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The homeostatic theory in the measurement of life satisfaction in Mexico through a fuzzy inference system

La teoría homeostática presente en la medición de la satisfacción con la vida en México a través de un sistema de inferencia difuso

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Abstract

It has been seen that the objective economic measures as the GDP, do not faithfully reflect the welfare of the society. Therefore, other subjective measurements have been used such as the life satisfaction, this being the main indicator for subjective well-being that is examined through self-assessment, that the person makes about their own life. This has given place to the homeostatic theory. This theory indicates that the person evaluates their level of life satisfaction in a positive way and in the most general sense. The response that the person expresses reflects the level in which the homeostatic system operates, as a mechanism of self-regulation, in order to adapt to variations from the outside. The objective of the current research is to show the presence of such system when measuring life satisfaction through the fuzzy inference method. To achieve this measurement, a part of the published data on subjective well-being, generated by the BIARE Basic survey managed by the National Institute of Statistics and Geography (NISG) is used. The numeric result of this process shows a positive and stable behavior, illustrating with this the principle of homeostasis that rules this theory.

JEL Code: C65, I31, M31
Keywords: subjetive wellbeing; life satisfaction; homeostatic system; fuzzy inference system; fuzzy logic

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Resumen

Se ha visto que las medidas económicas objetivas como el PIB no reflejan fielmente el bienestar de la sociedad. Por ello, se han utilizado otras mediciones subjetivas como la satisfacción con la vida, siendo éste el indicador principal del bienestar subjetivo que se examina por medio de la autoevaluación que hace la propia persona sobre su vida. Lo anterior ha dado lugar a la teoría homeostática. Esta teoría indica que la persona evalúa su nivel de satisfacción con su vida de forma positiva y en el sentido más general. La respuesta que la persona manifiesta, refleja el nivel en el que opera el sistema homeostático como mecanismo de autorregulación para adaptarse ante variaciones del exterior. El objetivo de la presente investigación es mostrar la presencia de dicho sistema al medir la satisfacción con la vida a través de un método de inferencia difuso. Para lograr tal medición, se utiliza una parte de los datos publicados referentes al bienestar subjetivo que genera la encuesta BIARE Básico, gestionada por el Instituto Nacional de Estadística y Geografía (INEGI). Los valores numéricos de este proceso muestran un comportamiento estable y positivo, ilustrando con esto el principio de la homeostasis que rige dicha teoría

Código JEL: C65, I31, M31
Palabras clave: subjetivo; satisfacción con la vida; sistema homeostático; sistema de inferencia difuso; lógica difusa

Introduction

In recent decades, it has been demonstrated that measuring the development of society through objective economic indicators such as Gross Domestic Product (GDP) has not been able to reflect the well-being of society fully. Therefore, other types of subjective indicators have been developed that relate to aspects closer to personal life, such as happiness or consumer trust (Veenhoven, 2007, 2009). One of the aspects studied for some decades in scientific articles is subjective well-being. This term concerns the process of perception of life according to the subjects themselves, which is why life satisfaction is studied as an important indicator of subjective well-being (Arita, 2005).

When measuring life satisfaction through a person's self-assessment of their life in general or through different aspects such as personal achievements, health, work, and many more, their evaluation has a cognitive origin (Diener et al., 1998).

The literature has shown that a dominant way to measure satisfaction is to break down this construct into different life domains (or satisfaction domains) such as health, work, or family, among others (Cummins, 2005; Rojas, 2007a, 2007b; Rojas & Elizondo-Lara, 2012; Veenhoven, 1996). The number and definition of these domains are generally arbitrary as long as they retain parsimony, meaning, and utility (Rojas, 2007a, 2007b). This model has served as a basis for many works to study and understand the complex relation between life domains and life satisfaction.

Cummins and later writers borrowed the term 'homeostasis' from biology to develop what is known as the homeostatic theory of well-being (Cummins, 2000; Cummins et al., 2003; Cummins, 2016).

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This theory indicates that the response that the person manifests when assessing their own life satisfaction reflects the general state of subjective well-being and is the level at which the homeostatic system operates as a self-regulatory mechanism to maintain a balance in the face of variations from the outside. Cummins et al. (2003) state that “the homeostatic system has the role of creating a positive sense of well-being that is non-specific and highly personalized” (p.163).

Taking this theory as a starting point, this paper aims to ‘show the presence of a homeostatic system in measuring life satisfaction in Mexico through a fuzzy inference system.’ The contribution of this paper is to provide further empirical evidence for this theory through a different perspective.

To achieve the above, the measurements of the 12 life domains collected by the Basic BIARE survey conducted by the National Institute of Statistics and Geography (INEGI; Spanish: Instituto Nacional de Estadística y Geografía) are taken. With these data, a reduction to 4 new life domains is achieved through a factor analysis, which are used as input variables to the Fuzzy Inference System (FIS). With the fuzzy rules that allow the FIS to operate, a new measurement of life satisfaction in general is obtained. When analyzing the values of this calculation, the existence of a homeostatic system is revealed by having measurements within a very narrow and positive range, estimating a homeostatic point, which is the value where the system operates as a self-regulating mechanism to maintain equilibrium and stability in the face of external changes (Cummins et al., 2003). This provides further empirical evidence for this theory.

This paper is divided into the following sections. The first section presents the theoretical framework containing the most relevant concepts and findings in the literature review on subjective well-being, life satisfaction, and the measurement of the latter construct. The second section shows the methodology for designing the FIS, showing a conceptual framework on fuzzy logic, incorporating the terms fuzzy set and linguistic variable. The third section presents the application of the methodology to obtain the measurement of life satisfaction in general in Mexico. Subsequently, the results are presented, and some conclusions of interest are included at the end of the paper.

