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Non-linearity, Complexity and Limited Measurement in the Relationship Between Satisfaction with Specific Life Domains and Satisfaction with Life as a Whole

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Abstract In this article we defend that the adoption of a non-linear approach, theoretically framed on complexity theories can make some contribution to the bottom-up approach, which explains the levels of satisfaction with life as a whole through the combination of the levels of satisfaction in different life domains. Two approaches have been tested: (Rojas in J Happiness Stud 7:467–497, 2006) constant elasticity of substitution model and the model with quadratic terms and interaction effects (González et al. in Soc Indic Res 80:267–295, 2006; González et al. in Qual Quant 42:1–21, 2008). In order to prevent obtaining false non-linear relationships they have been analysed twice taking into account or not limited measurement of satisfaction with life as a whole. Results show that: (a) any of the two non-linear models fits better than the linear one; (b) any of the models failing to take into account limited measurement fits worse; (c) the non-linear model with quadratic terms and interaction effects fits better than Rojas'. The implications for the study of psychological well-being are discussed.

Keywords Psychological well-being · Adolescence · Non-linearity · Complexity theories · Limited measurement

1 Introduction

Satisfaction is a central concept to research on psychological well-being. Within this context, the study of the relationships between satisfaction with life as a whole and satisfaction with specific life domains (family, job, health, leisure, friendships, etc.) or life facets has been a widespread and common approach to psychological well-being since it was first described by Andrews and Withey 1976. At this respect, there is considerable agreement among authors that the study of these relationships is important for the better understanding of the structure of psychological well-being (Diener and Lucas 1992) which,

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we must admit, is not sufficiently well-known yet (Diener and Biswas-Diener 2000). There even exists a certain consensus in accepting the gestalt principle that satisfaction with life as a whole is something more than the sum of its parts, that is to say satisfaction with different domains in life (Veenhoven 1994).

Many theories have been formulated across time to explain psychological well-being (see Diener 1994 for more details), being those which try to explain the relationships among different aspects of well-being much fewer (Diener et al. 1999). Some of the latter have particularly focused in understanding the complex relationships between the more general and abstract dimension of the phenomenon, on the one hand, and the more concrete and specific aspects which are related to it, on the other hand. This is the case of the *bottom-up approach*. From this perspective, well-being is considered to be the accumulation of many small pleasures. In satisfaction terms, this would mean that satisfaction with specific domains leads to satisfaction with life as a whole. An example would be Sirgy's (2000, 2001) bottom-up spillover. In the field of economy, another example can be found in the work by van Praag et al. (2003), who postulate a two-layer model where individual overall subjective well being depends on different subjective domain satisfactions, which in turn, are considered to depend on objectively measurable variables, such as income.

By contrast, *top-down theories* assume that there is a general global tendency to experience events in a positive way (Casas 1996), so that satisfaction with life as a whole would influence satisfaction with specific life domains. In this same vein, Diener et al. (2000) consider that the differences between the two types of measure of satisfaction (global/abstract vs. specific/concrete), can be used as indirect measures of the greater or lesser disposition of people to evaluate life in a positive way. The authors adopt Kozma et al. (2000) *propensity model*, which defends the existence of a dispositional component which, while acting as a personality trait, is responsible for the stability of psychological well-being despite changes in life circumstances.

In general, an according to Mallard et al. (1997), the majority of research carried out on the relationships between global and domain satisfaction has used the bottom-up approach as a departure point. Due to the limitations of both bottom-up and tow-down theories, Mallard et al. (1997) broaden these two approaches with the adoption of a third, the *bidirectional model* drawing from Michalos (1995) Multiple Discrepancies Theory (MDT). From this perspective it is argued that the two influences (bottom-up and tow-down) take place simultaneously and, thus, relationships between satisfaction with life as a whole and with specific life domains are bidirectional. MDT represents satisfaction with life as a whole as the balance between the different sub-evaluations which are discrepancy judgments between perceptions of how life is and how it should be (Michalos 1995). MDT has been, moreover, the basis for many studies on satisfaction (Cohen 2000), although it has not been established that life satisfaction is determined in a causal way by the sub-evaluations of different aspects in life (Veenhoven 1994), nor that sub-evaluations are caused by the levels of life satisfaction.

Another contribution which could be considered within the bidirectional approach is Cummins and collaborators' homeostatic model of well-being (Cummins 1998; Cummins and Cahill 2000; Cummins and Nistico 2002). The authors suggest the existence of a homeostatic control mechanism, which is assumed to control both overall subjective quality of life and the particular articulation of satisfaction with different life domains, evaluated through the personal well-being index (PWI). The psychological processing which is at its basis is considered to be a highly complex system which comprises both primary genetic capacities and a secondary protective system. The primary system provides a genetically determined range of well-being perception, and includes personality

traits and beliefs. If the influence of the outer environment is aversive enough, then the protective effect of the above mentioned determinants can be reduced, and so, well-being would have an inferior level. What it is more frequent, however, is that this adverse influence is compensated through both outer and inner mechanisms. From here on, there are some crucial questions still pending to be answered, which refer to the way all these elements combine to each other in order to attain certain levels of well-being and to which is the nature of these relationships. These queries bring us to the second point of this article.

