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A smooth transition modeling and forecasting of the nonlinear dynamics of renewable energy cycle in Tunisia

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***Abstract*— Modeling and forecasting the nonlinear dynamics of renewable energy cycles recently became the most attracted domain for many researchers. Several study have approved that such behaviors are highly nonlinear dynamics cycles and can exhibit usually an irregular phenomenon and complicated specially for prediction. In this context, we try to provide some theoretical and empirical studies for modeling and forecasting the nonlinear dynamic of Tunisian's renewable energy behavior especially under the chaotic transition in the post revolution period. Our methodology is based on the univariate STAR (smooth transition autoregressive) method composed by tow transition process types the logistic STAR model (LSTAR) and the exponential STAR model (ESTAR).**

In this paper, we focus on the problem of the energy transition in Tunisia were we suggest to study and modelling then forecasting the nonlinear dynamic of the endogenous renewable energy cycle. As results we found that the LSTAR process is more adequate for asymmetric data for our case. In this regard, our results indicated that the renewable energy can not only work as a possible factor for energetic strategy transition in Tunisia, but also, is a promising candidate for stability and socioeconomic development.

***Keywords*— Nonlinearity, Forecasting, Endogenous cycle, Smooth transition autoregressive model, Renewable energy in Tunisia.**

I. INTRODUCTION

It has long been known that the energy sector in Tunisia plays an important role and represents the core of the economic and social growth. Therefore, since the independence, the production and use of energy pose a major issue to the development. For that, energy transition has become the key to guarantee a better life under the start declining of the domestic energy production since 2000. Particularly, to confront the threats facing this sector because the massive exploitation and drain natural sources, the control of the energy transition and their socioeconomic and environmental dimensions, represents a primary necessity for identification of the main determinants of energy efficiency and reducing the excessive energy dependence and their financial charges.

Within this framework, The Tunisian National Agency for Energy Efficiency (ANME) has adopted a strategic policy mainly based on the mastery and rational use of energy and the development of renewable energies in order to ensure a sustainable growth, based on improving health care and education and social welfare [1]. However, since 2000, the energy balance between the supply and the demand has been broken [2]. Today, the revolution which has hard results in a prolonged political transition phase is responsible for the economic recession and growth instability. These fluctuations, in opposition to the existing theory of explanation exogenous causes of economic crises, they are intrinsic characteristics and are due to endogenous influences, such as the recurrent upturns and downturns of the economic system or dynamic indeterminacy. So, they can give new economic and social trends by fluctuating the existing economic and social fabric by provoking structural changes as a result of an irregular economic development in Tunisia post revolutionary period [3]. The situation of the energy report balance sheet is marked by an important structural imbalance that threatens to break the system of the energy supply of the country. Thus, an analysis of the situation in Tunisia has confirmed that the socioeconomic climate clearly risks being damaged and suffers from a deep recession particularly characterized by a simultaneous fall of the industrial production and market services activity [4].

Accordingly, several economic and social problems have arisen quite intense namely a lower economic growth, the fragility of the macroeconomic equilibrium, the worsening of the budget deficit, a strong decline in Dinar, the duplication of the inflation and issue of unemployment grew as well. Despite the growing awareness over this socioeconomic and energy crisis reflected mainly in the adoption of many ambitious programmers related to a mastering in the request of energy and a multiplicity of actions in favor of durable development, these efforts have attempted to minimize this complication and to solve its effects, yet unfortunately they are all unsuccessful [5]. According the energy consumption, which was 0.9 toe per capita in 2011 (5 times lower than the EU average), they have helped uniquely to create a slight reduction in the growth rates of energy consumption by 20%

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compared with that of 2000; also a substantial decrease of energy intensity yet, the deficit of energy remains growing. In this situation, the ultimate goal of energy sustainability implies the replacement of all fossil fuels (oil, coal, natural gas) by renewable energy sources [6].

The worsening of the structural deficit of the energy balance sheet caused by the lack of an efficient strategy for the control and analysis of the dynamics of policy evolution practiced in this sector of energy and because of the failure of the adopted politic in this interesting sector are considered among the major dominant factors of the present socioeconomic crisis in Tunisia [3]. In fact, several studies demonstrate that the remarkable slow down of the financial and economic activity is in a direct relation with the malfunction of the energy system which get worse as a result of chaotic events occurred just after the revolution [2]. On the other hand, important studies proved that a relatively smooth transition can be made to a renewable energy economy [7].

