Fuzzy Modeling of Migration from the State of Oaxaca, Mexico

Anais Vermonden and Carlos Gay
Programa de Investigación en Cambio Climático, Universidad Nacional Autónoma de México, CU, Mexico

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Abstract: This study shows an important innovation with the use of fuzzy logic to develop models on the migration factors occurring in the state of Oaxaca, México, since fuzzy logic has not been applied in this field. Migration is a complex system as individuals make their own decision to migrate. The major factors causing migration are: higher employment in the primary sector, high grades of unemployment, high marginalization index, small communities, soil degradation, violence and remittance received. Another tendency shown in these models is that municipalities in Oaxaca with greater levels of education are having higher migration levels due to the lack of opportunities to continue studies or well-paid jobs. Climate change may impose greater movement of people as it can worsen the already precarious soil situation. Even if the models present some error in the calculation of the migration index, it made clear what other variables should be included to show the impacts of climate change on migration.

1 INTRODUCTION

Oaxaca is located in southwest Mexico; it is divided into 570 municipalities. Oaxaca is one of the poorest states with 61.9% of the population living under the poverty line and, has one of the highest rates of rural migration. During the last three decades, the rate of migration has increased considerably. There has been a substantial movement of people from rural areas to urban areas and the United States (USA). Most of the migrants come from remote and marginalized villages and have a low level of education. Since 2005, it is estimated that over 80,000 people from Oaxaca live somewhere else in Mexico (Juarez 2008). Those who migrated to the United States (USA) concentrate in the states of California and Illinois. In 2007, it was estimated that the number of Oaxacans, residing in Los Angeles, could be up to 250,000 (Kresge 2007).

Part of the economy of Oaxaca is based on agriculture, mostly practiced communally in "ejidos" (communal land used for agriculture, on which community members possess and farm a specific parcel) or similar arrangements. 30% of the population is employed in agriculture, about 49% in commerce and services and 21% in industry. The commercial sector dominates the gross domestic product with 65.4%, followed by industry/mining with 18.9% and agriculture with 15.7% (INEGI 2013).

There are a number of causes for the migration from Oaxaca, and some of the most significant are lack of economic development, need for diversification of income (remittance), ecological deterioration, lack of educational opportunities, marginalization and growing violence.

The lack of economic development is the main cause for poverty and, migration is the best response farmers have found to benefit their household and communities by seeking better-paid and more secure employment. In the early 90's, when the North American Free Trade Agreement (NAFTA) initiated, the flood of cheap, subsidized American corn caused the price of the crop to fall 70% in Mexico (Wise 2010). The price of other crops such as beans and coffee also fell. As the prices fell, poverty rose causing the vanishing of subsistence farming. Many left to work in the industry sector, which became a complementary income in the family economy, but salaries in this sector have also fallen and the growing unemployment worsens the already fragile family economy (Contreras 2004).

The decreasing demand for local crops and the increasing large-scale agriculture had a detrimental effect on the traditional agricultural practices and land productivity. Environmental factors such as changing rain patterns, droughts, floods, use of chemicals, change of land use, add pressure on good

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farmland. People have historically left places with harsh or deteriorating conditions.

Violence is a growing factor, especially in the Mixteca region where political and agrarian conflicts have surfaced. Also, community self-defenses are getting organized in region of el Itsmo de Tehuantepec to protect the communities from the construction of wind parks and organized crime.

Migration is a complex system; many factors take place in the personal decision to migrate. Fuzzy logic is a powerful tool to better understand the relationships between those many factors. It allows the use of large qualitative and quantitative data sets resulting in migration patterns and variations in order to predict outcomes for the region and develop decision-making tools. This is the first attempt of using fuzzy logic to build a Migration Index.