Far from being resolved, this top-down/bottom-up/bidirectional debate connects with another substantial one which has to do with the linear versus non-linear conception of the nature of the relationship between satisfaction with specific life domains and satisfaction with life as a whole. In this sense, both bottom-up and tow-down perspectives, even bidirectional models as well, usually stem from a linear notion of this relationship. In this article we discuss and evaluate non-linear bottom-up approaches and make suggestions for their improvement.

Rojas (2006) points out that there are many questions that cannot be empirically answered from an additive conception of the bottom-up relationship between the more global and the more concrete dimensions of satisfaction, thus restricting our comprehension of this relationship. Examples of those questions are the following: is life satisfaction just a weighted average of domain satisfactions? How easy is to substitute satisfaction in one domain by satisfaction in another? What happens with the importance of one domain when satisfaction in another domain declines?

At this respect, complexity theories offer, in our opinion, a non-reductionistic approach to the study of psychological well-being which better captures its enormous dynamism and complexity (see González 2006 for more details). Despite the existence of some discrepancies among complexity researchers, there is a common conceptual body many authors agree on (Allegrini et al. 2004; Riofrío 2001; González 2006). It is the following: (1) Complex systems generally have, although not necessarily, a high number of elements; (2) The elements or aspects of a complex system interact in a dynamical way and change through time; (3) The nature of the relationships among the elements of a complex system is characterised by its high degree of connectiveness: one element influences and is influenced by a high number of other elements; (4) These relationships are non-linear: small causes generate big effects and the other way round (this is the so called sensitivity to initial conditions); (5) Relationships are short-termed; (6) There exists positive and negative feedback; (7) A complex system has a history: it evolves as time goes by and, so, its present state is determined by the past; and (8) It is difficult to establish borders within a complex system: the observer's perspective influences the definition of these limits as they are frequently a consequence of his/her descriptive objectives.

As regards the objectives of this article, to defend the existence of non-linear relationships between satisfaction with life as a whole and satisfaction with specific domains in life means to say that we cannot talk about the existence of a fixed relationship among these variables, and that this relationship is, at least to some degree, variable or even unpredictable (González 2006; González et al. 2006, 2008).

There is not a unique procedure to capture the potential non-linear nature of the relationship between satisfaction with life as a whole and satisfaction with specific life domains. Rojas (2006) proposes the use of the constant elasticity of substitution model, which accounts among others for synergy and non-constant returns. Synergy refers to the fact that the effect of dimensions on the dependent variable (satisfaction with life as a whole in this case) can be higher or lower depending on the values of the remaining

dimensions. Non-constant returns to the dependent variable can be related to curvature, upwards when returns are increasing and downwards when they are decreasing. Two model parameters govern synergy and return variation for all variables in the model as a whole.

González (2006) and González et al. (2006, 2008) have suggested the use of a non-linear model with both quadratic terms and interaction effects, which arguably better fits the theoretical assumptions of complexity theories as it accommodates different patterns of returns and synergy for different variables. For each variable there is a parameter governing the varying returns and for each pair of variables there is a parameter governing synergy.

In the background of the substantive debate around the use of linear versus non-linear models of approaching well-being, there is an important statistical debate which affects both kinds of models, which has to do with limited measurement of the dependent variable (satisfaction with life as a whole). This debate stems from the fact that satisfaction with life as a whole is generally captured through scales which have specific lower and upper bounds (0 and 10 in our case). This impedes the individuals to give answers below or above these points. This form of limited measurement is called censoring. Such floor or ceiling effects due to the measurement instrument can lead to an important misinterpretation of the obtained results. This effect can be especially dramatic when censoring is confounded with true non-linearity. In his article, Rojas (2006) himself suspected that a ceiling effect might be biasing his results.

The three main objectives of this article are the following:

- Testing whether a non-linear model better explains the relationships between satisfaction with life as a whole and satisfaction with specific life domains (satisfaction with personal security, groups of people belonging to, security for future, relations with other people, health, standard of living, life achievements, level of information and knowledge, leisure time and spirituality or religious beliefs) compared to a linear one.
- Testing whether accounting for censoring or failing to do it affects the comparison and interpretation of linear and non-linear models.
- Testing whether a non-linear model including interaction effects and quadratic terms better explains these relationships, compared to Rojas' constant elasticity of substitution model.

We have also three research hypotheses. First of all, that a non-linear model will better explain the relationships between satisfaction with life as a whole and satisfaction with specific domains compared to a linear one. Secondly, that accounting for censoring of the dependent variable (satisfaction with life as a whole), will help to increase the explanatory power of the model, being it linear or non-linear. And, finally, that a non-linear model including interaction effects and quadratic terms will better explain these relationships compared to Rojas' constant elasticity of substitution model.

2 Methods

2.1 Procedure and Sample

Data collection was carried out in 2005 in the context of a broader research about the use of television and other audiovisual equipment by compulsory secondary school attendant adolescents throughout the territory of the Autonomous Community of Catalonia (N.E. of Spain) (see Casas et al. 2007 for more details). The research was financed by the Catalan

Audiovisual Council. A questionnaire was specifically designed for this research including 11 questions aimed to evaluate psychological well-being at these ages (11–17 years).