This article would be divided as following: the first section will describe the situation of the Tunisian energy system and define some theoretical foundations about the both key arguments of sustainable development and energy transition. The second section will provide a representation of the univariate STAR model. The third section will provide the available data. The fourth section will explain the econometric methodology of specification, estimation and evaluation the renewable energy cycle transition in Tunisia. Finally, the fifth section will present some conclusions to summarize the main results.

II. THEORITICAL FOUNDATIONS

For a long time, petrol, the coal and the natural gas are known as a conventional energy sources. Indeed, the coal and petrol are considered as the oldest sources of energy and they have become at the heart of the socioeconomic development. These natural resources are largely helped the emergence of modern civilization which mainly based on the industrial revolution since the early 19th century [8]. But, despite these economic and social structural changes, the transition to new manufacturing processes by using modern production methods sometimes provokes different economic and geopolitical conflicts for the reason of a non equitable distribution of these natural resources and the supply shortage resulting from a massive and increasing demand on these limited and rare materials. In this situation, the energy security and the reliability of energy supply between poor and developing countries have become among the major problems that have a risk of causing a socioeconomic and geopolitical instability in the world. This could largely attributable to the non equitable access to these natural resources caused by the pursuit of dominance and monopolizing of natural resources, sources of raw materials and mainly the sources of energy [9].

So, because of the non-abundance of these natural resources, some countries take a practical steps as a strategic politic to dominate some developing countries rich by these main sources of natural materials producing energy which is considered a basis of any manufacturing operation. There are several reasons for this, in particular, the egoism and the greed which can manifest in the behaviors consumers of energy, added to that the absence of planning and governance at the level of the manner through which energy would be managed and the excessive and not rational use of energy. All these factors have serious consequences for energy production capacity and cause a depletion of most energy sources [10].

Thus, to fill this gap and especially to globally satisfy the increasing utility of consumption of these raw materials, the renewable energy has recently dominated people's preferences as new alternative energy source and started to be seriously studied and be taken into account. Hence, the majority of theoretical analysis such as [11] defined the concept of the renewable energy as energy that is collected from resources which are naturally replenished on a human timescale, or in other words is an energy originating from a deposit which can be reconstituted permanently at a pace equal to or above that of consumption. It may contain several resources such as biomass, wind turbine, hydropower, solar and geothermal. In addition, these analyses confirmed that such use is not respectful to the environment. Because its process of reconstitution produces in most cases many waste materials which tackle the environment; this would necessitates additional costs to remove them. But, despite this it can have a significant positive effect on sustainable development and particularly socioeconomics development [12].

The initial renewable energies come mainly from: the sun, the wind and the water. They come from non fossil sources, so they are obtained from inexhaustible sources contrary to the fossil fuels such as (coal, petrol, natural gas…). In this sense, these renewable energies involve natural phenomena such as the light of the sun, the wind, tides, photosynthesis and the geothermal heat as the International Energy Agency explains [13].

This mode of development which respects all these aspects is a durable socioeconomic development, in a sense; it requires a model of global development capable to take into account the economic, the social and the environmental aspect. This is mean that this mode does not exhaust the sources of investment of natural resources on which every structural change is based on, resultant of an endogenous transition followed by a dynamic reorganization [14]. The latter will be able to create a true development and to ameliorate the social fabric or rather the opposite, it lets to its destruction if we face a situation of disorder or a complex structure resulting from a chaotic transition.

Several empirical studies [15] and [16] have declared that during the last twenty years, the world consumption to energy increased to around 58% and exactly around 2.5% in 2011. For this reason, these studies estimate that the world stocks of fossils energy sources will be exhausted towards the end of the first half of the 21^{th} century. Thus, multiple countries introduce a destined strategic politics to accelerate the transition towards a low carbon economy and to increase the use of renewable energies [17]. In this context, the domestic fossil energy sources have become increasingly limited in Tunisia whose energy balance between supply and demand

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has been broken since 2000. As demonstrated in Figure 1, this amounts to the continuation of the natural decline in energy supply compared to a faster increase in energy demand.

