Emerging Markets Queries in Finance and Business

Testing Random Walk hypothesis for Romanian consumption: a continuous time approach

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Abstract

In this paper I addressed the random walk hypothesis of the permanent income theory (RW-PIH) for Romanian economy in a new vision based on a continuous time approach. In the literature exists several econometric ways to test for the implications raised by the new RW-PIH theory advocated by Hall (1978), among which perhaps the most used is the class of unit roots test. As pointed out by Cochrane in successive works, the use of unit roots test for stationarity could provide ambiguous information from different reasons. In that sense, here I switch to a continuous environment that allows for a much larger view on what we call stationarity in discrete time. For example, the population of a stochastic process may follow an Ornstein-Uhlenbeck style process, but because the short sample counterpart we found signs for non-stationarity in discrete time. For this purpose I have restored three methods to fit an Ornstein-Uhlenbeck process on the Romanian non-durable goods consumption, in order to identify some important stochastic properties of the underlined series. Also in the current paper I emphasized the following problem: in the emerging countries, heteroskedasticity of the shocks which affect the data generating process for consumption may be due to the sharp switching to different states caused by several types of jumps and not necessarily to the way in which the agents set their decisions.

Keywords: Consumption, Mean Reverting, Ornstein-Uhlenbeck process, Random Walk, Stationarity

1. Introduction

The analysis of consumption dynamics raised a huge interest in the macroeconomic literature such the prominent economists studied in detail this topic. Nobel prizes Franco Modigliani (1957) with life-cycle theory and a bit later Milton Friedman with permanent income theory came to neglect the Keynes theory about consumption behavior. Maybe the most appealing was the permanent income theory which states the households’ consumption is linked to the permanent income and not to the correct income (PIH theory). In that sense, Robert Hall 1978 showed that if the permanent income theory is correct, then under certain conditions

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Selection and peer-review under responsibility of the Emerging Markets Queries in Finance and Business local organization

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the consumption dynamics follow a random walk process (RW-PIH theory). In fact, the Hall proposal represents a central point within the theory of rational expectations throughout its stochastic implications. Since then many researchers have found if the Hall’s hypothesis really resemble the real situation. But the empirical evidences are ambiguous even that many balance tends to lean on the side of those who contradict the theory of Hall. Flavin (1984) and Deaton and Campbell (1989) launched two theories that rejects the RW-PIH hypothesis: the “excess sensitivity” hypothesis which shows the consumption is very sensitive to movements in the permanent income and “excess smoothness” that argue the contrary in regard with the relation between consumption and permanent income. On the other hand, Reis (2009) showed a highly positive correlated process describe the US consumption, but is not a random walk process. All the studies mentioned before referred to US economy for which large samples of data are available. But what we can say about the predictability of consumption in an emerging economy for which only a small sample of data is available? Not so much studies are done on this topic for such economies. Maybe the first toll to be carry to test the random walk hypothesis are the unit roots based analysis. Instead, Cochrane (1988, 1991) in successive works drew the attention the unit roots test should be carry with cautions owing to the local episode of non-stationarity. In fact, here I address a gap between the philosophies of the RW-PIH theory, the use of some analysis to test that hypothesis such are the unit roots based analysis and the context of emerging economies. More exactly, the researcher that I mentioned above put the persistence of the shocks that affect consumption on the back of the rationality posed by agents in their process to take decisions regarding consumption problem. I split the analysis of this topic in two studies. In the current study I propose the use of a mean-reverting continuous time approach for the study of consumption behavior. Three reasons are behind this approach. On the first ground, a continuous model it is a more natural choice to describe the data-generating process. Secondly, as Baille (1996) points out there could be an important difference between a covariance-stationary process and a mean-reverting process. Thirdly, the use of continuous models enriched with jumps doesn’t neglect the uncertainty as the linearized models do as Merton (1975) and Posch (2007) underline. This paper represents the first part of a study designed to analyze the link between RW-PIH theory, the use of some analysis to test that hypothesis such are the unit roots based analysis. Here I calibrate an Ornstein-Uhlenbeck process to data on consumption expenditures in order to get information about mean-reversion parameter and the half-life of unanticipated shocks. The main advantage of using a continuous time approach against its discrete time counterpart or unit root test is the first class of models provides a better description of the data when there it is the case of near-unit root phenomena. For the calibration of Ornstein-Uhlenbeck process on consumption data I called three techniques: the first one is based on the Arithmetic Ornstein-Uhlenbeck approach proposed by Dixit and Pindyck (1997); secondly I use an estimation based approach based on the general method of moments (GMM) for a mean-reverting process with constant elasticity of variance (CEV) and thirdly I appealed the method proposed by Ait-Sahalia (2011) which suppose the sequential approximation of the transition probabilities of a Markov Chain in order to obtain a closed form solution for the density function.