The primary sampling units (schools) were selected by non-proportional stratified random sampling. Strata were defined by the urban/semi-urban/rural context of the school, by its public/private ownership, and by its location in one of the 4 provinces of the Autonomous Community of Catalonia. A total of 58 centres participated in the study.

At each school we reported our goals both to the director and to the parents association, and we proceeded in accordance with regular ethical guidelines for the administration of questionnaires to children. Once participation in our research was agreed, we randomly selected a classroom from each scholar year and we asked for cooperation to the responsible teacher. After that, adolescents were kindly asked for co-operation and were informed that data would be treated confidentially. The questionnaires were group administered in their regular classroom. One of their usual teachers and one or two researchers were present during the administration and clarified any of the children's questions that arose. The session was usually about 1 h long for the youngest and about 35–40 min for the oldest.

The sample size was 5,140, 262 of which did not answer the satisfaction questions at all. A further 199 individuals gave constant answers to all 11 satisfaction items and were eliminated. A further 9 individuals had 5 or more missing values for the 11 satisfaction items and were also eliminated. The final sample size was 4,670 cases. This reduced sample had in average 1.3% of missing values in all 11 satisfaction items (the highest missing data rate was 2.8% for satisfaction with spirituality). The remaining missing values were imputed using the regression method, by adding a randomly drawn residual to the predicted value.

The percentage of boys and girls participating in the study and their ages are displayed in Table 1.

2.2 Description of the Variables

The 11 satisfaction items were measured with 0–10 scales following Cummins and Gullone's (2000) recommendations. The dependent variable was satisfaction with life as a whole, which was explored through the following question: "Nowadays, how satisfied are you with your life taking it as a whole? (0 = *Completely dissatisfied* and 10 = *Completely satisfied*). The explanatory variables included the 8 items of the PWI scale (Cummins 2003; Cummins et al. 2003): "Satisfaction with personal security", "Satisfaction with

Table 1 Demographic characteristics of the sample

Gender (%)	
Girls	50.4
Boys	49.6
Age (%)	
11 year-olds	1.1
12 year-olds	19.2
13 year-olds	23
14 year-olds	24.7
15 year-olds	25.4
16 year-olds	5.9
17 year-olds	0.7

groups of people belonging to", "Satisfaction with security for the future", "Satisfaction with relations with other people", "Satisfaction with health", "Satisfaction with standard of living", "Satisfaction with life achievements", and "Satisfaction with spirituality or religious beliefs", plus two more items which have a lower level of abstraction. They are "Satisfaction with level of information and knowledge" and "Satisfaction with leisure time". In Table 2, means and standard deviations for each of the 10 explanatory variables and the dependent variable are displayed:

The 10 explanatory variables were submitted to a principal component analysis with oblimin rotation (Table 3):

Four interpretable dimensions have emerged which explain 70.9% of the variance:

1. Dimension 1 (satisfaction with security and relations, Alpha coefficient: 0.777):

    - Satisfaction with personal security
    - Satisfaction with groups of people belonging to
    - Satisfaction with security for the future
    - Satisfaction with relations with other people

Table 2 Means and standard deviations of the variables explored

	Mean	SD
Satisfaction with health	8.09	2.218
Satisfaction with standard of living	8.23	1.941
Satisfaction with life achievements	7.75	2.029
Satisfaction with personal security	7.36	2.241
Satisfaction with groups of people belonging to	8.10	2.069
Satisfaction with security for future	7.31	2.241
Satisfaction with relations with other people	7.80	2.090
Satisfaction with level of information and knowledge	7.12	2.187
Satisfaction with your leisure time	6.98	2.573
Satisfaction with spirituality or religious believes	4.86	3.596
Satisfaction with life as a whole	7.83	2.234

Table 3 Rotated loading matrix of the principal component analysis

	Dimension			
	1	2	3	4
Satisfaction with health	−0.101	−0.044	0.927	0.036
Satisfaction with standard of living	0.098	−0.017	0.831	0.002
Satisfaction with life achievements	0.298	0.056	0.585	−0.088
Satisfaction with personal security	0.427	0.013	0.361	−0.130
Satisfaction with groups of people belonging to	0.827	−0.007	0.071	0.091
Satisfaction with security for future	0.513	0.094	0.113	−0.239
Satisfaction with relations with other people	0.885	−0.005	−0.091	−0.022
Satisfaction with level of information and knowledge	−0.051	0.310	0.218	−0.586
Satisfaction with your leisure time	0.049	−0.137	−0.092	−0.921
Satisfaction with spirituality or religious believes	0.016	0.980	−0.080	0.059

2. Dimension 2 (satisfaction with health, standard of living and achievements, Alpha coefficient: 0.807):

   - Satisfaction with health
   - Satisfaction with standard of living
   - Satisfaction with life achievements

3. Dimension 3 (satisfaction with knowledge and leisure, Alpha coefficient: 0.491):

   - Satisfaction with level of information and knowledge
   - Satisfaction with leisure time

4. Dimension 4 (satisfaction with spirituality/religion):

   - Satisfaction with spirituality or religious beliefs

For each of the dimensions the corresponding items were summed according to the process followed by Rojas (2006), which will be described in more detail at the end of this same section.