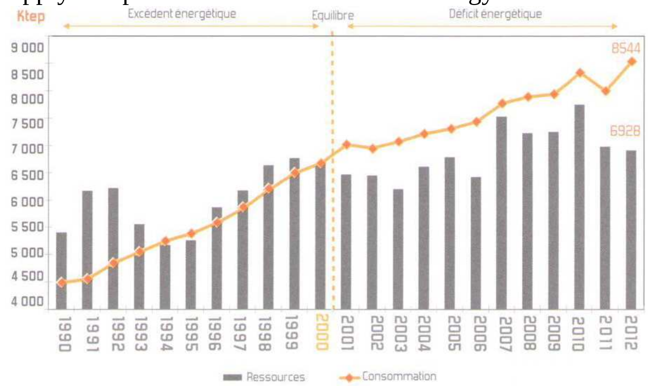

Fig.1 Energy balance (Ktoe) in Tunisia during the period from 1990 to 2012.

On the other hand, as it is illustrated in figure 4, during the period from 1990 to 2013 the structure of the production of renewable energy sector is dominated by the Hydropower source by 59.514% and the wind power by 39.862% but solar power remains negligible 0.623%.

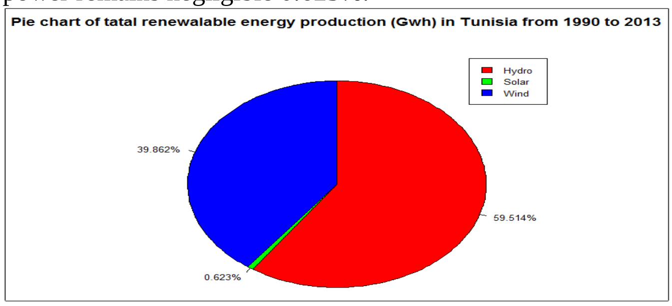

Fig.4 Share of total renewable energy production (Gwh) in Tunisia during the period from 1990 to 2013.

However, the development of renewable energy is chaotic around the world and the energy production patterns change due to structural instabilities related to the behavior of economic agents and dynamic instabilities due to the fact that every time a given growth rate determines a new growth path for future periods [15]. But today, the use of other sources of alternative energy is a need to solve the blocking of the current Tunisian energy system. From then, Tunisia has tried to improve its policy of energy conservation and promotion of renewable energies by adopting a national program based on self-generating of renewable energy sources and energy saving. Then in another stage covers the period 2010 to 2016, Tunisia has tried to enrich its national renewable energy policy by adopting a new program based on the solar energy production, in order to increase efficiency in its renewable energy production capacity [20].

Today, the structural and cyclical analysis of the dynamic of Tunisian industry dynamic shows that the renewable energy system is unstable and actually known by its erratic endogenous fluctuations which can passes through deep structural changes. The concept of energy transition is defined as «*a fundamental structural change in the energy sector of a certain country, like the increasing share of renewable energies and the promotion of energy efficiency combined with phasing out fossil energies*» ([12], p. 3).

The present paper examines the possibility of both nonlinearity and endogenous structural change. The nonlinearity of the asymmetrical approach had been examined for many years, so that it can help the existence of many regimes with different dynamics for one single variable. On the other hand, the structural breaks considered can be relatively smooth, rather than necessarily abrupt. So, our framework is the class of smooth transition autoregression (STAR) models. This class is particularly attractive here, because it can used for encompasses both nonlinearity and endogenous structural change [17].

So, the STAR empirical approach consists to define the different conditions for identify dynamic regimes in order to allow the nonlinear dynamic behavior of an analyzed time series, depends on the regime of energy cycle in a given moment according to which an industry is situated in a phase of expansion or in a phase of recession. The formalization of the endogenous cycle transition of Tunisian renewable energy system is studied with the expression (1).

Before studying the contemporary phenomena of the endogenous cycle transition intrinsically generated by endogenous instability of the dynamics fluctuation of time series, it seems advantageous to have a look at the STAR model according to the methodology described in [24], [25] and recently in [26].

