (2002) defined Dynamic Bayesian Networks (DBN) as a method that extends BN to model probability distributions over semi-infinite collections of random variables, $Z_1, Z_2, \ldots,$ usually divided into discrete-time stochastic processes. It is a pair, $(B_1, B_\rightarrow)$ where B_1 is a BN that defines the prior $P(Z_1)$, and $B_\rightarrow$ is a two-slice temporal Bayesian network (2TBN). It defines $P(Z_t|Z_{t-1})$ by means of a DAG as

$$P(Z_t|Z_{t-1})\prod_{i=1}^{N}(Z_t^i|P_a(Z_t^j)) \qquad \text{(Eq. 1)}$$

where Z_t^i is a i^{th} node at time t, and $Pa(Z_t^i)$ are the parents of Z_t^i. There are no parameters associated with the nodes in the first time-slice of a 2TBN. In the second time-slice of the 2TBN, every node has an associated conditional probability distribution (CPD), defining $P(Z_t^i \mid Pa(Z_t^i))$ for all $t > 1$. A node's parents, $Pa(Z_t^i)$, can either be in the same time-slice or in the former time-slice, and in most cases it is assumed that the model is a first-order Markov. The links between time-slices reflect the causal flow of time from left to right. The directed edge within a time-slice represents an "instantaneous" causation. Undirected links within a slice demonstrates correlations or constraint rather than causation. According to Murphy (2002), the parameters of the CPDs are considered to be time-invariant. The parameters that vary are added into state-space and are treated as random variables. When there is only a finite set of probable parameter values, a hidden variable may be added that chooses which set of parameters to use. A dynamic Bayesian network's semantics can be described by "unrolling" the 2TBN until T time-slices with the resulting joint distribution given in Eq.2 (Murphy, 2002).

$$P(Z_1{:}T) = \prod_{t=1}^{T}\prod_{i=1}^{N} P\left(Z_t^i \,\middle|\, P_a(Z_t^i)\right) \qquad \text{(Eq. 2)}$$

The BN initial structure for PH rice industry shown in Fig. 2 is based on Kargbo (1979) Sierra Leone rice industry causal structure and United States rice industry structure built by Grant & Leath (1979), since there is no available rice industry structure in the Philippines. The BN structure is composed of 12 nodes and directed edges between the nodes indicate definite relationships.

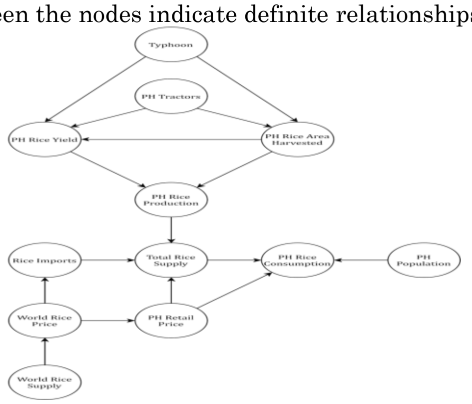

Fig.2. BN structure for Philippine rice industry

Time-delay links that were added to BN to make a DBN was based from time series models (Mapa, Castillo, & Francisco, 2015). A time-delay link is a directed edge that indicates that the child node's value depends on the parent node's value at an earlier time (Norsys, 1997). Figure 3 shows some nodes of the previous year that affects the nodes of the current year. It shows that PH retail price of the previous year affect PH rice production and PH retail price of the current year.

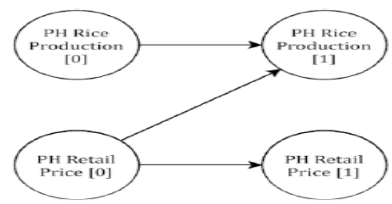

Fig. 3. Partial DBN of PH rice industry

After the BN structure was formed, the parameter learning was carried out using the software Netica. Parameter learning is the automatic learning of particular relationships nodes have with the parent nodes using case data, once it has been decided which nodes are the parents of each node. In Netica, different links may have distinct time delays, thus, time slices may have a distinct structure from each other when the network is extended. Netica replicates nodes that have a time-delay link in the expanded net. This means that when the DBN is expanded, some nodes in the BN become multiple nodes in the expanded net, showing the values of the variable at different time points (Norsys, 1997).

3. RESULTS AND DISCUSSION

Results include various case scenarios that affect the target nodes, PH rice production and PH retail price. The baseline model with calculated conditional probabilities is shown in Figure 4. DBN of PH rice industry under the influence of category 'high' of typhoon is shown in Figure 5. The impact on Philippine rice production when typhoon is set to 'high' is a decrease from 44.4% in Figure 4 to 43.5% in

Figure 5 implying that there was a decrease in rice production in the current year caused by the tremendous number of typhoons that made landfall in the Philippines.