Theoretical framework

Subjective well-being and its elements

The importance of Gross Domestic Product (GDP) since the 1960s and 1970s as an indicator of societal development has disappointed governments and researchers. “None of us doubt that economic data have admirable qualities; the question is, how well do they represent the national quality of life?”(Campbell, 1976, p.117).

Campbell (1976) indicates that between 1957 and 1972, while economic and social indicators rose rapidly, the proportion of the population that described itself as very happy declined steadily. Easterlin (1974) conducted several studies to analyze the relation between income and happiness and confirmed that higher incomes are not associated with higher happiness levels. Thus, in the 1960s and 1970s in the United States and Europe, the Social Indicators Movement arose as a reaction to the excessive use of GDP to measure the well-being and development of society (Angner, 2011; Campbell, 1976; Castellanos, 2012; Veenhoven, 1994).

Veenhoven (1996, 2007) indicates two approaches to social indicator research: the objective and the subjective. The former measures hard data such as income in national currency or housing in square meters. The criticism of this approach made by Jaramillo (2016) lies in capturing information from the 'top down' where experts define what well-being consists of and, based on this, evaluate people. The second approach to social indicators cited by Veenhoven works with data that are by nature personal and subjective. Jaramillo (2016) indicates that this approach goes from the 'bottom up': the information must come from the people as the concepts are close to them, such as trust, satisfaction, happiness, and well-being, among other indicators.

This paper is limited to the study of subjective well-being. Ed Diener is one of the most representative authors who has studied this topic. Diener (1994a) points out that the area of study of subjective well-being has three distinctive characteristics: the first is the subjective nature of the information, as its origin lies in the experience of each individual. The second includes positive aspects since this is not only about the absence of negative factors. Finally, the third includes a global assessment or judgment of all aspects of a person's life.

Subjective well-being is measured by a person's self-evaluative responses to their own life, either in terms of life satisfaction or affection (Diener et al., 1998). Lyubomirsky et al. (2006) indicated that the broadest accepted definition proposed by Diener et al. of subjective well-being results from the combination of life satisfaction and a balance of positive feelings over negative ones. In other words, it is a cognitive-affective evaluation of life whose main indicators are life satisfaction and happiness (Arita, 2005).

The cognitive component is present mainly in life satisfaction when people are asked how much they like their lives. The affective or emotional component is present in happiness, and Veenhoven (1991) defines it as "the degree to which an individual judges favorably the overall quality of their life" (p.2). Diener (1994b) indicates that "Affection includes facial, physiological, motivational, behavioral, and cognitive elements. Self-reports basically assess the cognitive component of affection and, therefore, are unlikely to provide a complete picture of respondents' emotional lives" (p.103).

Consequently, Villatoro (2012) states that "subjective well-being is a multidimensional concept, which includes different assessments that people make about their lives, the things that happen to them, and the circumstances in which they live" (p.24). Due to this complexity, the present work is limited to studying life satisfaction (cognitive component).

Life satisfaction and the homeostatic theory of well-being

As mentioned, life satisfaction is a component of something larger, which is subjective well-being. Veenhoven (2009) establishes 4 types of satisfaction that can be described in a 2x2 matrix. On the vertical axis, there are 2 possibilities: aspect of life vs. life as a whole. On the horizontal axis, there are two scenarios: transient vs. lasting. Table 1 illustrates these 4 types of satisfaction mentioned by the author:

Table 1
The 4 types of satisfaction

	Transient	Lasting
Aspect of life	Pleasure	Satisfaction with an aspect (life domain)
Life as a whole	Summit experience	Satisfaction as a whole

Source: adapted from Veenhoven (2009)

This research only considers the two types of satisfaction corresponding to the upper and lower right quadrants of Table 1. They are satisfaction in some aspects of life such as marriage, work, and family, among many others called 'life domains' or 'satisfaction domains,' and satisfaction as a whole.

Veenhoven (1994) notes that a question frequently discussed is whether life satisfaction can continuously grow. In this regard, the author indicates that two theories show this is not possible. The first theory indicates that life satisfaction is relative, i.e., if living conditions improve, satisfaction increases, but only temporarily since the standards of comparison undergo an adjustment. The second theory indicates that life satisfaction is an immutable attribute, i.e., people are either satisfied or dissatisfied regardless of their circumstances.

While life satisfaction is not ideal in all respects, it is reasonably good for most people. This process of adaptation or adjustment experienced by an individual is explained by the homeostatic theory of well-being, which is part of the scientific legacy of Alex Michalos (Cummins, 2016). This theory is so called because of the presence of two elements: the first is the term homeostasis, whose origin is found in biology and ecology and is applied to the topic of well-being.

The physiologist Walter Bradford Cannon coined the word in 1930 to explain that living organisms can maintain a steady state even when beset by conditions that tend to disturb them (Cooper, 2008). Cannon studies the living organism as a whole whose parts are closely related. The second element arises from the interest in explaining or understanding the reason for the high degree of stability of subjective well-being data (Cummins, 2016). The small range of values where the person's assessment falls is the level at which the homeostatic system operates, unless the objective conditions are unfavorable and break the homeostasis (Cummins, 2000; Cummins et al., 2003).

Cummins et al. (2003) indicate that: "the homeostatic system has the role of creating a positive sense of well-being that is non-specific and highly personalized" (p.163). That is to say, each person's life assessment is in the most general sense and is individual. With the single question: How satisfied are you with your life as a whole? (Andrews & Withey, 1976, as cited in Diener, 1994b), it is possible to estimate the homeostatic point, which is the level at which the system operates as a self-regulating mechanism to maintain equilibrium and stability in the face of external changes (Cummins et al., 2003). Therefore, life satisfaction in general is the main indicator of this theory and reflects the general state of subjective well-being.

