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LARGE SCALE KNOWLEDGE-BASED SIMULATION MODELS: AN APROXIMATION TO THE NORTH-SOUTH REMITTANCES MODEL

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ABSTRACT

This paper studies the evolution throughout the time span of those covariates that remittances depend on. Not only economical variables but also demographic, social and political ones have been taken into account in a Monte-Carlo-based simulation model. Expert knowledge was incorporated modeling fuzzy dependence relationships (DR) between covariates based on standard macroeconomic models. An improved procedure to make fuzzy rules explicit and to evaluate them automatically was designed and tested in a multilevel fuzzy inference engine. Primary covariates (inputs in a dependence relationship) were defined by standard statistical distributions (uniform). The multilevel fuzzy inference engine evaluated DR outputs, following a hierarchical structure once the input values were known. Using this methodology, a North-South remittances model was designed and evaluated. Results showed that intermediate DR outputs matched the expert-based expectations reasonably as did the remittances.

1 INTRODUCTION

Simulation is a well-known technique to evaluate economic changes and policies in complex and uncertain environments (Stern 1997, Kydland 2006). The objective of this paper is to design and develop a computer system based on Monte-Carlo simulation and Fuzzy Logic which can help us explain the behavior of economic variables that influence the remittances (Borjas 2008) received in a specific country throughout the time span. The Monte-Carlo simulation model is a very powerful tool to evaluate macroeconomic environments (García-Alonso and Pérez-Alcalá 2008) but, without expert knowledge to guide the simulation process, it is completely blind and its results arguable. Modelling imprecise dependence relationships (DR) between socio-economic covariates as expert-based fuzzy sets (García-Alonso 2008), a multilevel fuzzy inference engine was designed and developed to evaluate automatically those DR that cannot be modeled using algebraic functions. This engine was included in a simulation model where Monte-Carlo was used to determine DR input values based on expert-based prerequisites and statistical distributions (Fishman 1996, Stern 1997, García-Alonso and Pérez-Alcalá 2008).

When expert knowledge can be made explicit using rules, Fuzzy Logic is one of the most appropriate methodologies to translate it into a computer system (Setnes et al. 1998, Cox 2005, García-Alonso 2008). Fuzzy inference is used to design inference engines to evaluate the values of output variables when the corresponding values of input covariates are known. In this situation, we do not need any explicit algebraic function to relate inputs and outputs, we only need well-structured rule-bases (Gegov 2007). The number of rules in these rule-bases is the main problem to deal with when designing a fuzzy inference engine is necessary (Guven and Passino 2001, Pal et al. 2002). The huge amount of these expert-based rules can be a serious problem because experts cannot accurately define all of them (Wang et al. 2005) and, in addition, their evaluation is very computer demanding (Gegov 2007).

In order to deal with the rule number problem, in this paper we have improved a new procedure to make rule design and evaluation automatic (García-Alonso 2008, García-Alonso and Pérez-Alcala, 2008). This procedure can only be used in structured systems where experts can identify which variables (outputs) depend on others (inputs) as well as some additional parameters to use as rule-design guidelines. Rather than defining and stating all the rules explicitly in a rule-base (Xiong and Litz 2002, Gegov 2007), this procedure designs, instantiates and evaluates only the appropriate rules when needed. The evaluation of remittance in a north-south remittances model, evaluation in a complex macroeconomic system, has been chosen to check our model improvements.

Remittances, mainly in poor countries, are one of the key elements for economic development. In 2008, official international remittances were formally estimated at $397,047 million per year (World Bank 2008). Remittances have been defined as cash transfers transmitted by migrant workers to their families and communities back home (Van Doorn 2001) However, remittances can be sent through formal (financial transfers) and informal ways (usually in cash). In literature only formal transfers are considered because informal ones are outside the standard financial system and their evaluation is very complicated.

Borjas (2008) considered that wages of migrant populations abroad depend on a socio-economic vector that describes the structure of the host countries, the number of years that migrant workers are living in the host country, the worker's age in the year analyzed and, finally, the moment of their arrival to the host country. Following the neoclassical theory, the microeconomic model of individual choice (Borjas 2008) establishes that people decide to migrate depending on a cost-benefit relationship that involves: the differential of wages among countries (origin and host), the unemployment differential and the initial investment needed (transport costs, language, religion, culture, nationality requisites, etc). A potential migrant decides to migrate if, according to his skills, he expects to obtain a measurable profit.