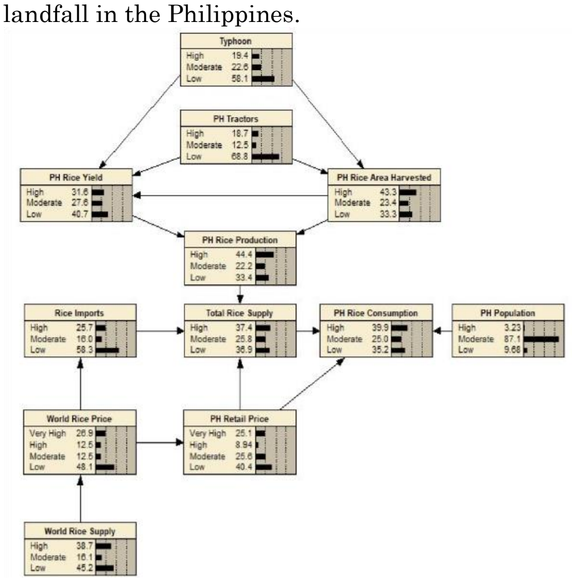

Fig. 4 Baseline DBN for PH Rice Industry

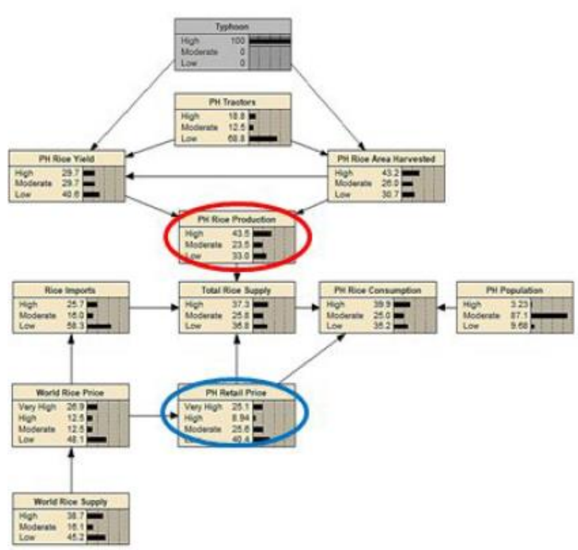

Fig.5. DBN for PH Rice Production under the influence of typhoon

In order to assess the time effects of typhoons in PH rice production the 2-time-slice DBN was run for 1, 2 and 5 time steps, to approximate 1, 2 and 5 years respectively. After a year, the model shows 35% probability of having a high rice production under the influence of the 'high' typhoon category which is a decrease from the previous year of 43.5% probability and then remained the same after 2 and 5 years.

A big decrease of 12% resulted when 'low' PH rice area harvested was integrated to 'high' typhoon. The DBN model shown in Figure 6 shows that under the influence of 'high' typhoon and 'low' PH rice area harvested the probability of having 'high' PH rice production decreased from 44% to 32% for years 1, 2 and 5.

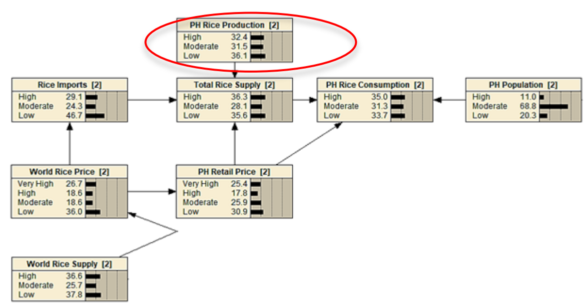

Fig.6. DBN for PH Rice Production under the influence of 'high' typhoon level and 'low' PH rice area harvested after 2 years

Results further show that world rice price has a direct impact on PH retail rice price as shown in Figure 7. Setting the world rice price to 'very high' would produce an immediate increase from 25% to 42% to PH retail price. This suggests that as world rice price increases, PH retail price also increases. The DBN further shows that under the influence of the world rice price, the probability of having high PH rice retail price decreased from 42% to 30%, 28% and 26% after 1, 2 and 5 years.

The study was exhaustive by considering the other case scenarios. Results show that 'very high' rice imports depicts a decrease in PH rice retail price from 25% to 21%. Furthermore, the integration of 'high' PH rice consumption and 'low' PH total rice supply bring about an increase from 25% to 37% of having very high probability in the retail price of rice.

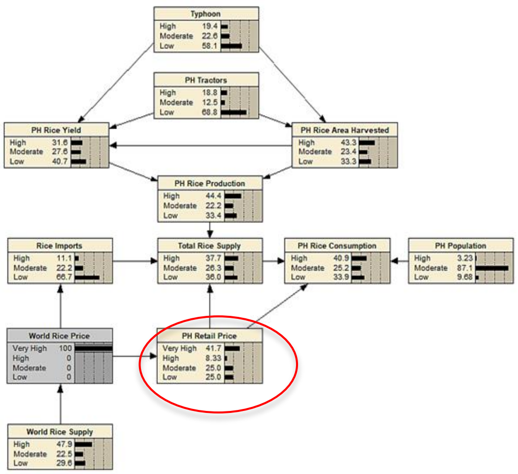

Fig.7. DBN for PH rice industry under the influence of world rice price

4. CONCLUSIONS

DBN was used in a number of scenarios to forecast changes in the PH rice production and PH rice retail price. The results of the analysis show that the number of typhoons that made landfall in the Philippines and the area harvested for rice affect the production of rice in the Philippines. A tremendous number of typhoons in the Philippines and insufficient area for rice to be harvested are the causes of the downfall in rice production which prevent the country from achieving 100% rice self-sufficiency. The effect of 'very high' world rice price causes an increase in the PH rice retail price while 'high' rice imports impacts the rice industry by bringing about a decrease in the PH rice retail price. Nevertheless, the continuing dependence of the Philippines to rice importation compromises the country's food security. The integration of 'high' PH rice consumption and 'low' PH total rice supply resulted to an increase in PH rice retail price. Recommendations for future studies can include other factors in DBN structure such weather and government programs.

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