2. Theoretical background

Lucas proposed the first consumption based asset pricing model that attempts to link the inter-temporal decisions taken by a representative agents to its budget constraints. In that sense it was proposed an optimization program to solve and obtain the optimal solution for a typical consumer in taking the decision which governs his life. Such an optimization problem it is described by the following relations:

\[ \max_{\{C_t\}} U_t = E_t \left( \sum_{t=0}^{\infty} \beta u(C_{t+1}) \right) \]  \( (1) \)
(i) \( A_{t+1} = A_t R_t + Y_t - C_t \),
(ii) \( \lim_{t \to \infty} (\Pi_{s=0}^{t-1} R_s)^{-1} A_t = 0 \),
(iii) \( A_0 \) is given,

where \( \beta \) denotes the discount factor of consumption flows \( \{C_0, C_1, C_2, \ldots \} \) and satisfies \( 0 < \beta < 1 \), \( A_t \) represents the non-human wealth, \( R_t \) is the real ex-post interest rate and \( Y_t \) is labour income\(^{\dagger} \). The discount factor is equal with \( \frac{1}{1+\delta} \), where \( \delta \) define the inter-temporal preferences of our representative agent. Therefore, small values of the discount factor \( \beta \) show a high degree of impatience which turns out in a high preference to consume now in place of a future consumption. In fact, the level of \( \beta \) represents a measure for perceived expectation by investors about future economic outlook. The above relation shows that a representative agent with a infinite horizon of time and without liquidity constraints maximizes its utility \( U_t \) by choosing an optimal path which satisfies the budget constrain (i) and the non-Ponzi game relation (ii), in the context of an initial stock of a non-human wealth. We can combine the states of the three constraints in order to derive the following relation for the streams of non-human wealth at different moments in time:

\[
A_0 = E_t \sum_{t=0}^{\infty} \left( \prod_{s=0}^{t-1} R_s \right)^{-1} (C_t - Y_t)
\]

Here we referred to a stochastic version of the consumer problem as the operator \( E_t \) represents the uncertainty surrounding the marginal utility from consumption. For example the class of RBC models states the underlined uncertainty is induced by the real shocks that affect the endowment process. Within the literature exists several solution to the above optimization program, but here we use the Bellman approach. Here it is assumed that utility function from relation (1) it is defined by the CRRA style function:

\[
u(C_{t+1}) = \frac{C_{t+1}^{1-\gamma}}{1-\gamma}
\]

where \( \gamma \) represents the Arrow-Pratt measure for agents' risk aversion which is defined as \( \frac{-u''(c)c}{u'(c)} \). In fact, the parameter \( \gamma \) is the absolute value of the elasticity of marginal utility, being therefore determined by the concavity of the utility function. It is important to note that there exists an inverse relationship between inter-temporal substitutability of consumption between sub-sequent periods and the risk aversions parameter. On the other hand, another important remark is that \( \gamma \) parameter is independent of consumption level.

In relation (1), the operator \( E_t \) represents the rational expectation formed at the moment \( t \) based on the whole available information at that moment. Therefore considering the available set of information \( I_t \) formed upon the moment \( t \) the following relation will hold: \( E_t(C_{t+1}) = E_t(C_{t+1} | I_t) \) that means the forecast errors are uncorrelated with the variables from the information set: \( E_t(C_{t+1} - E_t(C_{t+1} | I_t)) = 0 \). Given all these facts, the next step consists in optimizing the above program in order to get the optimal decision for our representative agent. We recall that for this purpose will be used the Bellman\(^{\ddagger} \) optimality principle which supposes the conversion of an infinite horizon of time to a two-period horizon and any optimal solution to the new two-period horizon is valid also for the original problem. The state variable of our representative agent is

\( Y_t \) could also be treated at aggregate level as an endowment process.