III. REPRESENTATION OF THE STAR MODEL

The autoregressive model of smooth transition STAR is initially proposed in its univariate form in [27], [24]. In general, the two regime STAR model with order p for the variable S_t is given by the explicit expression (1) as,

$$s_t = \beta_0 + \boldsymbol{B}'\boldsymbol{S_t} + (\theta_0 + \boldsymbol{\Theta}'\cdot\boldsymbol{S_t})\cdot F(s_{t-d}\,;\gamma, c) + u_t \qquad (1)$$

where, $\boldsymbol{S_t} = (s_{t-1}, s_{t-2},..., s_{t-p})'$, $\boldsymbol{B}' = (\beta_1, \beta_2,..., \beta_p)$, $\boldsymbol{\Theta}' = (\theta_1, \theta_2,..., \theta_p)$, $u_t \sim \text{iid}(0, \sigma_u^2)$.

The continuous mathematical function $F(s_{t-d}\,;\gamma\,, c)$ is known as the function of transition which bounded between zero and one when the variable of transition s_{t-d} of the endogenous s_t increases. The role of this transition function is to authorize the model to switch dynamically between different regimes smoothly. The delay parameter of transition d is the optimal lag length; c is the threshold parameter and $\gamma > 0$ is the smooth transition speed between the possible regimes. Here, the non-linearity is ensured by the conditioning on the lagged values such as the past of the realized value of s_{t-d}. The delay parameter d gives the periods number which brings the variable transition s_{t-d} change in the dynamic. The first form of the transition function frequently utilized in literature is that of the logistic function on which the explicit expression is defined by:

$$F_L(s_{t-d}\,;\gamma, c) = \left(1 + \exp\left(-\gamma\,(s_{t-d} - c)\right)\right)^{-1} \qquad (2)$$

where the expressions (1) and (2) contribute to the logistic STAR model (LSTAR). In the figure 5 (a), the function of the

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logistic transition varies in an increasing and monotonous way in function of s_{t-d} for different values of smoothing parameter γ=1; 5; 10. We note that when γ tends to infinity, if $s_{t-d} \leq c$ then $F_L(s_{t-d}; \gamma, c) = 0$, if $s_{t-d} > c$ then $F_L(s_{t-d}; \gamma, c) = 1$ which means it becomes a threshold autoregressive (TAR) model. When γ tends to zero, $F_L(s_{t-d}; \gamma, c)$ becomes a linear autoregressive (AR) model. A second function is proposed by [28], it is the function of exponential transition where the explicit expression is defined as:

$$F_E(s_{t-d};\gamma,c) = 1 - \exp(-\gamma(s_{t-d} - c)^2) \quad (3)$$

Hence, theoretically speaking, the specification LSTAR allows one to describe the situation of asymmetry where cycles could be characterized by different dynamics whereas the ESTAR model may give rise symmetric dynamics for phases of expansion and recession of cycles but with some intermediary stages characterized by a different dynamics. While, both process of transition becomes steeper if γ is larger.

IV. EMPIRICAL DATA

In this study we used data collected from the IEA's Tunisia statistics dataset [21]. Our main variable is the total renewable energy production (Gwh) during the period[1] from 1990 to 2013. This annual time series of renewable energy source denoted RES include hydro, wind and solar photovoltaics. Our motivation for choosing this variable is for three main reasons. Firstly, one of the primary motivations for adopting renewable energy sources is the contribution of the diffusion of renewable as sources of sustainable energy to identify a national energy mix trend. Second, from policy perspectives, most of the empirical literature on the energy transition policies used RES as a dependent variable that can play a significantly role in energy policy regulation including RE policies. Specially, such policies have a fundamental role for transition from coal, oil, and natural gas to wind, solar power, and geothermal energy. Third, the contribution of RES to total electricity generation is more appealing as it would allow energy policy makers to reduce CO_2 emissions generated from electricity production, not consumption [22].

TABLE I
DESCRIPTIVE STATISTICS OF MONTHLY SERIES OF IPI

Length	**Min**	**Max**	**Median**	**Average**	**Variance**
24	39	429	91	126.875	8734.027

Source: Estimates made by the authors.

The analysis of graphic of the curve illustrated in figure 6 about the total renewable energy time series at a determinant level demonstrates that this time series is not stationary since it is evident that his evolution over time presents an increasing trend, without a seasonality effect.