We are aware that the four dimensions of satisfaction domains included in this article may be a poor representation of the phenomenon. However, they served well for illustrating the methodological purposes of this paper.

2.3 Censored Variables in Linear and Non-linear Models

Figure 1 shows the distribution of the dependent variable, satisfaction with life as a whole measured with a response scale from 0 to 10. The high frequency of 10 answers resulting from the upper limit of the response scale suggests a censored distribution. The problem of having a limited dependent variable adds more complexity to the linearity versus non-linearity issue. The graph in Fig. 2 shows a simulated data set with a linear relationship ($y = 2 + 0.25x + \varepsilon$) but with a censored dependent variable whose upper bound is 10.
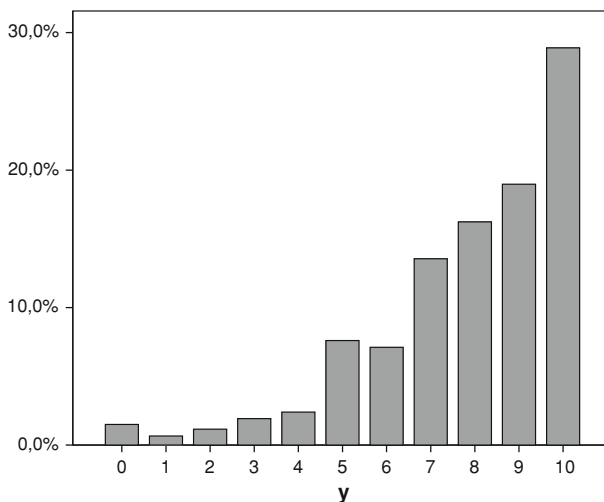

Fig. 1 Bar chart of the dependent variable satisfaction with life as a whole
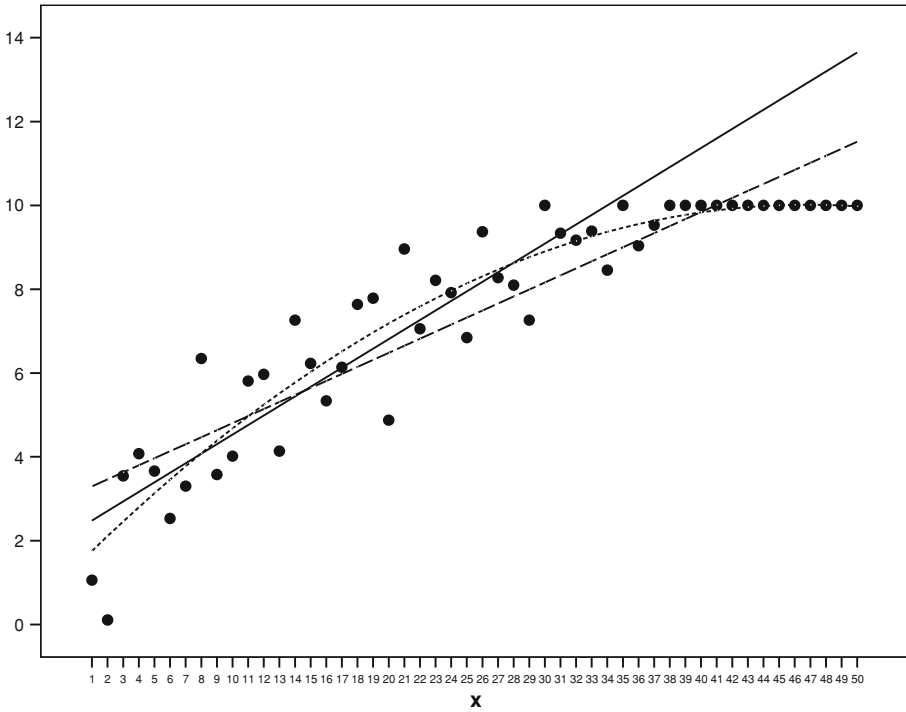
Fig. 2 Simulated example. Vertical axis censored at 10. *Solid line*: censored linear fit. *Broken line*: OLS linear fit. *Dotted line*: OLS quadratic fit

The respondents with the highest values of the dependent variable are not observed at the true value. Unfortunately, thus, the fact of observing or not the true value is not random as it is in an experimental setting (Rubin 1974), but correlated with individual's characteristics other than the explanatory variables. This makes selection of individuals who are not observed at their true value to be non-ignorable, which is also referred to as endogenous selection, informative selection or selection on non-observables (see Heckman 1976). This type of selection causes bias if not accounted for by means of the so called treatment effects models (Heckman 1976).

Tobin (1958) first suggested a particular case of treatment effects model, namely a censored regression model (Amemiya 1984; Schnedler 2005) whose general expression for a single explanatory variable is the same as a linear regression model:

$$y^* = \beta_0 + \beta_1 x + \varepsilon$$

with ε independent identically distributed N(0, σ).