The propensity of the migrant population to remit wages back to their families is a relevant variable that is difficult to evaluate. According to Adams (2008), it is a function of the migrant profile and skills, the number of years in the host country, the size of the family at home, the size of the family in the host country and the differential of interest rates. Freud and Spatafora (2005) and Higgins et al. (2004) included the transmission costs, the exchange rates and the social stability of the country of origin in the previous function. Finally, Gallina (2004) also took into consideration the number of years (duration) that migrants had been in the host country.

In addition to standard covariates identified by the neoclassical economic approach, the New Economy of Migration (Massey et al. 1998) includes the host country benefit, and the relevant personal position of the migrant population (Bartel 1979) and the existence of social networks in the host country, the Social Capital Theory (Massey and Parrado, 1994).

According to the Segmented Labor Market Theory (Piore 1979), all of these covariates in a remittances model can be defined taking into consideration different segments of the migrant population. This theory explains international migration as an answer to the permanent demand for immigrant labor that is inherent to the economic structure of developed nations.

In our simulation model, we have taken into account all the covariates defined by the most relevant macroeconomic models. However, some of them have been evaluated in relative terms (differentials), because, for example, the propensity to migrate is determined by the relative distance between the global situation in the home country as compared to the situation in the host country (i.e. the differential of expected earnings explains why people decide to migrate from Africa to Europe and why there is no migration between countries with similar levels of earnings). The greater the difference, the more intensive the migration flows are.

Covariates that describe the socio-economic structure of the migrant population and define the final amount of remittances can be modeled in a computer-based macroeconomic system. Monte-Carlo simulation determines iteratively the input values according to the predefined socio-economic structure of the migrant population and, then, the multilevel fuzzy inference engine evaluates DR output values depending on the structure of the expert-based rule-bases. The total amount of remittances is finally determined and analyzed.

This paper is structured as follows: First, the simulation model is described in section two and remittances model is theoretically developed in section three. The fourth section introduces the structure of an approximation to the north-south remittances model used as an illustrative example. Some relevant results obtained using our expert-based simulation model are described in section five. Finally, a brief discussion of relevant issues concludes this paper.

2 THE SIMULATION MODEL

The simulation model is based on standard Monte-Carlo and, with respect to outputs, it has a steady-state behavior. As shown in Table 1, the model structure has three loops; the first one (steps 2 to 15) controls the number of simulations until a predefined error (Goldsman 2007) is reached (steps 12 to 14); the second evaluates the time interval (step 2 to 9) and, finally, the third manages the covariate calculation process when their values depend on fuzzy dependence relationships (DR) or algebraic functions (steps 5 to 8). For each specific simulation run (step 2) and year (step 3) in the time interval chosen, the calculation process continues until all the covariates are determined (steps 5 to 8).

2.1 Structure of the covariates

Covariate values are determined using three different procedures: (i) Monte-Carlo simulation (step 4, Table 1), (ii) the multilevel fuzzy inference engine that evaluates DR (step 6, Table 1) or, finally, (iii) resolving standard algebraic functions (step 7, Table 1). Random variables (step 4) are described by the corresponding statistical distributions based on expert knowledge. DR are described taking into consideration only one output and many inputs. Each *output=f(inputs)* function is a DR that groups many fuzzy rules which depend on the number of fuzzy membership functions (MF) chosen (García-Alonso and Pérez-Alcalá 2008). Rather than using complex rule-bases, a simplified way of representing expert knowledge is used to design and evaluate fuzzy rules automatically (García-Alonso 2008). This procedure can manage the exponential number of rules that the simulation model has to know to evaluate outputs (step 6, Table 1). The maximum number of rules that the system should be capable of managing, r, is an exponential function (Cordon et al. 2003) of the number of inputs m, membership functions p and, finally, the number of DR d in the form $r = dp^m$. Finally, when an algebraic function defines the value of a covariate, it is evaluated when the value of all its independent variables is known (step 7, Table 1).

Table 1: Model structure. (1)Number of simulations to carry out, (2)Number of years to be analyzed, (3)Dummy variable to determine when all covariate values have been calculated, and (4)Maximum admissible statistical error admissible.

Step	Description
1	Determination of membership function (MF) limits for all the inputs and outputs (all symmetric triangular and Z functions)
2	**For** *simulation=1* to *simulations*[1] **do**
3	**For** *year*=1 to *years*[2] **do**
4	Evaluation of the covariate values (primary inputs) using Monte-Carlo
5	**For** *stop*=False[3] **do**
6	Evaluation of the DR (outputs) using the multilevel fuzzy inference engine using and the MFs limits (step1)
7	Evaluation of the covariates (outputs) defined by algebraic functions
8	**End for** *stop*
9	**End for** *years*
10	Results are saved
11	Evaluation of the statistical error (procedure based on batches)
12	**If** *error*<=*errorlimit*[4]
13	**End for** *simulations*
14	**End if**
15	**End for** *simulations*

2.2 Dependence relationship structure

According to García-Alonso (2008), the structure of a DR has two sections. In the first one, general properties of its rules are described and, in the second, input characteristics are specified. Rule properties include: i) the DR type, that is a category, defined by system designers and comprehensible for experts, which describes how specific combinations of input MF identify the output MF in a fuzzy inference engine; ii) a probability for establishing when DR rules are instantiated; iii) the DR intensity, another category to describe the inner ambiguity of the rules in each specific DR; finally, iv) a minimum probability for rule fulfillment related to the intensity chosen.