\( \dagger \) The main idea behind the Bellman approach is to define a new function, called the value function. This function denotes the maximised value of the objective function achieved from the moment \( t \) onwards, given the level of the state variable.
constituted by the certain amount of resources at the end of moment $t$: $A_t R_t + Y_t$. On the other hand, the control variable $C_t$ helps the agent in managing his resource at $t+1$ moment. Given these observation, we form the following value function\(^\S\) related to Bellman equation\(^\SS\):\(^{15}\)

$$V_t(A_t R_t + Y_t) = \max_{C_t} \{u(C_t) + \beta E_t V_{t+1}(A_{t+1} R_{t+1} + Y_{t+1}) \}$$  \hspace{1cm} (4)

Above Bellman equation states the future agent’s income $A_{t+1} R_{t+1} + Y_{t+1}$ is uncertain which attains a stochastic feature to $V_{t+1}$. The next step in optimizing the consumer’s program consists in getting F.O.C with respect to $C_t$ and $W_t$, where $W_t$ represents the total certain wealth owned by our representative consumer\(^\dagger\): $A_t R_t + Y_t$. Therefore the two partial differentiations are:

$$\frac{\partial V_t}{\partial C_t} = u'(C_t) - \beta R_t E_t V_{t+1}'(W_{t+1}) = 0$$  \hspace{1cm} (5)

$$\frac{\partial V_t}{\partial W_t} = \beta R_t E_t V_{t+1}'(W_{t+1})$$

Calling then the Benveniste-Scheinkman theorem it results our work-horse, namely the so-called consumption Euler equation under CRRA preferences:

$$C_t^{-\gamma} = \beta R_t E_t(C_{t+1}^{-\gamma})$$  \hspace{1cm} (6)

Two important remarks arise in regard with derived consumption Euler equation. On the first ground, the Euler equation makes prediction on the short-run dynamics of interest variables. Secondly, the derived Euler equation represents a first order condition for optimality and not a closed form solution, which means the relation (6) cannot be interpreted as a consumption function.

Under the rational expectation assumption which assumes $\beta R = 1$ at the steady state, then consumption dynamics follow a random walk: $\Delta C_{t+1} = \varepsilon_{t+1}$, where $\varepsilon_{t+1}$ denotes the expectation error with the property $E_s[\varepsilon_t] = 0$, for each $s < t$. Or putting otherwise, I reinsert the idea mentioned before according to which the forecast errors are uncorrelated with the variables from the information set: $E_t(C_{t+1} - E_t(C_{t+1}|I_t )) = 0$.

The statement in regard with stochastic behaviour of consumption dynamic is usually tested (in discrete time) by estimating an autoregressive model with intercept or by applying a unit root test which in fact represents also an auto-regressive representation of the underlined data. For a bundle of reasons such are those ones specified in the introduction, here I will prefer a continuous time approach for the modelling of consumption dynamics. Firstly I will specify a mean-reverting process without CEV specification:

$$dC_t = \alpha(\theta - C_t) dt + \sigma dW_t$$  \hspace{1cm} (7)

where $C_t$ represents consumption data, $\theta$ is its long-run mean, $\alpha$ is a speed reversion of consumption to its

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\(^\S\) In mathematical terms, the value function is defined as a functional equation.

\(^\SS\) Relation no. (4) is well known in the literature as the Bellman equation.

\(^\dagger\) It is commonly assumed that interest rate is non-stochastic, so the time subscript doesn’t make any sense in that case.

\(^\ddagger\) Therefore $W_{t+1} = R_t(W_t - C_t)$. 
long-run mean, \( \sigma \) denotes the diffusion parameter, while is a Wiener process. The above described process called in the physics as the Ornstein-Uhlenbeck process represent a special type of a random walk process, because it show a tendency to move around a central location. If the speed reversion is very low, then the Ornstein-Uhlenbeck process behaves like a random walk. Vasicek (1977) proposed for the first time such a model to determine the term-structure of interest rates. More exactly, deriving on our case, the defined Ornstein-Uhlenbeck process says that if the instantaneous consumption it is located above its long-run mean, then the drift will be negative in order to assure a move back for instantaneous consumption to its long-run level. A important feature of the Ornstein-Uhlenbeck is that in contrast to Geometric Brownian Motion based models, the variance not evolves proportionally within the tendency pose by instantaneous consumption to move back towards its long-run mean. Using the approach followed by Dixit and Pindyck we consider 

\[
dc_t = \delta + \beta c_{t-1} + \sigma \varepsilon_t, \varepsilon_t \sim N(0,1)
\]  

(8)

where \( \delta = \alpha \mu \Delta t \) and \( \beta = -\alpha \Delta t \). Depending on closeness of \(|\beta|\) to 1, we will classify the process as being random walk, near random walk or mean reverting. Even that we move back to an AR type specification, the purpose followed here is to see the statistical significance of \( \beta \) and the persistence of shocks implied by the size of \( \beta \). This observation is important because even an underlined process has a economic and financial meaning for mean reverting in its population terms, owing to the short sample our process will count for a random walk behaviour. But this remark will be exploited in another technique that will be use here in order to obtain a high accuracy of information. In that sense I will use another measure to describe the mean reverting behaviour called the half life of shock: \( t_{1/2} = \frac{\ln(2)}{\alpha} \). The half life measure counts the half time necessary to our underlined process to revert to its long-run mean after an unanticipated shock.