However, the true value y^* of the dependent variable is only observed (y) within a specific range defined by a lower bound y_L and an upper bound y_U.

$$
\begin{aligned}
y &= y^* && \text{for } y_L < y^* < y_U \\
y &= y_U && \text{for } y^* \geq y_U \\
y &= y_L && \text{for } y^* \leq y_L
\end{aligned}
$$

If only the lower bound limits the distribution, then the model is called censored below, if only the upper bound limits the distribution, then the model is called censored above, which is our case:

$$y^* = \beta_0 + \beta_1 x + \varepsilon$$
$$y = y^* \quad \text{for } y^* < y_U$$
$$y = y_U \quad \text{for } y^* \geq y_U$$

The solid line in Fig. 2 presents the fitted value with a censored estimation (the slope of this line is 0.23 with the simulated example data, close to the true 0.25 value).

Ordinary least squares (OLS) estimation ignores y^* and fits the y variable instead:

$$y = \beta_0 + \beta_1 x + \varepsilon$$

It has long been known (Tobin 1958) that limited dependent variables bias the OLS estimates. If we estimate a linear model by OLS we obtain the broken line in Fig. 2. The slope of this line (0.17) is considerably lower than 0.25 due to the absence of values higher than 10 in the upper right corner of the graph.

What is less widely understood is that failing to acknowledge censoring can result in specification errors in the model (Greene 2007). If we fit a model with a quadratic term x^2 by OLS we obtain the dotted curved line in Fig. 2. The estimate of the quadratic term is negative, which causes the predictions to curve down when they approach the $y = 10$ upper limit. The fit of the quadratic model is considerably better and the quadratic term is statistically significant ($t = -5.6$). Let us recall that the simulated data were linear; only the failure to account for the limited dependent variable has caused a spurious non-linear effect. If we fit a quadratic term in the censored model it is non-significant ($t = -1.34$).

This makes it extremely important to take censoring into account when comparing linear and non-linear models. Rojas (2006) raised this point in the conclusion of his article, but did not perform any censored estimation. González et al. (2006, 2008) were faced with an ordinal dependent variable, not with a censored one. Accordingly they used an ordered Logit model.

2.4 Alternative Linear and Non-linear Models for Predicting Satisfaction with Life as a Whole

The presence of y^* or y at the left side of the equal sign showing the use of censored estimation or least squares, we shift our attention to the conceptually richer right side of the equation. In this part the linear or non-linear formulations appear. We considered three such formulations.

The first model we considered was a *linear* model:

$$\left.\begin{array}{c} y \\ y^* \end{array}\right\} = \beta_0 + \sum_{i=1}^{4} \beta_i \, dim_i + \varepsilon$$

The second model was the *constant elasticity of substitution* model recommended by Rojas (2006):

$$\left.\begin{array}{c} y \\ y^* \end{array}\right\} = \left(\sum_{i=1}^{4} \beta_i \, dim_i^\gamma \right)^{\delta/\gamma} + \varepsilon$$

This model captures certain types of non-linearity in the relationship between domain satisfaction and satisfaction with life as a whole. Particularly interesting are what Rojas calls *synergy* (the effect of one dimension on the dependent variable can be higher or lower depending on the values of the remaining dimensions) and *non-constant returns* to the dependent variable, which can be related to curvature, upwards when returns are increasing and downwards when they are decreasing. Parameters γ and δ govern returns and synergy.

The third was a model with *quadratic and interaction terms* as in González et al. (2006, 2008).

$$\left.\begin{array}{c} y \\ y^* \end{array}\right\} = \beta_0 + \sum_{i=1}^{4} \beta_i \, dim_i + \sum_{i=1}^{4} \beta_{4+i} \, dim_i^2 + \beta_9 \, dim_1 \, dim_2 + \beta_{10} \, dim_1 \, dim_3$$
$$+ \beta_{11} \, dim_1 \, dim_4 + \beta_{12} \, dim_2 \, dim_3 + \beta_{13} \, dim_2 \, dim_4 + \beta_{14} \, dim_3 \, dim_4 + \varepsilon$$

With this model, the linear or non-linear character of the effects can change from dimension to dimension. Return variations are governed by the parameters β_5–β_8 and can thus change from variable to variable. Synergy can emerge between certain pairs of dimensions and not between certain others. The parameter (s) from β_9 onwards associated to the interaction or product terms imply changes in the effect of one variable depending on the value of another. A positive parameter implies positive synergy. These changing degrees of return variation and synergy across variables best fits into the complexity paradigm.

The quadratic and interaction term model thus implies that effects of variables may change depending of their own values and the values of all other variables. For instance, the effect of dim_1 on y or y^* is:

$$\beta_1 + 2\beta_5 \, dim_1 + \beta_9 \, dim_2 + \beta_{10} \, dim_3 + \beta_{11} \, dim_4$$

and only equals β_1 if dim_1 to dim_4 are equal to zero or if β_5 and β_9–β_{11} are equal to zero.

Each model was estimated twice, by least squares (OLS for the linear and quadratic and interaction term models and non-linear least squares for the constant elasticity of substitution model) and as a censored above model (by maximum likelihood in all cases).

As in Rojas (2006), dim_1 to dim_4 were transformed to a 1–100 scale. In models without a constant term such as Rojas', scaling homogeneity is critical to the results. These 1–100 scales were used untransformed for the constant elasticity of substitution model and mean-centred for the linear and quadratic and interaction term models. Mean centring was recommended by Irwin and McClelland (2001) in order to prevent collinearity in models with quadratic and interaction terms, and in order to make the estimates of β_1–β_4 comparable with those of a linear model. If this is done, the β_1–β_4 estimates refer to the mean values of all variables instead of referring to a zero point which may represent a relatively atypical situation.