2 METHOD

Fuzzy logic is a form of multi-valued logic; approximate reasoning can be modelled, as fuzzy variables may have a partial truth-value ranging from 0 to 1 (Perfilieva et al. 1999). Furthermore, linguistic variables may be used; these degrees can be managed by specific functions. For this study nine variables were used to describe migration. These variables are: percentage of the economically active population occupied (EAP), percentage of the EAP working in the primary sector (SIM 2014), educational index (CONEVAL 2012), marginalization index, percentage of the population living in localities with less then 5000 people, percentage of the indigenous population (CONAPO 2014), average of the soil degradation (INEGI 2002), the rate of homicides (INEGI 2014), and the percentage of households receiving remittances (CONAPO 2014), all at municipality level. The average of land degradation was calculated using the map of land use, extracting agricultural practices and grazing and averaging the degree of land degradation in the areas within the municipality. The migration intensity was calculated using the information form the Instituto Nacional de Estadística y Geografía (INEGI) (National Statistics and Geography Institute), of total population numbers of 2000 and 2010.

Due to the quantity of variables fuzzy clustering will be used to determine the strength of the association between the elements and the clusters. For this study both the fuzzy c-means (FCM) and subclustering will be used. The FCM is a clustering technique wherein each data point belongs to a cluster to some degree that is specified by a grade of membership (Bezdec 1981). The subtractive method is a fast one pass algorithm to estimate the number of clusters and the cluster centres in a dataset (Chiu 1994). The subclustering best approximation to reduce both errors to a minimum was ten clusters, with a radii of 0.62 which is a vector that specifies a cluster center's range of influence in each of the data dimensions, assuming the data falls within a unit hyperbox. The FCM method showed no reduction in the calculated errors with the increase in clusters, from 2 to 100, the results were the same. Five clusters were used to generate the model to allow a greater improvement with the use of ANFIS. From three to five clusters there was an improvement using ANFIS, five being the best number of clusters, over six there were no notable improvements.

To be able to check the models, 75% of the data was used to construct the models using GENFIS3 and GENFIS2 from MATLAB (MATLAB 2009), which respectively used the FCM and Subclustering method to generate the FIS's. The resting 25% of the data was used to check the models. Both models will be improved using Adaptive Neuro Fuzzy Inference System, or simply ANFIS, which is a neural network based on Takagi-Sugeno fuzzy inference system. By integrating both neural networks and fuzzy logic principles, it has the potential to capture the benefits of both in a single framework. It has the ability to construct sets of fuzzy if-then rules to approximate nonlinear functions. ANFIS also can appropriate membership functions to generate the stipulated input-output pairs (Jang 1993) to be used in the model. The Neuro-adaptive learning techniques provide a method to build a fuzzy model from the information contained in a dataset. The fuzzy system enables flexibility in the variables and the representation of incomplete data, as membership to a fuzzy set is denoted by the degree of membership to the set. Since the ANFIS can deduce relationships between the inputs/outputs. ANFIS forms an input output mapping based both on human knowledge (based on fuzzy if-then rules) and generated input/output data pairs by using a hybrid algorithm that is the combination of the gradient descent and least square estimates (Jang 1993). The main characteristic of the Sugeno inference system is that the consequent, or output of the fuzzy rules, is a function as shown in equation 1.

$$\begin{aligned} &\text{R1: If A is A1 and B is B1 the} \\ &\quad f1=p1*a+q1*b+r1 \\ &\text{R2: If A is A2 and B is B2 the} \\ &\quad f2=p2*a+q2*b+r2 \end{aligned} \tag{1}$$

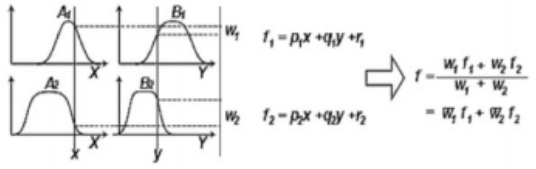

Figure 1: Diagram of a Sugeno model (Evaluation of two fuzzy rules with two input variables, i.e. A and B). (Raveendranathan 2011).

The first step combines a given input tuple (Figure 1), x and y, through antecedent rules by determining the degree to which each input belongs to the corresponding fuzzy set. The min operator is used to obtain the weight of each rule, which is later used in the final output computation, f. Sugeno has two differentiated set of parameters, the first set corresponds to the input variable and the second to the output function of each rule, i.e. pi, qi and ri. ANFIS uses two optimisation algorithms to automatically adjust the two sets of parameters. Back-propagation (gradient descendent) to learn the parameters of the antecedents (membership functions) and least square estimation is used to determine the coefficients of the linear combinations in the rules' consequents.