Due to its highly abstract nature, the proposal to use a single question as an indicator of subjective well-being leaves out other life aspects that can contribute positively or negatively to well-being. To compensate for the drawback of this approach, it is useful to assess life satisfaction using life domains or satisfaction domains (Cummins et al., 2003). These domains are assessed separately, although their number and definition are completely arbitrary and must preserve parsimony, meaning, and usefulness (Rojas, 2007a, 2007b).

Studies have shown that while the assessment of life satisfaction as a whole is close to the homeostatic point, this is not true for the assessment of satisfaction domains, which may be above or below that point (Arita, 2005; Cummins et al., 2003; Jiménez, 2010). Cummins et al. have identified proximal-distal dimensions that relate to the satisfaction domains. Thus, self-evaluations of satisfaction through life domains close to the person are valued by factors as simple as the need to protect the 'self' from negative appraisals, which results in higher figures at the homeostatic point and low sensitivity (Cummins et al., 2003).

As life domains are more distant from the person—such as friends, society, community, or country—the ratings fall below the homeostatic point with greater sensitivity (Cummins et al., 2003). Jiménez (2010) thus indicates that since assessing the level of satisfaction through the domains is directed to more specific aspects of life, the homeostatic effect on the response is diluted.

Given this general approach to homeostatic theory, it is possible to understand this paper's aim: 'to show the presence of a homeostatic system in the measurement of life satisfaction in Mexico through a Fuzzy Inference System.' Therefore, to conclude the theoretical framework, an outline of the data capture and the classical approach to measure life satisfaction are presented, which will mark some differences with the methodology proposed in the present work.

Measuring life satisfaction

In the 1960s, life satisfaction became popular in survey research (Veenhoven, 1994). The same author indicates that since it is difficult to infer from external behaviors, asking is the only alternative. Diener (1994b) indicates that the evaluative approach consists of having respondents make a cognitive reflection of their lives. This is done through surveys, where the person is asked to assess their general life satisfaction or certain aspects of their life.

Andrews and Withney (1976, as cited in Diener, 1994b) proposed a Likert scale with 7 alternatives as a measurement instrument in its first applications. Nonetheless, many scales have been studied in research works to analyze reliability and validity, in addition to other elements such as the number of items or questions, phrasing in the latter, order of presentation, and size of the measurement scale (Diener et al., 1985; Diener et al., 2013; Liaudat, 2012; Schmidt et al., 2015; Veenhoven, 1996; Villatoro, 2012). Villatoro (2012) indicates as a conclusion that data collection instruments to capture perceptions, such as life satisfaction, despite their limitations, possess acceptable levels of validity and reliability to be monitored when applied systematically.

The vast majority of definitions, models, and instruments for measuring life satisfaction have considered the decomposition of this construct into different life domains. Nevertheless, the characterization of such domains is uncertain (Cummins, 2005). Veenhoven (2009) indicates that a person can be dissatisfied in one domain and satisfied with life in general or vice versa. Despite these drawbacks, measuring life satisfaction in general from life domains has been the dominant paradigm in many works. Therefore, a good part of the methods for its measurement has been based on regression models in their different forms (Lagarda et al., 2022; Rojas, 2007a, 2007b; Rojas & Elizondo-Lara, 2012; Salazar et al., 2021; Van Praag et al., 2003).

Following this review of the literature on the subject and especially taking homeostatic theory as a starting point, the following section explains the methodology proposed to have a different perspective in calculating this construct.

Methodology

To show the methodology to measure life satisfaction using a fuzzy inference system (FIS), this paper presents a conceptual framework necessary to understand the functioning of such systems.

An approach to fuzzy logic

Professor Lotfi A. Zadeh of the University of California published the first work on fuzzy logic in 1965 under the title 'Fuzzy Sets' in the journal Information and Control. In that journal, Professor Zadeh reported the first results on the subject (D'Negri & De Vito, 2006).

Fuzzy logic can be understood as an extension of classical logic where the latter accepts only one of the two values for any statement: false or true. In classical set theory, an element either belongs or does not belong to the set. Conversely, fuzzy logic, based on the notion of a set, establishes that every element always belongs to the set to a certain degree, measured within a continuum between zero and one (Zadeh, 1965). "Thus, fuzzy logic is a type of non-classical logic that allows multiple values" (Enciso et al., 2013, p.74).

Furthermore, fuzzy logic allows values to be assigned to linguistic variables such as tall people, adult people, or healthy people. This is one of the main differences with classical logic. The term fuzzy refers to situations of vagueness, uncertainty, and lack of precision, among other meanings. Some basic components of fuzzy logic are presented below.

Introduction to fuzzy sets and linguistic variables

It is necessary to clarify the notion of fuzzy set and linguistic variable to understand the proposed FIS better. Zadeh (1965), a pioneer of this new way of thinking, established the principle that a person or object always belongs to a set by assigning it a certain degree of membership.

Figure 1 shows the fuzzy set 'healthy people' as an example. If the individual responds on a scale of 0 to 10 (where 0 is totally dissatisfied and 10 is totally satisfied with their health), as they respond with values approaching 10, they will have an increasing membership level in that group. Conversely, as they respond with values approaching 0, they will have a lower membership level in that group. The membership function linked to the fuzzy set determines the degree of membership.

Figure 1. Fuzzy set: healthy people
Source: created by the author

Cruz and Alarcón (2017) indicate that "the commonly used membership functions are the triangular, trapezoidal, Gaussian, and generalized Bell's function" (p.128).