3 Results

Table 4 shows the estimates of all three models by least squares and as censored models. The fit of the models was compared with Akaike's information criterion (AIC). This measure of model fit takes into account the number of model parameters and as such it penalizes heavily parametrized models such as the quadratic and interaction term model. In spite of this, this model appears to be better (i.e. has lower AIC) regardless of the method

Table 4 Least squares and censored estimates of the three models

	Least squares		Censored	
	Estimate	t-value	Estimate	t-value
Linear				
Intercept	7.83326	317.31**	8.30792	236.77**
dim_1	0.03029	15.01**	0.03835	14.27**
dim_2	0.04183	19.44**	0.05457	18.92**
dim_3	0.03228	20.14**	0.04346	20.06**
dim_4	0.00019	0.17	−0.00062	−0.38
AIC	18,144.4		10,598.0	
Constant elasticity of substitution				
dim_1	0.11990	3.99**	0.10869	3.79**
dim_2	0.16256	4.18**	0.14543	3.96**
dim_3	0.11460	4.67**	0.10467	4.41**
dim_4	0.00016	0.04	0.00027	0.08
γ	0.45563	4.20**	0.50612	4.41**
δ/γ	2.00948	4.31**	1.80697	4.54**
AIC	18,128.2		13,235.9	
Quadratic and interaction terms				
Intercept	7.91327	178.16**	8.12855	138.45**
dim_1	0.03501	13.93**	0.05019	14.73**
dim_2	0.03819	15.41**	0.05496	16.23**
dim_3	0.02950	16.40**	0.04279	17.23**
dim_4	−0.00008	−0.07	−0.00086	−0.54
dim_1^2	0.00031	3.05**	0.00064	4.83**
dim_2^2	−0.00021	−2.16*	0.00001	0.09
dim_3^2	−0.00024	−3.52**	−0.00003	−0.35
dim_4^2	−0.00003	−0.37	0.00002	0.18
$dim_1 dim_2$	−0.00009	−0.64	−0.00003	−0.19
$dim_1 dim_3$	−0.00022	−2.05*	−0.00015	−1.07
$dim_1 dim_4$	0.00009	0.96	0.00011	0.82
$dim_2 dim_3$	0.00016	1.45	0.00036	2.45*
$dim_2 dim_4$	−0.00008	−0.78	−0.00014	−1.10
$dim_3 dim_4$	0.00002	0.29	−0.00001	−0.13
AIC	18,124.2		10,546.1	

* $p < 0.05$; ** $p < 0.01$

of estimation. This supports the complexity of the life satisfaction construct. If we use least squares estimation, the constant elasticity of substitution comes second best, while if we use censored estimation, the linear model comes second best. This supports the importance of censoring when comparing linear and non-linear formulations.

If we look at the quadratic and interaction term model into detail we see that estimates markedly differ between the least squares and the censored estimates. In order to accommodate the upper bound of the dependent variable, the estimates of β_1–β_4 which are significant and positive are considerably lower for the least squares estimation (this also

holds for the linear model). In order to accommodate the upper bound, a negative significant quadratic term appears for the least squares estimation which fails to appear for the censored estimation and the same occurs for a negative significant interaction term. The quadratic and interaction terms which are positive and significant according to the censored estimation are lower or even non-significant in the least squares solution.

We thus consider the censored estimates of the quadratic and interaction term model for interpretation. Satisfaction with security and relations (dim_1), with health, standard of living and achievements (dim_2), and with knowledge and leisure (dim_3) have a positive effect on satisfaction on life as a whole for the average respondent. Satisfaction with security and relations has increasing returns, as shown by the positive quadratic term; that is, the effect of satisfaction with security and relations on satisfaction with life as a whole is progressively higher the higher the value of satisfaction is with this dimension. Satisfaction with health, standard of living and achievements and satisfaction with knowledge and leisure have positive synergy. In other words, the effect of satisfaction with health, standard of living and achievements on satisfaction with life as a whole is higher for individuals with a high satisfaction with knowledge and leisure, or, conversely, the effect of satisfaction with knowledge and leisure on satisfaction with life as a whole is higher for individuals with a high satisfaction with health, standard of living and achievements.

We are aware that the large sample size, while increasing the power of statistical tests, may result in some effects of low magnitude being significant. A measure of effect size is thus helpful. Even if standardized estimates cannot be directly interpreted in terms of standard deviation changes for models containing quadratic and interaction terms, they do provide a measure of effect size. The standardized censored estimates for the five significant effects in the quadratic and interaction term model are 0.29 (dim_1), 0.31 (dim_2), 0.27 (dim_3), 0.11 (dim_1^2), and 0.05 ($dim_2 dim_3$).