On the other hand, each input is described by its weight w_i (i=1,2, …, m) and influence (positive or negative) on the output. Weights can be considered as the relative relevance of the inputs on the corresponding output and are chosen by the experts according to the situation under study. Once all the input MF are determined, MF_i (i=1,2, …, m), in a fuzzification process (Cox 2005) and taking into consideration both the rule and input characteristics, the MF of the output MF_o is determined by (García-Alonso 2008):

$$MF_o = round\left[\left(\sum_{i=1}^{m} w_i MF_i \Big/ \sum_{i=1}^{m} w_i\right) + Q + D\right] \tag{1}$$

Q being an integer chosen according to p ($\left|Q\right| \leq \left(p-1\right)/2$) and the DR type selected by the experts. D being the distortion, an integer that makes $1 \leq MF_o \leq p$ and shifts the original MF_o to the right or to the left depending on the intensity selected (step 6, Table 1). Once all the rules that correspond to each MF_i (i=1,2, …, m) combination without repetition are instantiated and evaluated to identify the corresponding MF_o s, the fuzzy inference engine uses the product-sum-gravity with superposition method (Cox 2005, García-Alonso 2008) to evaluate the final value for the output.

3 THE GENERAL REMITTANCES MODEL

Remittances which are received by a country in a specific year *y* are cash transfers transmitted by migrant workers to their families and communities back home (Van Doorn 2001). This definition has been translated into the following equation:

$$Tre_h = \sum_{j=1,i=1,k=1}^{m,n,2} (Wx_{ijkh} * Nem_{ijkh} * Rw_{ijkh}) + B_{kh} \tag{2}$$

which collects a classification of remittances based on migrant skills *i*, migrant categories *j* and types of ways of sending remittances *k* (*k*=1 formal and *k*=2 informal), *Tre* being the remittances, *Wx* being the wages abroad, *Nem* being the migrant population, *Rw* being the propensity to remit wages and, finally, *B* is the Brownian variable.

From a macroeconomic point of view, migrants can be classified into groups or collectives with very different socio-economic characteristics. Our model (1) distinguishes migrant collectives according to:

- Their skills (*i*=1, 2 and 3). According to Docquier and Marfouk (2005), there are three categories *i*=1 low-skilled (less than 8 years of schooling), *i*=2 medium-skilled (9 to 12 years of schooling) and *i*=3 high-skilled (13 years of schooling of more).
- Migrant categories (*j*=1 and 2). The International Monetary Fund (2008) identifies two categories *j*=1 workers abroad for more than one year and *j*=2 workers residing abroad for fewer than 12 months.

Following Borjas (2008),wages abroad *Wx* are the monetary units earned by migrants in the host country and can be estimated by the equation:

$$\log w = \phi X + \delta A + \alpha y + \beta C + \gamma \pi + \varepsilon \tag{3}$$

where *w* is the wage of migrants according to a vector of standardizing socioeconomic characteristics *X*, the worker's age at the year considered *A*, the number of years that migrant have lived in the host country *y*, the year of arrival in the host country C, a dummy variable to indicate if the observation was drawn from the one determined Census π and the error ε.

The model (3) can be generalized including a new variable, employability *Em*, and redefining the concepts included in Borjas' model:

$$Wx = f(w_{1ih} Sec_{ih}, w_{2ih} Yr_{ih}, w_{3ih} Em_{ih}) \tag{4}$$

w_{1ih}, w_{2ih}, and w_{3ih} being the weights of each variable and *Sec* including the socioeconomic characteristics of the environment (mainly the labor framework). This variable has been defined as a decreasing variable throughout time and with a positive influence on *Wx* (the better the socioeconomic conditions in the host country, the greater the migrant wages). *Yr* is the number of years in the host country, this variable also increases throughout time and has a positive influence on *Wx* (the longer the migrant stays, the greater the wages). Finally, employability *Em* encloses all the individual characteristics: schooling, experience, language proficiency, orientation, religion, etc., this variable also increases and has a positive influence. Generalized *Wx* (3) is then the output of a DR(4) based on expert knowledge.