For the estimation of Arithmetic Ornstein-Uhlenbeck I will use Bayesian techniques. Modern Bayesian econometric tool of analysis gives the researcher the opportunity to incorporate its own knowledge about observed phenomena into the estimation process of different models of regression. More exactly, in the classical econometrics, the research conducts its analysis on the relation between two variables using the likelihood function in order to estimate the vector of coefficients and variance of error term. Instead the Bayesian econometrician call the Bayes Law from the probability theory and writes the posterior distribution, which in the case of a simple regression model \( Y_t = \beta X_t + \varepsilon_t \), with \( \varepsilon_t \sim N(0, \sigma^2) \), takes the following form:

\[
H \left( \frac{1}{\sigma^2}, \beta | Y_t \right) = \frac{1}{(\sqrt{2\pi \sigma^2})^d} \exp \left( -\frac{(Y_t - \beta X_t)^2}{2\sigma^2} \right)
\]

(9)

The above relation states that Bayesian econometrician updates its prior beliefs postulated under the form of probabilities distribution for coefficients \( \beta \) and variance of error term \( \frac{1}{\sigma^2} \) (the first term from the right hand of equation) with the information on observed data provided by the likelihood function (the second term). In order to infer the two sets of parameters, the researcher has to isolate the marginal distribution of \( \beta \) and \( \frac{1}{\sigma^2} \) from the
The posterior distribution which in fact is a joint distribution:
\[
\Omega(\beta|Y_t) = \int_0^\infty \Omega\left(\frac{1}{\sigma^2},\beta|Y_t\right) d\frac{1}{\sigma^2} \Omega\left(\frac{1}{\sigma^2}|Y_t\right) = \int_0^\infty \Omega\left(\frac{1}{\sigma^2},\beta|Y_t\right) d\beta
\]

The approximation of both the joint distribution and the two marginal distributions it is possible with the help of Gibbs Sampling algorithm which is a numerical procedure that draws from conditional distribution.

The second approach that I use in this paper is based on the GMM estimation of a mean-reverting process with CEV specification. I enriched the standard model with this CEV specification to see if there is the case of a nonlinear relationship between instantaneous consumption and volatility and role of the drift in such a situation.

The used model has the form
\[
dc_t = \alpha(\mu - c_t)dt + \sigma c_t^\gamma dW_t
\]
where \(c_t^\gamma\) represents the CEV specification, implying that
\[
dc_t = \alpha(\mu - c_t)dt + Var[dC_t] = \sigma c_t^\gamma dt.
\]
The GMM method supposes the minimization of the following relation:
\[
\min_\theta \left( \sum_{t=1}^T [f(X_{t+i},\theta)z_t] \right) \Psi^{-1} \left( \sum_{t=1}^T [f(X_{t+i},\theta)z_t] \right)
\]
where after the discretisation \(dt = 4, f(X_{t+i},\theta) = \left( \frac{\Delta c_t - (\delta + \beta c_t-1)/4}{(\Delta c_t - (\delta + \beta c_t-1)/4)^2 - (\sigma c_t^\gamma)/4} \right)\), \(\theta\) is a vector of parameters and \(z_t = [1, c_t]\) is a vector of instrumental variables and \(\Psi^{-1}\) is a weighting matrix. Thus the derived moment conditions are: \(m_t = \left( \frac{\Delta c_t - (\delta + \beta c_t-1)/4}{(\Delta c_t - (\delta + \beta c_t-1)/4)^2 - (\sigma c_t^\gamma)/4} \right) \otimes [1, c_t]\), where \(\otimes\) is the Kronecker product.

The third approach called here is based on the Ait-Sahalia (2011) technique which supposes the sequential approximation of the transition probabilities of a Markov Chain in order to obtain a closed form solution for the density function. Giving the Markovian property of diffusion models, using the Bayes rule it is obtained the log density for the underlined process:
\[
L_n(\theta) \equiv \sum_{l=1}^n \ln P_C(\Delta, C|\Delta, C_{(l-1)\Delta}; \theta)
\]
where \(P_C\) represents the transition function of the Markov process defined as a conditional density which depends on the state variables \(C_\Delta\) at a future time \(\Delta\) given the initial \(C_{(l-1)\Delta}\), while \(\theta\) is a vector of parameters.