4 Conclusions

Traditionally, satisfaction with life as a whole has been explained through a linear combination of satisfaction with specific life domains. This is the so-called bottom-up approach, which has been the prevailing tendency for many years. The relationship between the more general and the more concrete dimensions of satisfaction has often been formulated in terms of an arithmetic sum, thus presupposing that all dimensions had more or less the same influence on life satisfaction. With time, an agreement arose in considering the gestalt principle that the total is not the simple sum up of the parts, and so, satisfaction with life as a whole might be something qualitatively different from the mere accumulation of satisfaction across different life domains (see Hsieh 2002).

The adoption of this gestalt principle lead, among other things, to the formulation of complementary theoretical explanations such as the notion of bottom-up spillover, and, simultaneously, to suggest some calculation procedures such as the weighting of satisfaction scores with importance ranks across life domains, in order to empirically test the hypothesis that not all domains have the same importance. The substantial discrepancies that exist among authors around the theoretical and empirical contribution of such weighting procedures for the comprehension of psychological well-being (see Wu 2008; Cummins 2002, for instance), as well as the different results they have obtained, might be indicating, from our point of view, the need of questioning the linear conception of the relationship between the global and the concrete dimensions of satisfaction that this approach has generally assumed for such a long time.

Consequently, we totally agree with Rojas (2006) that the adoption of a non-linear approach to the study of psychological well-being (global satisfaction and life facets satisfaction in the case of this article) from a bottom-up perspective, helps to overcome some limitations of the accumulative perspective (being it simpler or more sophisticated), and so, to substantially increase our comprehension of this relationship. However, not all non-linear procedures of analysis fit equally well within the complexity theory foundations, because they also have some constraints. For instance, we have seen in this article that the non-linear model with quadratic terms and interaction effects fits better than Rojas' constant elasticity of substitution model and better accounts for complex relationships which are characterised by the presence of interaction, sensitivity to initial conditions and, generally, the lack of proportion between the input and the output (Hayles 1998; Coveney and Highfield 1992).

As regards the six models we have estimated, it is noticeable that, with independence of their linear or non-linear nature or the fact of taking or not censoring into account, all dimensions of satisfaction with specific life domains (with the exception of satisfaction with spirituality/religion), have a positive effect on satisfaction with life as a whole. However, remarkable differences emerge from here on when we compare linear to non-linear models as only the latter are capable of capturing synergy and return variation among those dimensions in relation to the dependent variable (satisfaction with life as a whole). At the same time, only the estimated model through quadratic and interaction terms is able to make visible that positive synergy exists among one pair of dimensions. This is the case of satisfaction with health, standard of living and achievements in relation to satisfaction with knowledge and leisure (see the quadratic and interactions terms model using censored estimation in Table 4).

Although the positive synergy that exists among the just mentioned dimensions is not of easy interpretation. It could be the case that both dimensions have been considered by the adolescents as referring to more quantifiable or tangible even more individualistic aspects, in life, and so, adolescents who tend to attribute strong importance to the things they have achieved in life could also consider that the things they have learned or the things they do during their leisure time are very important for their overall life satisfaction, too. This would at least partially explain the lack of positive synergy among any of these two dimensions with the one of satisfaction with security and relations, which could be comparatively understood as comprising less quantifiable, more intangible and less individualistic aspects in life.

One of the main assumptions of the paper is that satisfaction with life as a whole is not bounded. Consequently, the fact of having limited measurement (0–10-point scales in our case) of the dependent variable (satisfaction with life as a whole) could lead to the obtention of false non-linear relationships. In relation to this, we have observed in our data a high frequency of answers located at the upper limit of the response scale which might be suggesting that some participants would have given even higher responses if they had had the chance to. The reported applications of continuous magnitude estimation measurement scales to subjective well being provide arguments for this. Saris et al. (1998) report continuous line drawing scales to have higher validity. These line production scales are usually bounded but grant respondents much more freedom in expressing a wide range of opinions. Batista-Foguet and Saris (1988) provide an example of unbounded line production measurement scale in the field of job satisfaction. Censoring has not as much to do with the number of scale points (if the scale had run from 0 to 15, then 15 might likely have been the modal value and censoring would still be present) as with the measurement procedure.

By contrast, some authors argue that well-being might be bounded and then, both satisfaction with life and with specific life domains are adequately and preferably measured through bounded scales (Rojas 2008). Some neurological and evolutionary studies as well as philosophical arguments are mentioned in order to support this statement, being the main one the fact that the nervous system of humans has limitations which lead to saturation from stimulation.

Although the results obtained in this paper are not a definitive answer to this controversy, and so, more research is still required, the fact that the goodness of fit of the model with quadratic and interaction terms estimated through censoring is remarkably higher compared to least squares, seems to stick up for a better consideration of satisfaction variables as not bounded.

Censoring is not the only form of limited measurement. Sometimes the dependent variables are binary, ordered categorical, unordered categorical or count data. Appropriate formulations of the left hand side of the equations include logit, probit, ordered logit, ordered probit, polynomial logit, binomial regression and poisson regression among others (McCullagh and Nelder 1989). In all these cases, failing to account for these measurement issues can lead to spurious non-linear effects. In some situations, more than one approach is reasonable. Our response scale may also be considered to be ordinal, although this is an uncommon specification for measurements with as many as 11 categories. To test for differences between both approaches, we fitted the quadratic model with interaction terms as an ordered logit model. The mean absolute difference between standardized censored and logit estimates across the 14 slope parameters was a mere 0.0079.