Migrant population *Nem* is the number of people who have migrated and can be calculated as a percentage of the total population in the home country:

$$Nem = w_{4ij} Mp * w_5 Nt \tag{5}$$

where *Mp* is the propensity to migrate (%) and *Nt* is the total population in the home country.

$$Mp = f(w_{6ijh} Wd_{ijh}, w_{7ijh} Wu_{ijh}, w_{8ijh} In_{ijh}, w_{9ijh} Hsb_{ijh}, w_{10ijh} Es_{ijh}, w_{11ijh} Ps_{ijh}, w_{12ijh} Sn_{ijh}) \tag{6}$$

In this DR:

1. Differential wages *Wd* (Todaro 1989, Borjas 2008) between home and host countries. This variable decreases throughout time and has positive influence on *Mp*.

2. Differential unemployment rates *Wu* (Todaro 1989, Borjas 2008) between home and host countries. This variable decreases and has a positive influence on *Mp*.
3. Initial investment *In* (Todaro 1989, Borjas 2008). This variable encloses transport costs, language, culture, nationality requisites, etc and decreases and has a negative influence on *Mp*.
4. Host country benefits *Hs* compared to the home country. This variable includes general and institutional labor market conditions, i.e. unemployment insurance, retirement insurance, credit market, etc; characteristics will help people reduce their income risks (Massey 1998). This variable decreases and has a positive influence on *Mp*.
5. Host economic structure *Es* compared to the home country. This variable shows the potential growth difference between rich (host) and poor (home) countries. It is a decreasing variable with a positive influence on *Mp*.
6. Migrant personal characteristics *Ps* in the host country. This variable is affected by personal position, because is even when though other variables exist, people do not stay in the host country as they have family in the home country, or due to age, and other situations which normally prevent people from moving (A.Bartel 1979). Time variation has not been established for this variable. It has a positive influence on *Mp*.
7. Social networks *Sn*. The existence of people who have been born in the same country, have the same religion, language, culture, etc. can be a very relevant factor in the selection of a host country. This is a increasing variable and has a positive influence on *Mp* .

The three first variables are related to the decision to migrate according to an investment (cost-benefit) function. Variables 4, 5 and 6 are related to the decision of staying in the host country and, finally, variable number 7 influences both decisions.

The tendency being to remit wages *Rw*, the percentage of earnings which migrants send to their family in their home country can be formulated as a new DR:

$$Rw = f(w_{13ijh}Sk_{ijh}, w_{14ijh}Ag_{ijh}, w_{15ijh}Hmf_{ijh}, w_{16ijh}Hsf_{ijh}, w_{17ijh}Id_{ijh}, w_{18ijh}Tc_{ijh}, w_{19ijh}Xr_{ijh}, w_{20ijh}Sst_{ijh}, w_{21ijh}Md_{ijh}) \quad (7)$$

w_{13ijh}, … being the weights of each variable and:

- Skills *Sk*: this variable includes schooling years, academic level, experience and labor orientation of workers. It is an increasing variable throughout time and has a negative influence on *Rw*.
- Age *Ag*: the age of migrants. It is an increasing variable and has a negative influence on *Rw*. Older people remit less than younger people.
- Family in the home country *Hmf*: the size, social class, children, family income, etc. determine the amount of money sent back home. If migrants have a large young low-income family, they will probably send more money that in the opposite situation. For these reasons this variable is decreasing and has a positive influence on *Rw*.
- Family in host country *Hsf*: If migrants stay for a long time in the host country and create a family, then they will send back less money. This variable is an increasing one and has a negative influence on *Rw*.
- Interest rate differential *Id*: the difference between the interest rates in both the home and the host countries. This variable has been established without any time variation. It has a positive influence on *Rw*.
- Transmission costs *Tc*: the cost of sending money between countries. This variable is decreasing and has a negative influence on *Rw*.
- Exchange rate *Xr*: this variable has been defined without any time variation and has a negative influence on *Rw*.
- Social Stability *Sst*: this variable shows if the home country is politically and socially stable. This variable does not have any time variation and has a positive influence on *Rw*.
- Migration duration *Md*: this variable encloses the migration plan, in other words, if the migrant intends to stay a short or long time in the host country. This variable has a constant value and has a negative influence on *Rw*.

In conclusion, the remittance model has three fuzzy DR based on expert knowledge and two algebraic functions.