3 DATA

The data chosen for this study were: percentage of the economically active population occupied (EAP), percentage of the EAP working in the primary sector, (SIM 2014), educational index (CONEVAL 2012), marginalization index, percentage of the population living in localities with less then 5000 people, percentage of the indigenous population (CONAPO 2014), average of the degradation of soils (INEGI 2002), the rate of homicides (INEGI 2014), and the percentage of household receiving remittances (CONAPO 2014), all at municipality level.

These variables were chosen over the studies directed over the years in different municipalities of Oaxaca, like "Transnational Migration in Rural Oaxaca, Mexico: Dependency, Development and Household" (Jeffrey 2001), Contreras focused on the Indigenous region of the Cuicateca (Contreras 2004) only focuses on the Zapotec region, Bautista focused on the region of the Central Valleys (Bautista 2011). The study produced by Ana Margarita Alvardo Juárez, Migration and poverty in Oaxaca sets four important conditions for migration to happen: 1. The existence of high rates of marginalization and poverty; 2. The deterioration of rural activities where more than half of the population is economically active; 3. The lack of jobs well paid, and low educational levels; and 4. Social and family networks can promote the movement of people. These are conditions repeated in the previous works in the different regions. Therefore, from these articles were selected the variables of percentage of the EPA, percentage of the EAP working in the primary sector, educational index, and the percentage of household receiving remittances. Another important migration happening everywhere in Mexico (and the world) is the movement of people from rural areas to urban areas (Lall et al. 2006), and (UNITAR 2010). Thus the variables of percentage of the population living in localities with less then 5000 people and percentage of the indigenous population were introduced.

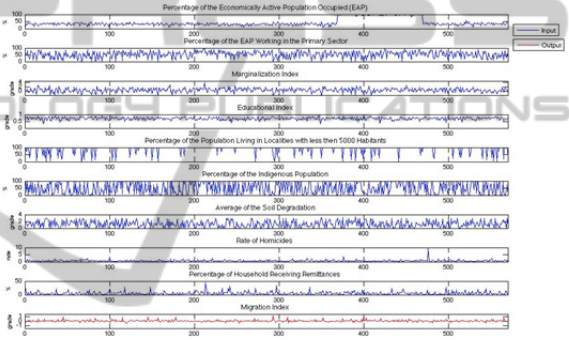

Figure 2: Graphs showing the input variables in blue and the output variable in red.

Also, soil degradation, especially in the Mixteca region, has caused the reduction in crop production, leading to increase poverty and promoting migration according to several non-profit organisations (NGO's) like Ecoinflexiones (Nuñez et al. 2013), the World Wildlife Fund and government agencies such as the Comisión Nacional Forestal (CONAFOR 2013).

According to the director, Rufino Domínguez, of the Instituto Oaxaqueño de Atención al Migrante in an interview with held in 2013 (Nssoaxaca 2013), violence, within three municipalities, are causing people to leave the communities where hundreds have died and several have received death threats. Many NGO's, like Casa Collective, have reported paramilitary violence, causing people to migrate to safer areas (Jonathan 2008). The Drug War in Mexico is an increasing factor of migration as people flee the violence, this happens especially in the region of the Itsmo de Tehuantepec region, which is also the region were many migrates from

Central America to cross to the USA (Basu et al. 2013), (Esteva 2007), and (Vogt 2013). The information on homicides, provided by INEGI, comes from the Secretariado Ejecutivo del Sistema Nacional de Seguridad Pública (SESNSP), which online database provides less information then the one given by the INEGI's online database, showing inconsistencies and lack of information on different crimes related to violence, such as rape, injuries caused by knives and battery. The most complete database was on homicides. The homicides index is based on the proportion of the number of crimes on the total population in each municipality.

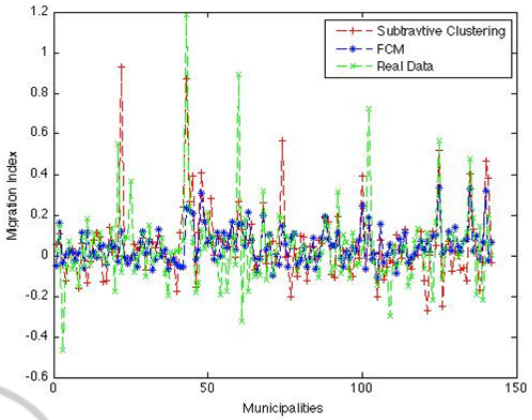

Figure 3: Graph showing both models, FCM in blue, subtractive in red and the real data in green.