As in traditional set theory, fuzzy sets also possess the operations of union, intersection, and complement, and the associative, commutative, distributive, idempotent, involution, and transitive laws, and Morgan's laws. Using these operations, laws, and modifiers such as 'much,' 'more,' 'less,' 'near,' and 'some,' among others, a considerable number of linguistic expressions can be achieved (González, 2015).

Zadeh (1975) indicates that using words or phrases in linguistic variables facilitates the ability of human beings to reach useful conclusions starting from information that is imprecise, incomplete, or with a certain degree of uncertainty, which provides an important basis for the so-called approximate reasoning explained below.

Linguistic variables are symbolized employing fuzzy sets, taking as reference a numerical interval as the natural domain of the variable in question. Each fuzzy set must be associated with a label or linguistic term. In precise terms, Zadeh (1975) proposes that:

A linguistic variable is characterized by a quintuple (V, T(V), X, G, M) in which:

V = is the name of the variable

T(V) = is the set of labels or linguistic terms for the variable V

X = is the universe of discourse of the variable V

G = is the grammar rule for generating T(V) labels

M = is a semantic rule that associates each linguistic term with its meaning (p.199)

Figure 2 shows an example of a linguistic variable with its constituent elements:

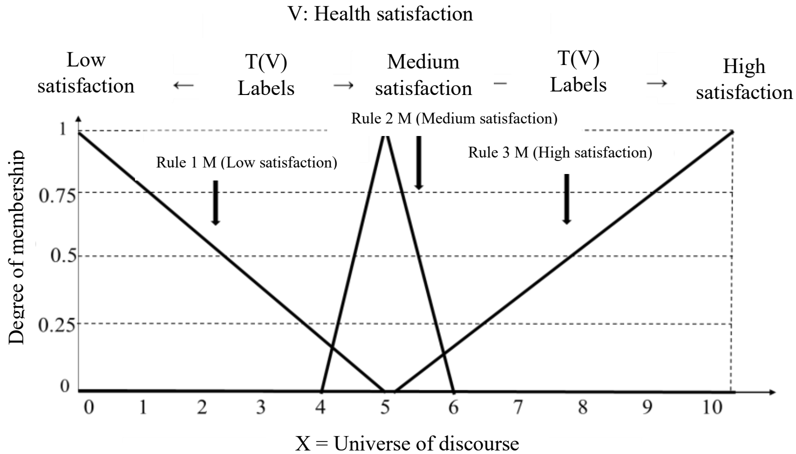

Figure 2. Linguistic variable 'health satisfaction'
Source: created by the author

Configuration of a Fuzzy Inference System (FIS)

Enciso et al. (2013) indicate that a FIS: "is a method applied for the interpretation of subjective assessments; it incorporates the knowledge of one or several subjects who have extensive experience in a given topic and are therefore considered experts" (p.74). Flores and García (2013) indicate that the FIS: "is designed based on the non-linear correspondence between one or several input variables and an output variable" (p.236).

To configure a FIS, the following three stages must be developed (Enciso et al., 2013; Martínez et al., 2020; Muñoz et al., 2017; Peña et al., 2021).

Stage 1: Fuzzification. It defines the system's linguistic input and output variables necessary to reach the desired result. This includes the determination of the membership functions for each label.

Stage 2: Fuzzy Rules. Employing a set of rules of the type IF<precedent>THEN<consequent>, the bridge between the input variables and the output variable of the system is established (Medina, 2006). Such rules, together with some inference mechanism such as that of Ebrahim Mamdani in 1975 or in 1985 of Takagi-Sugeno-Kang (TSK) (December, 2017) and logical operators such as "OR" with the T-conorm (maximum $a \vee b$) or "AND" with the T-norm (minimum $a \wedge b$), including the complement operator ($\bar{a}$) (Kaufmann & Gil Aluja, 1993) allow the fuzzy system to operate.

Medina (2006) indicates that: "approximate reasoning is an inference procedure used to derive the conclusions from a set of fuzzy <if-then> rules and the input data to the system by applying Max-Min composition relations" (p.205).

Stage 3: Defuzzification. It consists of the transformation of the fuzzy outputs of the system to numerical or crisp values located in the universe of discourse of the output variable.

Figure 3 shows a fuzzy inference system.

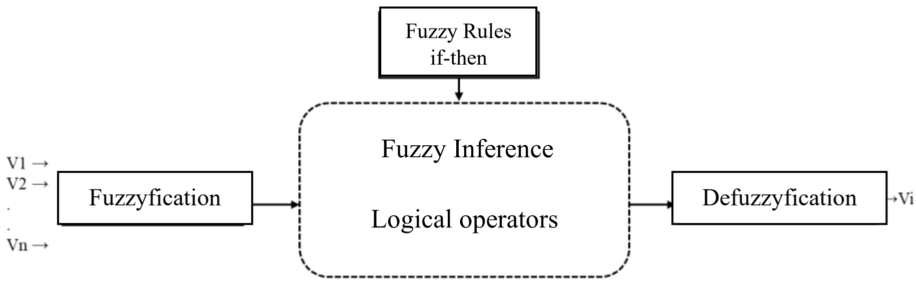

Figure 3. Fuzzy inference system
Source: created by the author with adaptations from various authors

Methodology application; Measuring life satisfaction

For the construction of the FIS to obtain a measure of life satisfaction and verify the presence of a homeostatic system with this new perspective, the origin of the data is shown below.

Origin of the data

Mexico is a member of the Organization for Economic Cooperation and Development (OECD). This organization has recommended to its members to capture unconventional statistical information such as subjective well-being and therefore one of its main indicators: life satisfaction.