4 AN APPROXIMATION TO THE NORTH-SOUTH REMITTANCES MODEL

In order to check our remittances model, we have firstly selected only one factor from (1) $Tre = Wx * Nem * Rw$ but the number and characteristics of covariates and DR are identical to the general model. The characteristics selected for the inputs (statistical distributions, weights and influence on outputs) describe a specific socio-economic situation to be studied (Table 2). According to the north-south remittance model selected, uniform statistical distributions [left limit, right limit] were chosen for primary inputs (those that are only inputs). The values of these primary inputs are determined in step 4 (Table 1) before other covariates which are calculated using the fuzzy inference engine-(4), (6) and (7)- or the appropriate algebraic function-(1) and (5) following a hierarchical structure (Figure 1). Output and secondary input ranges (Table 2) are only expert based expectations used to analyze the results obtained.

The macro-economic framework defined by covariate characteristics is:

- Migrants are low-medium skilled and young, have a young extensive low income family in the country of origin and intend to stay between 10 and 20 years in the host country; finally, remit a high percentage of their wages.
- The host country has a high demand for low-medium migrant workers. There are well established social networks and, finally, the socio-economic differences in comparison with the home country of migrants are very relevant.
- The home country has medium-high social stability.

Table 2 :Covariate description. (1) Expert-based range to be analyzed. (2) Monetary units.

	Left limit	Right limit	Unit	Type
Tre	3,000	15,000	MU(2) (millions)	Output in (1)
Wx	7,500	18,000	MU per person	Output in (4)/Input in (1)
Nem	1	4	MU (millions)	Output in (5)/Input in (1)
Rw	30	60	Percentage	Output in (7)/Input in (1)
Sec	50	80	Scale [0,100]	Input in (4)
Yr	0	30	Years	Input in (4)
Em	30	40	Scale [0,100]	Input in (4)
Nt	40	60	MU (millions)	Input in (5)
Mp	1	4	Percentage	Output in (6)/Input in (5)
Wd	2	4	Number of times	Input in (6)
Wu	2	5	Number of times	Input in (6)
In	40	60	Scale [0,100]	Input in (6)
Hsb	40	60	Scale [0,100]	Input in (6)
Es	60	80	Scale [0,100]	Input in (6)
Ps	60	80	Scale [0,100]	Input in (6)
Sn	50	80	Scale [0,100]	Input in (6)
Sk	20	50	Scale [0,100]	Input in (7)
Ag	18	35	Years	Input in (7)
Hmf	50	80	Scale [0,100]	Input in (7)
Hsf	0	20	Scale [0,100]	Input in (7)
Id	0	5	Number of times	Input in (7)
Tc	20	50	Scale [0,100]	Input in (7)
Xr	2	5	Number of times	Input in (7)
Sst	40	80	Scale [0,100]	Input in (7)
Md	10	20	Years	Input in (7)

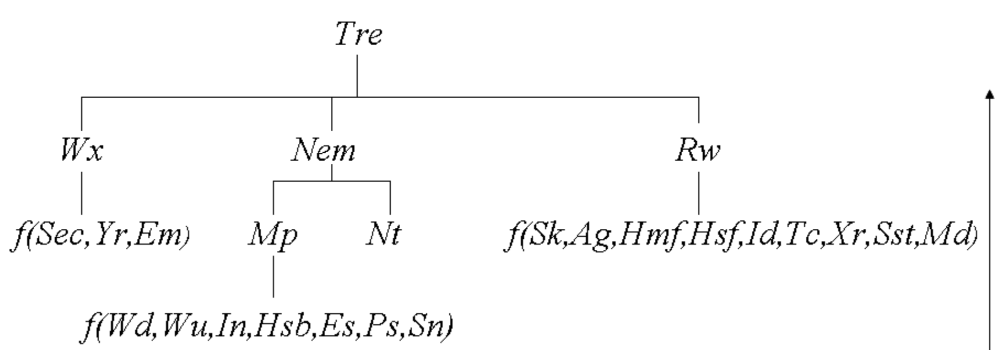

Figure 1: Hierarchical relationships between covariates.

According to the macro-economic profile described above, the expert-based relative relevance or weights of primary inputs in DR (4), (6) and (7) are shown in Table 3.