[1] Over the 1990-2013 sample period, the renewable sources include hydro, solar photovoltaics and wind power. The start date was chosen to reflect the rapid deployment of RES after 1990 as a result of the energy policies adopted in Tunisia, while the endpoint was chosen based on the availability of data when we started this study.

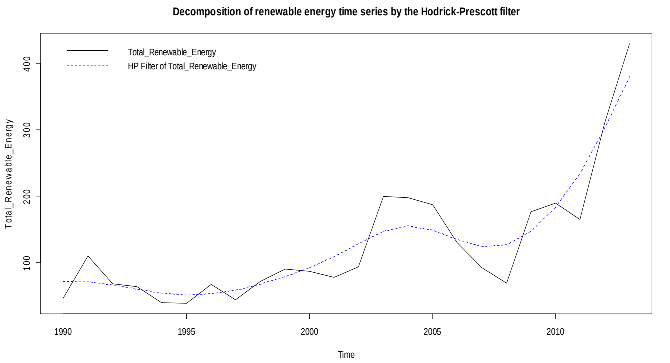

Fig. 6 The Hodrick -Prescott filter decomposition and the evolution of the annual total renewable energy time series in Tunisia from 1990 to 2013.

The decomposition using the Hodrick Prescott filter clearly demonstrates that this time series evolves over time through a nonlinear general tendency, but without any deterministic seasonality. So, we will think to use a sophisticated approach based on a nonlinear regression modelling. Now, we will expose the methodology of STAR modeling cycle.

V. METHODOLOGY OF CYCLE CHARACTERIZATION

The methodology of nonlinear specification, estimation and evaluation of cycle of STAR models consists in following a described procedure [25], based on the five following steps:

- Step 1: Specify the autoregressive linear AR (p) model;
- Step 2: Test the linearity for different values of delay parameter d of transition variable and determine the optimal lag length of d, when the test is rejected;
- Step 3: Choose the appropriate model among the LSTAR and ESTAR models using a sequence of hypothesis tests;
- Step 4: Estimate the parameters of the selected STAR model;
- Step 5: Forecast and evaluate the appropriate model using diagnostic tests.

These steps are briefly detailed as following:

1) Specification of the AR(p) model:

According to [25], we fixed a maximum of lag length equal to p=12 and we tried to applied the Akaikae information criterion (AIC) and the Schwartz Baysian criterion of (SIC), in order to compare different autoregressive process AR(p) for the analyzed data of the stationary time series. The calculations of these two criteria for different delay orders of the annual total renewable energy time series data are stored by many R commands. The main of results confirmed p = 2 is the optimal lag length. We conclude that the model AR (2) is already the most appropriate process selected by reference to both criteria.

2) Testing Linearity against STAR model

For the case of LSTAR process and by reference to the procedure introduced in [28], to address the parameter identification problem, [25] suggests to approximate the logistic transition function by a third-order Taylor's polynomial development. This approximation is an auxiliary

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regression given by the following expression, assuming that d is known:

$$s_t = \alpha_0 + \alpha' \cdot w_t + \sum_{j=1}^{2} \alpha_{2j}\, s_{t-j} s_{t-d} + \sum_{j=1}^{2} \alpha_{3j}\, s_{t-j}\, s_{t-d}^2 + \sum_{j=1}^{2} \alpha_{4j}\, s_{t-j} s_{t-d}^3 + e_t$$

where, $w_t = (s_{t-1}, s_{t-2})'$, $\alpha' = (\alpha_1, \alpha_2)$, e_t ~ iid(0, σ_e^2).
According to the null hypothesis of linearity,

$$H_0 : \alpha_{2j} = \alpha_{3j} = \alpha_{4j} = 0, \quad \forall j = 1, 2$$

This is equivalent to the fact that the parameter of transition γ is null in the explicit expression of logistic transition function. Hence, the appropriate statistic is similar of the LM-type-statistic asymptotically distributed according to the chi-square law with 3p degrees of freedom.