Under the line marked by the OECD to capture information regarding subjective well-being, in Mexico, the INEGI has conducted since 2013 a quarterly questionnaire incorporated in the National Survey on Consumer Confidence (ENCO; Spanish: Encuesta Nacional Sobre Confianza del Consumidor) under the name Self-Reported Well-being Module (BIARE; Spanish: Bienestar Autorreportado), where the contraction Basic BIARE (INEGI, 2013) has been adopted to refer to said section.

The Basic BIARE questionnaire comprises several items that integrate subjective well-being. Notwithstanding, this study will only refer to two items related to life satisfaction whose objectives are: item 1. “To capture people’s satisfaction with their life in general” (INEGI, 2013, p.11) and item 5. “To capture people’s satisfaction with certain specific aspects called satisfaction domains” (INEGI, 2013, p.19). In both cases, responses are given with some value in [0, 10], where 0 means ‘totally dissatisfied’ to 10, ‘totally satisfied.’

To carry out the FIS, the data originated only in item 5, where 12 satisfaction domains are established, each requiring a value located in [0, 10]. Table 2 in the following section shows the questions that make up this item. The questionnaire is administered to a person who is 18 years of age or older, selected in one of the 2 336 dwellings in the sample. A limitation is that the sample only represents the urban population as a whole (INEGI, 2013).

Since the literature indicates that the number of satisfaction domains is arbitrary as long as it retains meaning and utility (Rojas, 2007a, 2007b), it is proposed to reduce the 12 domains of the BIARE Basic survey to a smaller number to simplify the FIS input variables.

Reduction of satisfaction domains of the basic BIARE survey

The domains were reduced through a factor analysis with SPSS software. A KMO=0.874 and a percentage of the variability of the accumulated information of 72.4% were obtained. Taking these figures as acceptable, the 12 domains of the basic BIARE survey have been abbreviated to 5 new life domains. This exercise has taken data from the July 2013 quarterly survey through January 2022.

Table 2 shows the questions of item 5 on the 12 life domains, the 5 new domains, and at the end, the correlations of the latter with life satisfaction in general of item 1 of the Basic BIARE questionnaire in the same period. It is observed that V_5, not being statistically significant, does not have a causal relation with life satisfaction; therefore, this variable is eliminated from the FIS.

Table 2
Questions from item 5 and grouping in the new variables

			Correlations with item 1		
Question 1	How satisfied are you with your standard of living?	V1 = Happiness satisfaction	0.842	Sig.	0.000
Question 3	How satisfied are you with your accomplishments in life?				
Question 4	How satisfied are you with your personal relationships?				
Question 5	How satisfied are you with your future prospects?				
Question 6	How satisfied are you with the available time to do what you enjoy?				
Question 8	How satisfied are you with your main activity (work, household chores, study, care for or assisting a family member)?				
Question 2	How satisfied are you with your health?	V2 = Health satisfaction	0.817	Sig.	0.000
Question 9	How satisfied are you with your home?		0.817	Sig.	0.000

Question 10	How satisfied are you with your neighborhood?	V3 = Community satisfaction			
Question 11	How satisfied are you with your city?	V4 = Homeland satisfaction	0.356	Sig.	0.042
Question 12	How satisfied are you with this country?				
Question 7	How satisfied are you with citizen security?	V5 = Citizen security satisfaction	0.149	Sig.	0.409

Source: created by the author

FIS to measure life satisfaction from new life domains

Figure 4 presents the fuzzy inference system with the 4 life domains as input variables, 16 fuzzy rules tested through the Mamdani inference method using the logical AND operator, and life satisfaction in general as output variable through defuzzification.

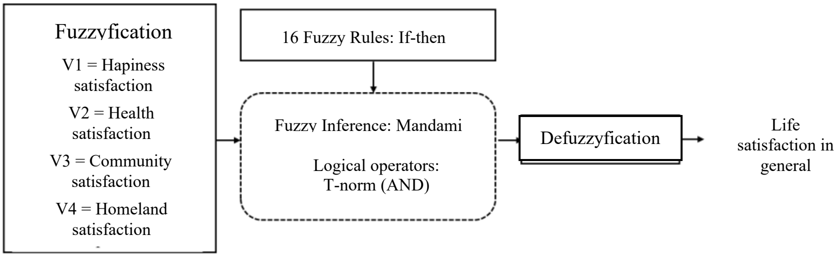

Figure 4. Fuzzy inference system to measure life satisfaction in general in Mexico (general urban area)
Source: suggested by the author

Stage 1: Fuzzification; input and output linguistic variables. The input variables are the 4 life domains resulting from the factor analysis. The output variable is the product of implementing the fuzzy rules to have an approximate assessment of life satisfaction in general.

To construct the labels of the linguistic variables, the theory that “life is an immutable trait, rather than a variable state, and people are chronically satisfied or dissatisfied, regardless of their circumstances” (Veenhoven, 1994, p.5) is taken as a reference. For this reason, for each variable, only 2 bipolar labels are proposed: ‘High’ and ‘Low’ satisfaction.

Several tests were performed to determine the membership functions for each label. Of these tests, the one that gave the best results was the trapezoidal function open to the right and open to the left for each label. Table 3 summarizes the characteristics and parameters of each variable of the system. The software used is MATLAB R2109a FuzzyLogicDesigner.