Table 3: Weights of primary inputs

Variable	Weight	DR
Skills *Sk*	0.04	7
Age *Ag*	0.06	7
Family in home country *Hmf*	0.04	7
Family in host country *Hsf*	0.04	7
Interest rate differential *Id*	0.02	7
Transmission costs *Tc*	0.12	7
Exchange rate *Xr*	0.03	7
Social Stability *Sst*	0.05	7
Migration duration *Md*	0.60	7
Wages differential *Wd*	0.25	6
Unemployment differential *Wu*	0.18	6
Initial investment *In*	0.15	6
Host country benefit *Hsb*	0.10	6
Economic structure *Es*	0.12	6
Personal position *Ps*	0.05	6
Networks *Sn*	0.15	6
Socioeconomic characteristic *Sec*	0.20	4
Number of years in the host country *Yr*	0.10	4
Employability *Em*	0.70	4

In DR 6 the wages differential *Wd* has the greatest weight (0.25), followed by the unemployment differential *Wu* (0.18), the initial investment *In* and the existence of social networks *Sn* (0.15 both) because the difference in labor conditions between countries are decisive. Concerning DR 7 among all the covariates that influence the output *Rw*, migration duration *Md* is the most relevant. Finally, in DR 4 the employability *Em* has the greatest weight (0.7), while the number of years *Yr* in the host country has a weight of 0.2 and socioeconomic characteristic *Sec* only 0.1. In other words, the job of the migrant and, therefore, his wages depend mainly on his employability (personal conditions).

5 RESULTS

As mentioned above with respect to outputs, the north- south remittances model has a steady-state behavior. The evaluation of the statistical error was dynamically designed by making batches of 500 simulations for 200 years. The simulation process stops when the statistical error of *Tre* was lower than 2.5% (α=0.05); in our proposed model 5,000 simulations (10 batches) are enough. All DR types were neutral (García-Alonso 2008), the probability of DR instantiation was 0.95, no intensity was considered and the minimum probability of rule fulfillment was 0.25.The number of MF which was chosen for all inputs and outputs considered in our three DR -(4), (6) and (7)- was 31. DR (4) has 3 inputs, DR (6) has 7 inputs and DR (7) has 9 inputs. Taking into account these values, the number of rules that the simulation model had to design and evaluate was greater than $2.64\ 10^{13}$.

The evolution throughout the time span of primary input values was absolutely as expected (Figure 2). Both the mean and median statistics were very close and the standard deviation (SD) showed a very regular pattern. The fuzzy inference engine gave us the possibility of relating covariates based on expert knowledge. The propensity to migrate in a population *Mp* is the output in DR (6) figure 3 shows its evolution during the first 100 years. From a macroeconomic point of view, the behavior of *Mp* is absolutely logical, during the first 40 years –first period- *Mp* was relatively higher and showed an irregular pattern because the host country attracted migrants strongly. In a second period –year 40 to year 80- *Mp* showed a regular pattern that indicates that the propensity to migrate is relatively constant. Finally, *Mp* showed an irregular and decreasing profile since the 80's –third period. The phenomenon in the third period matches with many real-life examples and it is due to administrative regulations, a decrease in the attractiveness of the host country, an increase in the socio-economic structure of the home country and so on. On the other hand, *Mp* values are not included within the expected range [1, 4] (Table 2); this deviation is not so high and is the result of inference engine behavior in the first period (distribution of the symmetric MF).

Results obtained from DR (7) –propensity to remit wages, *Rw*- and (4) –evolution of wages abroad, *Wx*- showed regular patterns (Figures 4 and 5), the second being a little bit more irregular because of economic cycles (expansive or not). Again, means and median values are very close and SD distributions are relatively uniform. According to this, the expectations of the model are: migrants will maintain their remittances within a constant range in an environment with relative variations on their wages in the host countries. This pattern is admissible in a north-south remittances model.

Finally, remittance *Tre* means showed (Figure 6) an increasing and sometimes irregular pattern. The simulation model showed that the amount of money received in the home country, on average, is within a range of[6000,9000] million. The increase the migrant population stock, related to an increase in the home country, causes the *Tre* tendency. Migrants send a, more or less identical amount of money, but the increase in their number provokes a more favorable situation in the country of origin.

Taking into account that the host country is very attractive and that the migrant characteristics are similar during the period of time analyzed, *Tre* are very relevant in the economy of the home country. Variations in the subjective attractiveness of the host country for potential migrants, due to the development of the home country during the period or to a decrease in both the relative wage or the unemployment ratios, may change the pattern of migration. However, remittances are still a very important source of income in the home country.