4 RESULTS

The two models showed errors in the approximation of the results. The Subtractive clustering method has the lower training error of 0.1297 whilst the FCM is 0.1640. But the checking data error is higher for the subtractive method with 0.1925 and the FCM is 0.1794. In figure 3, both results are compared to the real values. The FCM model has five rules and the subclustering model has six rules.

The two models show similar output surface, when the EAP, who works in the primary sector, tend to migrate more. This result was expected since the working conditions have worsened with time. As the workforce leaves, as the elderly and children stay behind, the level of food production reduces, making them more vulnerable and dependent on remittances of their relatives working in other regions or abroad. (Treviño-Siller et al. 2006). Another contributing factor of migration of people working in the primary sector is the degree of soil degradation, the tendency shows that, the higher the level of degradation, the higher the level of migration. It also shows that when the index of marginalization is high, migration will be high no matter which of the eight variables it is paired with. The same tendency of higher level of migration appears when the level of education is higher, when the municipalities are under 5000 inhabitants since there are less services available (also, municipalities with high percentage of indigenous populations, as they tend to live in smaller communities), and when municipalities have higher percentage of remittances since there is money to leave and a promise of a job somewhere else. Homicides, in both models, also show a similar surface, more homicides more migration.

Both the subtractive clustering model and the FCM model were submitted to an improvement using ANFIS. The training error for the subtractive clustering model was 0.1239 but the checking error increased 0.2171, for the FCM model the training error to 0.1519, and the checking error is 0.1395. The FCM model after being improved by ANFIS recreated better the behaviour, see figure 4.

The rule six in the subclustering model and the rule five in the FCM model are the same, if the medium percentage of people occupied (40%) and a lower percentage occupied in the primary sector (30%) and a medium marginalization index (0.02) and a higher education index (0.7) and low percentage living in localities with less then 5000 habitants and a low percentage of indigenous population and low soil degradation and a low homicide rate and a low percentage of households receiving remittances then there is a low inward migration.

This analysis confirms the four conditions: the higher the marginalization index, the smaller the communities (rural areas), the tighter the social and family network receiving remittances the higher the percentage of migration and higher percentages of the EAP working in the primary sector.

The results still show a significant error. Both models had showed stabilization within the first 20 epochs in training, determining the need for more variables to improve the index. Two municipalities showed a greater outward migration index than the one calculated, San Mateo Piñas and San Pedro Jaltepetongo. In both municipalities, the loss of productivity of agricultural lands has caused many to migrate, due to the effects of floods (San Mateo Piñas) and droughts (San Pedro Jaltepetongo) causing damages both to the infrastructure and loss of production. Both municipalities have violence issues, which are mostly reported in the local news and not reflected in the INGEI database. The

municipality of San Mateo Piñas has high levels of corruption, their last municipality president was charged several times by the magistrate for embezzlement but remained free and was murdered last year. Indices of flood and drought risk could be introduced to improve the migration index. Both municipalities have high grades of deforestation making them vulnerable to climate impacts. Their Municipality Development Plan considers reforestation. Based on that information, the variable of percentage of land without natural vegetation could be added.

Corruption indices are at state level only. To create a corruption index at municipality level would require another study.

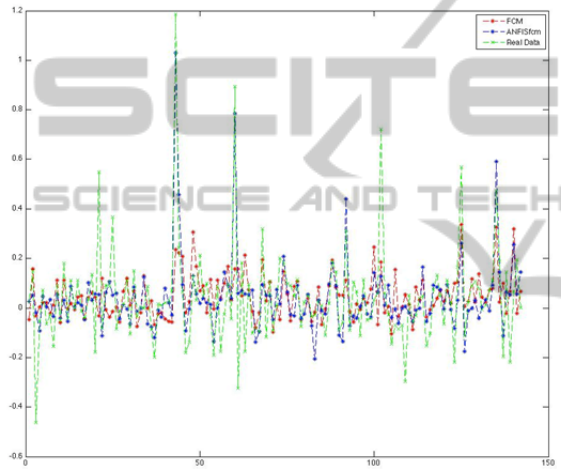

Figure 4: Graph showing the FCM model in red, the FCM model after being trained in ANFIS in blue, the real data in green.