Future research is needed in order to further analyse why the distribution of the dependent variable of satisfaction with life as a whole in our 11–17 year-old adolescents sample seems to be more polarised compared to general adult samples. It would be also desirable to extend this same analysis to older participants (17 and 18-year-olds) and younger ones as well (9 and 10 year-olds), following Easterlin (2006) idea of studying "life cycle happiness" but applied to adolescent populations. Besides, although the sample participating in the study is representative of the Catalan population of these ages, the analyses here presented are based on only one sample and, so, generalisations must be done cautiously. For this reason, it would be desirable to reply the same process using other samples of adolescents coming from other countries.

From a historical point of view, the bottom-up approach has been contrasted to a top-down influence, which in Diener's opinion, better explains the relationship between the more general and the more concrete dimensions of psychological well-being (satisfaction in our case). This suggestion is based on the idea that subjective well-being might be more a personality characteristic than something influenced by living conditions (Saris 2001). This opinion is also shared by Kozma et al. (1997) who carried out a revision of different pieces of research from a top-down perspective and concluded that an explanation in terms of propensity or disposition for top-down effects is the most plausible one. However, the authors have moved in last years towards the use of a combination of top-down and bidirectional models in order to explain well-being, especially what regards its evolution through time (Kozma et al. 2000). It is also worth mentioning that Davern et al. (2007) have recently defended that psychological well-being is essentially driven by affects and cognitive discrepancies rather than personality characteristics, at least in an isolated and preponderant way.

In any case, since Diener's assertion, different pieces of research have been carried out, which have complicated rather than resolved the bottom-up/top-down controversy (Saris 2001). Just to mention an example, while both in Lance et al. (1995) and Headey et al.

([1991](#)) a significant top-down effect of psychological well-being is found for the domains of job satisfaction and satisfaction with leisure activities, the effect for marriage satisfaction on psychological well-being was found to be explained through a bottom-up influence by the former and through a bidirectional one by the later. The concrete structure of satisfaction with life as a whole and satisfaction with specific domains in life can be then attributed to both individual and cultural differences (Diener [1994](#)), even to economic factors (Saris [2001](#)).

Beside the bidirectional model, there have been other attempts to overcome the bottom-up/top-down controversy, such as the constructionist approach suggested by Leonardi et al. ([1999](#)). This approach considers individual satisfaction as a construction, evoked by the specific question formulated within a particular context. This implies that both top-down and bottom-up concepts should not be read as a pattern of causal relationships between satisfaction with life as a whole and satisfaction with specific life domains, but as complex cognitive tasks. Consequently, their correlation might reflect the use of heuristic shortcuts (Leonardi et al. [1999](#)) rather than a causal relationship, those heuristics being modulated by emotional processes.

Although our approach has not been a top-down or a bidirectional one, both perspectives cannot be left aside from the non-linear perspective of approaching psychological well-being we are defending in this article, as in any of the cases, a linear assumption has traditionally been the dominating tendency. At this respect, one of the consequences of having adopted a linear conception in the study of psychological well-being is the fact that the comprehension we have nowadays on the relationships among different variables related to well-being, is very poor (Eid and Diener [2004](#)).

This is so to the extent that the power of the relationships among these elements can vary depending on which of them are taken into account when studying the broader concept of psychological well-being (see Cha [2003](#), for an example). Mathews et al. ([1999](#)) think that the fact of obtaining poor results (in terms of low correlations and low reliability), are due to the fact that we are studying complex (and, therefore, dynamic) systems with linear techniques rather than to the often quoted measurement errors or omission of relevant variables.

Important future challenges emerge from the process we have followed. The first one has to do with the adoption of a non-linear approach to the study of the relationship between satisfaction with life as a whole and with specific life domains also from a top-down, even a bidirectional perspective. For instance, Diener et al. ([2000](#)) measured what they called positivity disposition from the degree to which individuals evaluate global domains more positively than specific domains. They concluded that bottom-up influence may account for more individual variation on well-being whereas positivity disposition may account for more cultural variability in life satisfaction. This demonstrates in their opinion that top-down processes are more important that bottom-up ones, although the existence of the later is not denied. At this respect, Rojas ([2006](#)) thinks that the non-linear approach of studying the relationships between satisfaction with life as a whole and satisfaction with specific life domains adds an important challenge to the top-down perspective. From here on, at least two questions should be answered under the top-down approach: why the general disposition is transmitted more to some domains compared to others and why this transmission is so complex. Consequently, it would be interesting to check whether it makes sense to apply the process followed by Diener et al. ([2000](#)) to the study of the relationships between satisfaction with life as a whole and satisfaction with specific domains but from a non-linear approach.

The second challenge refers to approaching psychological well-being through other properties apart from non-linearity. Although non-linearity can be considered the core of

complex systems, there are also some other crucial properties (Munné [1993], [1995], [2004]), such as the discontinuity in the processes of change of phenomena (satisfaction with life as a whole and with certain domains in life in our case), which have not been explored in this article. The reason is that it requires the availability of repeated measures of the same variables and this is not the case for cross-sectional studies like ours. It would be desirable to develop longitudinal studies in order to be able to explore those properties too.

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