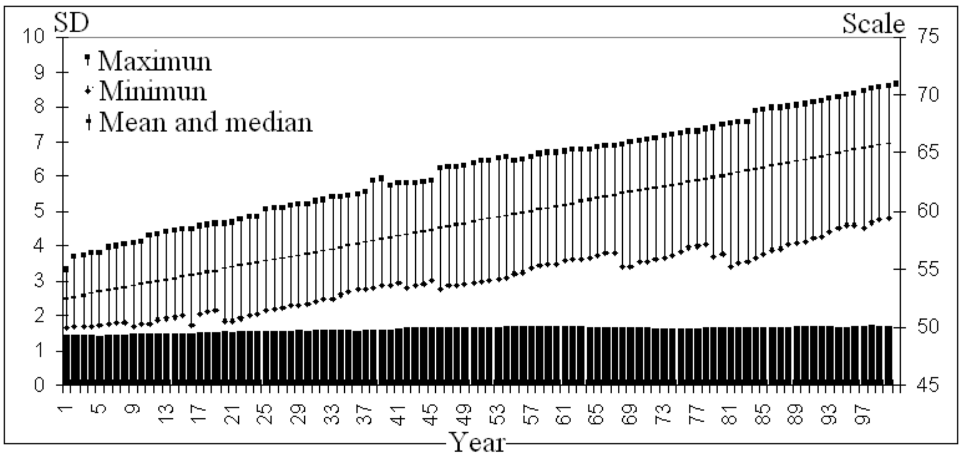

Figure 2: Evolution of networks *Sn* in 100 years.

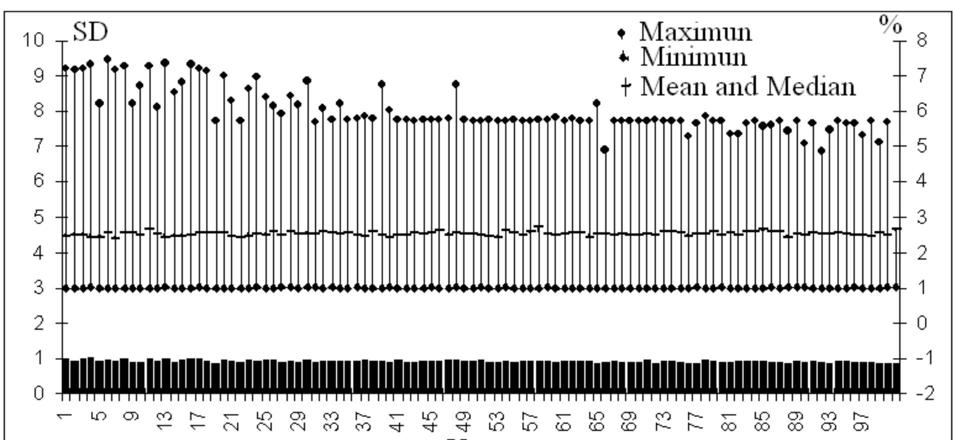

Figure 3: Evolution of propensity to migrate *Mp* in 100 years.

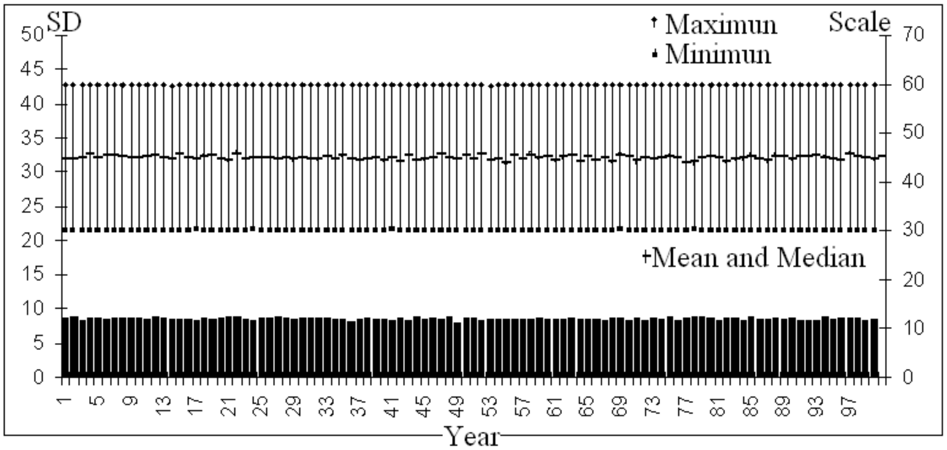

Figure 4: Evolution of propensity to remit wages *Rw* in 100 years.