The three municipalities that show the biggest error in the inward migration index are San Miguel Panixtlahuaca, San Pedro Comitancillo and San Simón Zahuatlán. They receive more migrants then calculated. The municipality of San Simón Zahuatlán has the lowest percentage of labour working in the primary sector, most work making balls and hats providing them with a steady income. It has one of the lowest homicide rates. It has a temperate humid climate ideal for agriculture; many are hired during the picking season as jornaleros. Both San Miguel Panixtlahuaca and San Pedro Comitancillo could be considered more urban municipalities, both have higher-grade education facilities and more health services. In San Miguel Panixtlahuaca, the main crop is coffee. The community is well organized and have certified their coffee as organic. They sell their produce for export getting better revenues even if the price of coffee has fallen over the years. They hire jornaleros during the picking season.

Other variables that could be included to improve the index for high receiving municipalities could be the number of schools at different levels, health indexes such as child death rate and, percentage of the EAP working in the other sectors then the primary one.

5 CONCLUSION

The models show an innovative form to measure the migration of the state of Oaxaca, Mexico. It is important to note the tendencies that could help develop adaptation plans to reduce the migration. Of the four conditions stated by (Juarez 2008), one is contradicted since the people with lower levels of education are expected to be the ones who migrate more, the analysis of the data shows otherwise, the higher education level, the higher the migration rate. This is due to lack of opportunities and well paid jobs in the state as mentioned by (Contreras 2004).

This analysis confirms the four conditions: the higher the marginalization index, the smaller the communities (rural areas), the tighter the social and family network receiving remittances the higher the percentage of migration and higher percentage of the EAP working in the primary sector.

Even with the lack of data on homicides, the tendency clearly shows that higher levels of violence will cause the population to migrate despite other favourable conditions, as seen in figure 5.

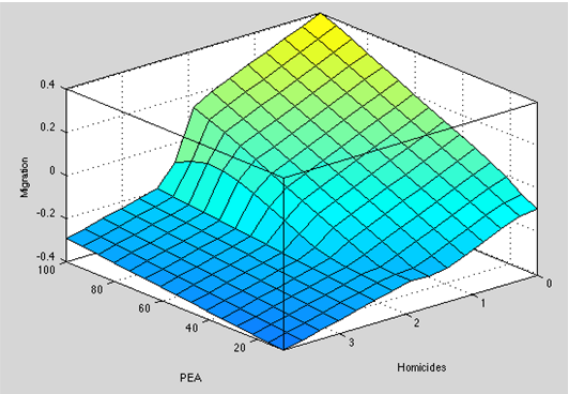

Figure 5: Surface of the rules between the PEA and homicides rates.

The model shows a tendency of people working in the primary sector to migrate and the increasing impact of soil degradation on migration patterns.

Land surface is an important part of the climate

system. The interaction between land surface and the atmosphere involves multiple processes and feedbacks. It is frequently stressed that the changes on vegetation type or cover can modify the characteristics of the regional atmospheric circulation and the large-scale external moisture fluxes (Sivakumar et al. 2007). Climate change can exacerbate the already hard conditions found in regions, such as the Mixteca region, that have deforested large areas and present high degrees of soil degradation, causing violent agrarian and political disputes, presenting the worst possible scenario that could be attained in other regions of the state of Oaxaca.

The downward spiral presented in the Mixteca region, high degrees of soil degradation, high percentage of the population working in the primary sector, high levels of violence, high marginalization index, result in high migration levels. This kind of modelling can help design public policies and adaptation measures to reduce vulnerability of the remnant population and prevent the Mixtecan scenario to be reproduced in other regions of the state.

The introduction of variables of extreme events could improve the models to better understand the future impacts of climate change on migration. Possible adaptation measures could be implemented with the use of more environmental indices to facilitate the understanding of the impacts on human migration.

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