Table 3
Definition of the variables of the fuzzy inference system

Variable type	Variable name	Universe of discourse	Linguistic labels	Membership function. Matlab notation used (parameters)
Input	V1: Happiness satisfaction	[0, 10]	High Low	trapmf [1 9 10 10] trapmf [0 0 1 1]
Input	V2: Health satisfaction	[0, 10]	High Low	trapmf [1 9 10 10] trapmf [0 0 1 1]
Input	V3: Community satisfaction	[0, 10]	High Low	trapmf [1 9 10 10] trapmf [0 0 1 1]
Input	V4: Homeland satisfaction	[0, 10]	High Low	trapmf [1 9 10 10] trapmf [0 0 1 1]
Output	Life satisfaction in general	[0, 10]	High Low	trapmf [1 9 10 10] trapmf [0 0 1 1]

Source: created by the author

Figure 5 shows the right-open and left-open trapezoidal membership functions for each of the 2 linguistic labels of the 4 input variables and the output variable of the system. The shape corresponds to the parameters in Table 3.

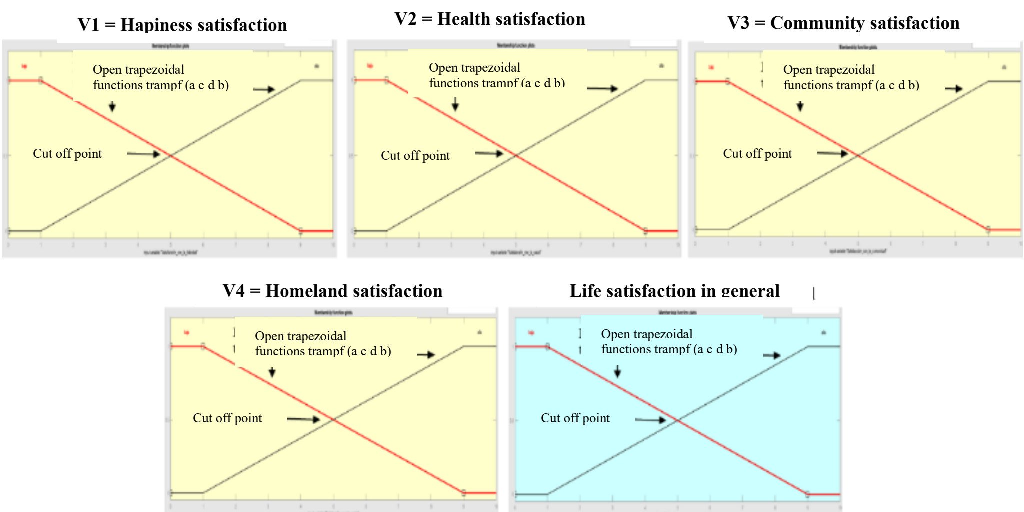

Figure 5. Membership functions of the input and output variables
Created by the author with MATLAB R2019a

Stage 2: Fuzzy Rules. The literature consulted has shown how life domains can explain, at least at some level, life satisfaction in general (Rojas, 2007a, 2007b; Rojas & Elizondo-Lara, 2012; Van Praag *et al.*, 2003). Based on this result, fuzzy 'if-then' rules were established, assuming a certain level of causality between life satisfaction in each domain and life satisfaction in general. For this purpose, each of the 16 (2x2x2x2) possible rules was analyzed by proposing one alternative as an answer (high or low satisfaction). Only those rules with a degree of controversy were submitted to some experts to improve the causal relation as far as possible, thus testing the approximate reasoning. Table 4 shows the rules used in the system.

Table 4
Rules for the Fuzzy Inference System (16 rules)

	V1 Happiness satisfaction		V2 Health satisfaction		V3 Community satisfaction		V4 Homeland satisfaction		Life satisfaction in general
1	high	and	high	and	high	and	high	then	high
2	high	and	high	and	high	and	low	then	high
3	high	and	high	and	low	and	high	then	high
4	high	and	high	and	low	and	low	then	high
5	high	and	low	and	high	and	high	then	high
6	high	and	low	and	high	and	low	then	high
7	high	and	low	and	low	and	high	then	low
8	high	and	low	and	low	and	low	then	low
9	low	and	low	and	low	and	low	then	low
10	low	and	low	and	low	and	high	then	low
11	low	and	low	and	high	and	low	then	low
12	low	and	low	and	high	and	high	then	low
13	low	and	high	and	low	and	low	then	low
14	low	and	high	and	low	and	high	then	low
15	low	and	high	and	high	and	low	then	high
16	low	and	high	and	high	and	high	then	high

Source: created by the author with the help of some experts

Stage 3: Defuzzification. An example is shown in Figure 6 with 4 fuzzy rules, 2 variables as precedents (happiness satisfaction and health satisfaction), and life satisfaction as conclusion so that the reader has an idea of how the system works to give as a result a fixed or crisp number. The exercise is presented using Mamdani inference, the logical operator AND and the centroid method for defuzzification. It should be recalled that the rules have the following form: IF <precedent> AND IF <precedent> THEN <conclusion>. The 4 rules are:

Rule 1. If <happiness satisfaction is high> AND If <health satisfaction is high> then <life satisfaction is high>.

Rule 2. If <happiness satisfaction is high> AND If <health satisfaction is low> then <life satisfaction is high>.

Rule 3. If <happiness satisfaction is low> AND If <health satisfaction is low> then <life satisfaction is low>.

Rule 4. If <happiness satisfaction is low> AND If <health satisfaction is high> then <life satisfaction is low>.