Wile, by applying the same mentioned procedure for the case of ESTAR process, [25] suggests approximating the exponential transition function by a first-order Taylor's polynomial development. The appropriate statistic is similar of the LM-type-statistic asymptotically distributed according to the chi-square law with 2p degrees of freedom. This leads to the auxiliary regression given by the following expression, assuming that d is known:

$$s_t = \alpha_0 + \alpha' \cdot w_t + \sum_{j=1}^{2} \alpha_{2j}\, s_{t-j}\, s_{t-d} + \sum_{j=1}^{2} \alpha_{3j}\, s_{t-j}\, s_{t-d}^2 + v_t$$

where, $w_t = (s_{t-1}, s_{t-2})'$, $\alpha'' = (\alpha_1, \alpha_2)$, v_t ~ iid(0, σ_v^2).
According to the null hypothesis of linearity,

$$H_0 : \alpha_{2j} = \alpha_{3j} = 0, \quad \forall j = 1, 2$$

By applying these two practice tests of linearity, every time, the delay parameter d is fixed arbitrary. To estimate the value d, for each test of linearity, the LM-statistic will be based on different values of d (1≤ d ≤ D) and can be obtained as usual form:

$$LM = T \times \frac{\left(SSR_{H_0} - SSR_{H_1}\right)}{SSR_{H_0}}$$

Where T is the number of observations, SSR_{H_0} and SSR_{H_1} are respectively the sum of squared residuals of the linear regression model AR (2) under the null hypothesis and the sum of squared residuals of the linear regression model under the alternative hypothesis, every time, based on the complete auxiliary regression of s_t. If the null hypothesis is rejected at least one d, then the appropriate value of d is to be estimated, we choose the one with the smallest p-value, which also gives the LM-test with the highest power significance. The results of LM linearity test are presented in table II and show that the null hypothesis of linearity is always rejected at 5% level for the delay of transition variable d = 1, which confirms that really there is a structural break in the dynamic of the annual total renewable energy time series for the indicated previously date and the appropriate delay parameter value is fixed as d = 1.

TABLE II
RESULTS OF LM LINEARITY TEST AND OPTIMAL CHOICE OF DELAY PARAMETER OF TRANSITION VARIABLE

	d^*=1	**d=2**
H_0	2.159 (0.0097)	1.014 (0.0238)

Source: Estimates made by the authors.
(*) Indicates the optimal lag length selected value of delay parameter below the threshold at the 5% significant level. H_0: AR model versus H_1: STAR model. The numbers between parentheses are the p-values of linearity test type of LM.

3) Choice between LSTAR and ESTAR models

After we have rejected the null hypothesis of linearity and fixing the optimal lag length, the following step consists on choosing the appropriate STAR model among the LSTAR and ESTAR models by applying a short sequence of intricate tests is as follow:

$$H_{01} : \alpha_{4j} = 0, \qquad \forall j = 1, 2$$

$$H_{02} : \alpha_{3j} = 0 \big| \alpha_{4j} = 0, \qquad \forall j = 1, 2$$

$$H_{03} : \alpha_{2j} = 0 \big| \alpha_{4j} = \alpha_{3j} = 0, \qquad \forall j = 1, 2$$

The decision rules of selection the form of smooth transition function between the LSTAR and ESTAR family of models[2] are introduced by [25]. First of all, if H_{01} is the only rejected null hypothesis, this could be interpreted as a favor of LSTAR model. If H_{01} is accepted while H_{02} is rejected, this could be in favor of the model ESTAR. If H_{01} and H_{02} are accepted, while H_{03} is rejected, in this case we should select the LSTAR model. The results of model selection are illustrated in the table III. In all cases the nonlinearities appear to be of a logistic form, which constitutes the criterion for choosing the LSTAR model specification. Accordingly, the selection appropriate model in this analysis case is the LSTAR model.

TABLE III
RESULTS OF TERÄSVIRTA TEST OF CHOICE BETWEEN ESTAR AND LSTAR FORM OF TRANSITION FUNCTION

H_{01}	**H_{02}**	**H_{03}**	**Transition**
5.036* (0.005)	1.927 (0.201)	1.203 (0.639)	LSTAR

Source: Estimates made by the authors.
(*) Indicates a rejection null hypothesis of linearity against LSTAR and ESTAR transition function at the 5% significance level. The numbers in parentheses are p-values of LM tests of linearity.

4) Estimate the parameters of the chosen LSTAR model

After specifying the adequate process LSTAR via the linearity tests type of LM, this step suggests estimating the nonlinear dynamic of the selected LSTAR model by minimizing the sum of squared residuals specified as:

$$Q_T(\psi) = \sum_{t=1}^{T} \hat{u}_t^2(\psi)$$

[2] We could choose the appropriate model by comparing the level of significance of the Fisher's three statistics. If p-value of test H_{02} is too small among the three, it will be advantageous to choose the ESTAR model, if it is not the case we choose the LSTAR model.