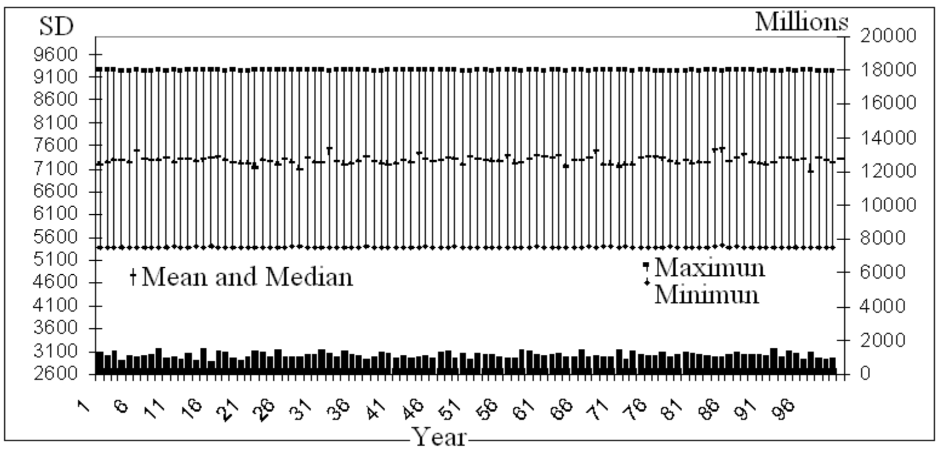

Figure 5: Evolution of wages abroad *Wx* in 100 years.

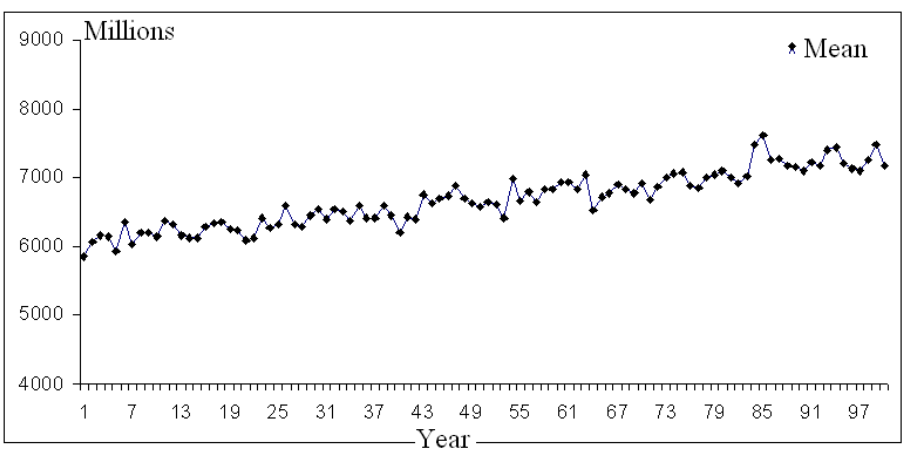

Figure 6: Evolution of remittances *Tre* in 100 years.

6 CONCLUSIONS

The simulation model empowered by the multilevel fuzzy inference engine which has been proposed in this paper has been demonstrated to be very efficient in managing a very large fuzzy macroeconomic system. When expert knowledge can describe complex dependence relationships among covariates, a new procedure (García-Alonso 2008) that formalize it in a very simple way has been improved and tested. This method offers the possibility of understanding real relationships that cannot be formalized in a standard way using statistics and/or operational models. According to expert knowledge that has been explicit, migration, relative wages and, finally, remittances were evaluated in a specific socio-economic framework: the north-south remittances models.

In this paper, the evolution of the socio-economic covariates which determine remittances has been modeled according to a Monte-Carlo simulation model. This model was used to determine values of primary covariates (inputs) which describe the socio-economic framework and relevant migrant characteristics. A multilevel fuzzy inference engine was designed to evaluate DR which relates inputs to only one output (that can then be an input in another DR or in an algebraic function) in a fuzzy way. This procedure includes expert knowledge in the simulation model and provides a methodology to manage a huge amount of fuzzy rules.

A careful statistical distribution selection for primary inputs are, first necessary to specify the socio-economic framework and, secondly, to make the model results interpretable. On the other hand, input weights are also very relevant because they translate the expert's opinion about input relevance to the output from the computer-based system. Weights can be used to analyze the influence of corresponding inputs on to a specific output according to different real-life or theoretical situations. Changes statistical distributions structure of each input or in their weights result in a new model. Higher precision in both the structure and in the weights could fit the model to a real situation. Finally, a DR instantiation probability of 0.95 is high enough to show high confidence in the fuzzy rules and, therefore, in the macroeconomic model they represent.

The model presented is relevant in three ways: first, it includes all the relevant covariates that influence migration and remittance flows between countries with different levels of development; secondly, it mixes these covariates in a general form, taking into account expert knowledge that can be manipulated to fit specific situations; and, thirdly, it permits evaluate different models of migrations and remittances to be evaluated. Obviously, the model and its results are coherent with main labor migration theories. This fact confirms both the existence of the DR designed using expert knowledge and the weights selected for each primary input. The north-south model can then be used to analyze real-life situations without evaluating complex algebraic functions using statistical regression.

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