The numerical example assumes that the values of 6.5 and 8.5 are captured for each variable. The value 6.5 is fuzzified for each of the 4 rules and the same is done for the value 8.5 according to the membership function in each rule. To do this, in the vertical column of 'Minimum' (AND or minimum a∧b) in Figure 6, it is observed with a line that the smallest value of each rule is chosen, which in turn cuts to the right the membership function of the conclusion. Subsequently, the downward union of the cut sets is performed to form the membership function, which is the conclusion according to the Mamdani method with the 4 rules. Finally, defuzzification is performed to have a numerical or crisp result. In the example, it is illustrated using the centroid method, which consists of dividing the area under the membership function into two equal parts, giving 5.92 as the resulting value.

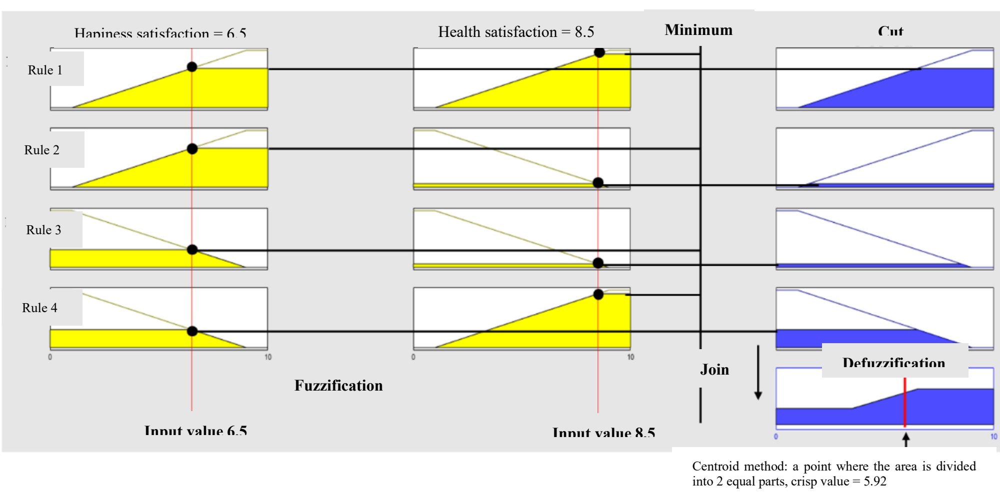

Figure 6. Graphical interpretation of the FIS with the Mamdani method applied to 4 rules
Source: created by the author

This same procedure was performed in the present study with 16 rules and 4 precedents to obtain a measurement of life satisfaction in general. Therefore, when capturing the data for each input variable, the system produces a numerical value in the closed interval [3, 7] that is contained in the initial interval [0, 10]. With this new interval, 3 means 'totally dissatisfied,' 7 translates as 'totally satisfied,' and a measurement of 5 is interpreted as an intermediate level of life satisfaction.

The result of the whole measurement process is shown in Table 5. The first 4 columns are the numerical values of the life domains incorporated into the FIS. The next column presents the new measurement of life satisfaction in general in the interval [3, 7] due to the defuzzification. Finally, in the

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last column are the figures published by INEGI for the same concept taken from the Basic BIARE questionnaire for item 1 in the closed interval [0, 10].

Table 5
Levels of life satisfaction in general based on the 4 life domains versus INEGI data

Quarterly Period	V1= Happiness satisfaction (average of BIARE P1, P3, P4, P5, P6, and P8). [0, 10]	V2= Health satisfaction (BIARE P2) [0, 10]	V3= Community satisfaction (average of BIARE P9 and P10) [0, 10]	V4= Homeland satisfaction (average of BIARE P11 and P12) [0, 10]	Life satisfaction in general FIS Interval [3, 7]	INEGI Item 1: Could you tell me on a scale of 0 to 10 how satisfied you are with your current life? Interval [0, 10]
2013/07	7.9	7.7	7.7	6.9	6.42	7.7
2013/10	7.9	8.0	7.8	6.8	6.47	7.9
2014/01	7.9	7.9	7.9	6.9	6.48	7.9
2014/04	7.9	8.1	7.9	6.9	6.48	7.9
2014/07	8.0	8.0	7.9	7.1	6.55	7.9
2014/10	8.0	8.1	8.0	6.8	6.50	7.9
2015/01	8.2	8.3	8.1	7.1	6.60	8.2
2015/04	8.2	8.3	8.1	6.9	6.57	8.1
2015/07	8.1	8.2	8.0	6.9	6.54	8.0
2015/10	8.1	8.2	8.0	6.8	6.53	8.0
2016/01	8.2	8.3	8.1	6.9	6.57	8.0
2016/04	8.2	8.3	8.0	6.8	6.56	8.0
2016/07	8.2	8.3	8.1	6.6	6.52	8.1
2016/10	8.2	8.3	8.0	6.6	6.52	8.1
2017/01	8.1	8.3	8.0	6.1	6.40	7.9
2017/04	8.2	8.3	8.1	6.6	6.52	8.2
2017/07	8.2	8.3	8.0	6.6	6.52	8.2
2017/10	8.2	8.3	8.0	6.7	6.54	8.2
2018/01	8.2	8.3	8.1	6.5	6.51	8.2
2018/04	8.3	8.4	8.1	6.6	6.55	8.2
2018/07	8.3	8.4	8.1	7.0	6.62	8.3
2018/10	8.3	8.4	8.2	6.9	6.60	8.3
2019/01	8.4	8.5	8.3	7.1	6.66	8.4
2019/04	8.3	8.4	8.2	7.1	6.63	8.3
2019/07	8.3	8.4	8.2	7.0	6.62	8.3
2019/10	8.3	8.3	8.2	7.1	6.63	8.3
2020/01	8.4	8.4	8.3	7.1	6.66	8.3
2020/10	8.4	8.4	8.3	7.3	6.69	8.1
2021/01	8.3	8.5	8.3	7.3	6.66	8.2
2021/04	8.3	8.4	8.2	7.1	6.63	8.0
2021/07	8.5	8.6	8.4	7.4	6.73	8.2
2021/10	8.4	8.5	8.4	7.4	6.70	8.3
2022/01	8.5	8.5	8.5	7.4	6.73	8.4
Averages	8.2	8.3	8.1	6.9	6.6	8.1