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where ψ = (Θ′, B', γ, c) and $\hat{u}_t(\psi)$ are residuals from the LSTAR model.

TABLE IV
ESTIMATION OF PARAMETRS OF LSTAR MODEL

Linear regime				
β_0	β_1		β_2	
0.8865** (2.4969)	-0.2328 (-0.8023)		1.7603* (1.8586)	
Nonlinear regime				
θ_0	θ_1	θ_2	γ	c
-0.9366** (-2.5062)	0.0202 (0.0529)	-1.6887* (-1.7236)	126.464	-0.0889

Source: Estimates made by the authors.
(**) and (*) Indicate respectively statistical significance at the 5% level and the 10% level. The residuals variance = 0.1038. The data between parentheses are the t-student values of parameters estimation for each linear and nonlinear part.

These results demonstrate that the estimated value of γ is 126.464, which implies a possible quick cyclical transition from one regime to the other. This confirms the smoothness of switching behaviour during different cyclical phases of expansion and contraction of endogenous cycle. So, the intrinsic dynamics is able to explain how accelerating renewable energy transition can return from one regime to other. This dynamic reasonably explains the significantly improved asymmetry of logistic generating process of transition variable.

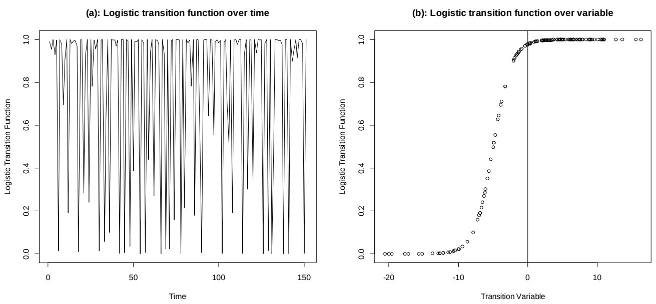

Fig. 7 Logistic transition functions versus time and transition variable.

5) Diagnostic tests

After estimate the adequate process LSTAR, this step consist to evaluate the fitted model, using the misspecification test based on LM statistic for LSTAR model residuals correlation proposed by [30]. We consider the skeleton of LSTAR model denoted by:

$$G(s_t,\psi) = \beta_0 + B' S_t + (\theta_0 + \Theta' \cdot S_t) \cdot F(s_{t-d}\,;\gamma, c)$$

In this specification, the no residual autocorrelation null assumption for LSTAR model can be tested against the alternative of serial dependence up to order *q* using an LM-test obtained as TR^2, where T is the number of observations and R^2 is the coefficient of determination from the regression of $\hat{u}_t$ on $\nabla G(s_t,\hat{\psi}) = \partial(s_t,\hat{\psi})/\partial\psi$, with ψ and *q* lagged residuals $\hat{u}_{t-1}, \hat{u}_{t-2}, ..., \hat{u}_{t-q}$. The resultant LM test statistic is asymptotically distributed according to the chi-square law with q degrees of freedom.

VI. CONCLUSION

Nowadays, it became a need to have a strong energy strategy to resist against the energy dependence and its high cost. In this way, we were confronted to the energy transition mechanism. The empirical evidences show that the dynamic of the renewable energy cycle transition in Tunisia has a nonlinear data generating process. Testing and modelling the presence of nonlinearity using the two regime univariate smooth transition autoregressive (STAR) model is proposed for the present study to investigate possible nonlinearity in average. All statistical tests can provide evidence of nonlinearity. Analysis shows that uses the STAR class of nonlinear models needs to have different functional choices between LSTAR and ESTAR type nonlinearities. Further empirical investigation shows that LSTAR model is more appropriate to capture observed asymmetries in our case. These results are important for our national policy makers in energy sector, as they offer improved explication for the nonlinear dynamism generating process of energy transition mechanism in Tunisia and give the necessary more accurate economic and social inferences. The results are also interesting for other perspectives open studies suggesting preference of nonlinear modelling with smooth transition when structural change is permitted.

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