Source: created by the author with data from the FIS and INEGI

Results

The first step in confirming the consistency of the new calculation was to check whether the FIS and INEGI measurements behave similarly, even though both figures are located in different intervals (see Table 5). For this purpose, the correlation coefficient was calculated, obtaining a value of r=0.735 and a significance level of 0.000. This indicates a moderate to high degree of correlation; therefore, both figures behave very similarly. It should be noted that the INEGI figures originate from a single question, and the FIS data are the product of capturing 4 input variables to the system and the use of the 16 fuzzy rules where, by carrying out the defuzzification process by the centroid method, the new measure of life satisfaction in general is obtained.

On the other hand, the following analysis was performed to verify the existence of a homeostatic system calculated using the FIS. According to the homeostatic theory presented in the theoretical framework, each person's assessment of life satisfaction in general falls within a small range of values, which is where the homeostatic system works.

To check this behavior with the new measure, the coefficient of variation was calculated with the data in Table 5, and a $CV_{(FIS)}$ = 1.3% was obtained. For comparison purposes only, the same operation was performed for the figures published by INEGI, obtaining a $CV_{(INEGI)}$ = 2%. With these percentages, it is evident that both measurements fall within a reduced range. It should be emphasized that the measurement of life satisfaction in general from the 4 life domains (satisfaction with happiness, health, community, and homeland) as the valuations of these satisfaction domains under normal conditions fall in a small range (see Table 5). This allows the fuzzy rules to operate satisfactorily, causing the new measure of satisfaction to also have little variation ($CV_{(FIS)}$= 1.3%), thus illustrating a homeostatic system within the FIS.

The homeostatic theory also indicates that a person's overall assessment of life satisfaction is generally positive and is a good estimator of the homeostatic point (Cummins et al., 2003). Therefore, to verify the above, the homeostatic point is estimated with the data from the new measurement (see Table 5) through the arithmetic mean, obtaining a value of 6.6 in the interval [3, 7]. This estimate, being close to 7, is located at a very positive level of well-being, which is consistent with the role played by the homeostatic system in maintaining equilibrium and stability in the face of external changes (Cummins et al., 2003). For comparison, there is a similar result with the figures provided by INEGI by obtaining a mean of 8.1 on a scale of [0, 10]. With the results of these last 2 paragraphs, a homeostatic system in the FIS has been demonstrated.

As a limitation of the present study, it is not possible to prove the existence of the two proximal and distal dimensions, which indicate that life domains are assessed below and others above the homeostatic point. The impediment lies in the fact that the output values by the FIS are in the interval [3, 7], and the input data to the system are located in [0, 10] (see Table 5). Nevertheless, these dimensions are presented with the 4 new life domains and the INEGI measurement. That is, V_4= Homeland satisfaction (distal) has a mean of 6.9, which is below INEGI's homeostatic point estimate of 8.1. On the other hand, V_1=Happiness satisfaction, V_2=Health satisfaction, and V_3=Community satisfaction (proximal) have means of 8.2, 8.3, and 8.1, respectively, which are equal to or above the homeostatic point of 8.1.

As has been conclusively demonstrated, by using the fuzzy 'if-then' rules of life satisfaction in general, it has been possible to illustrate the behavior of the homeostasis principle and even the estimation of a homeostatic point whose values and levels are consistent with the literature consulted.

Conclusions

The document was structured as follows: the first section presented the theoretical framework containing the most relevant concepts and findings on subjective well-being, its main indicator, which is life satisfaction, and the dominant paradigm for its measurement. Additionally, the so-called homeostatic theory is presented as a central element of the theoretical framework, which indicates that the person has a self-regulation mechanism to maintain balance and stability when expressing their level of life satisfaction. The methodology for designing the FIS that will serve as a tool for measuring life satisfaction was presented in the second section. The third section presented the application of this methodology, obtaining the values of this measurement. Finally, the results were presented to illustrate the presence of a homeostatic system.

The main contribution of this study has been to provide more empirical evidence for the homeostatic theory from a different perspective. To this end, the study took only one section of the information from the Basic BIARE questionnaire conducted by INEGI quarterly since 2013 as a starting point. As the first activity, the 12 life domains of the questionnaire were reduced to only 4 new domains that served as input variables to the FIS. Furthermore, constructing 16 fuzzy rules was necessary to operate this system, testing the approximate reasoning assuming only a causality relation. As a final result of the whole process, defuzzification was performed within the system to obtain a new measure of life satisfaction in general.

Two limitations have been discussed throughout the study: the sample is representative only of the urban population as a whole, and it is not possible to test for the presence of proximal-distal dimensions with the new measures of life satisfaction.

A future line of research is to apply the same methodology in another country and see if the homeostatic system is present as in Mexico. Alternatively, the same methodology could be applied in Mexico with data from INEGI, but by gender and age groups, to identify differences in the homeostatic points in these groups.

While these subjective measures, such as happiness and life satisfaction, have taken center stage in recent decades to measure the development of societal well-being, they will be most useful if used to complement traditional approaches to objective economic measures such as GDP.

Finally, it can be affirmed that the present document is incorporated into the body of studies on subjective social indicators such as life satisfaction, whose bases are found in fuzzy logic and in inference systems of that nature, this being only a small step in a road to be traveled.

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