The main idea behind Ait-Sahalia approach is to make two second transformation to original process \(C\) to close enough to a Normal variable around to which to construct a sequence for \(P_C\) and then to move back to the process \(C\) to obtain a sequence for \(P_C\) around a deformed Normal variable. The first transformation is based on the relation \(CC_t \equiv f(C_t;\theta) = \int C_t du(\sigma, u, \theta)\), which gives a nonlinear transformation of \(C_t\) unless \(\sigma\) is constant.

By Ito’s lemma it is obtained a new process for \(dCC_t\), while the second transformation implying a

\[**\]

\[***\] The obtained expression \(C_{CC_t} = \frac{(C_{CC_t} - C_{\Delta})}{\sqrt{\Delta}}\) converges to the Dirac shape for small values of \(\Delta\).
standardisation of $CC_t$: $CC_t = \frac{(CC_t - cc_0)}{\delta}$. The sequence of transformation implies that $CC_t$ is close enough to the Normal. Now using the so called “probability” Hermite polynomials $H_j(ccc) = e^{ccc/2} \frac{d^j}{dz^j} e^{-ccc/2}$, it is obtained the Normal standardized density: $\phi(ccc) \equiv \frac{e^{-ccc/2}}{2\pi^{1/2}}$. Using a Hermite expansion of order $J$ in the state variable $ccc$ of the transition function $P_{ccc}$ results the following relationship with fixed $\Delta$, $\theta$ and $cc_0$:

$$P_Z^{(j)}(\Delta, ccc|cc_0; \theta) \equiv \phi(ccc) \sum_{j=0}^{J} n_j(\Delta, cc_0; \theta) H_j(ccc)$$

(14)

Calling the orthogonally property of Hermite polynomials it is obtained an expression for $n_j$ as an expected value over the conditional density $P_Z^{(j)}$, which allows therefore to obtained the coefficients needed to approximate a deformed Normal density by reverse the engineering of transformations:

$$n_j(\Delta, cc_0; \theta) \equiv \frac{1}{j!} \int_{-\infty}^{\infty} H_j(ccc) P_Z^{(j)}(\Delta, ccc|cc_0; \theta) dccc$$

(15)

For $j \to \infty$, there it is applied a Taylor expansion of order $K$ around $P_Z^{(j)}$. The philosophy behind the approach proposed by Ait-Sahalia is to exploit the implications pose by the Central Limit Theory by applying a correction around a leading term, even that we cannot increase the sample size. Thus it is obtained an estimator $\hat{\theta}_n^{(j)}$ that converges to the real (unobservable) $\theta$ and get all its asymptotic properties.

3. Empirical Results

In this study data was collected from Eurostat on non-durable consumption spanning the period between 2001Q1-2012Q3. The data are seasonally adjusted and adjusted by number of working days. Here it is used data on the household and NPISH final consumption expenditure expressed in millions of national currency. There it is applied the logarithm operator to original data, after that are obtained growth rates for consumption. The first issue that I test here is related to existence of the unit roots in growth rates. The ADF accepted the null of unit roots, while the KPSS rejected the null of stationary data at 5% confidence level for the representation with trend and intercept, respectively at 10% for the case with only intercept. This is an important evidence about:

i) the case of high persistence of shocks; ii) rejection of covariance stationary hypothesis but there still could be the situation for mean-reverting or maybe fractional integration and even near random walk behaviour and iii) the presence of “big †††” jumps in data ‡‡‡. On the other size, judging in terms of Wold decomposition, the size of the random walk component is pretty important in consumption dynamics. Analyzing the exponential random walk component§§§, the null joint hypothesis of random walk hypothesis is rejected at 5 %, respectively 10% confidence level depending on the method use, while the strongest rejection came for the large portion from the original sample. Additionally the random walk hypothesis for innovations the affect log returns of data is rejected.

††† Here the concept of “big jumps” is related to finitely lived jumps from the semi-martingale theory.

‡‡‡ In short samples, the random walk processes post low frequency cycles so the drifts may look such a trend or broken trends, but in place there is the case of stochastic trends.

§§§ Because I used log-difference data.
These evidences show on the first ground a high persistence of shocks, the small sample feature may be an impediment in identifying the mean-reverting behaviour and the potential unit root is mainly due to the modification in intercept. In general it is well known that low power of unit roots tests as the low-order AR models tend to overestimate the random walk component. After running some basic analyses for the study of random walk hypothesis, the next consist in estimated a typical Ornstein-Uhlenbeck processes under the form described in previous section. In table 1 are reported the recovered structural parameters of a mean-reverting process calibrated for Romanian consumption.

Table 1. Estimated parameters of Ornstein-Uhlenbeck (OU) processes

<table>
<thead>
<tr>
<th>Arithmetic OU-Bayesian Estim.</th>
<th>GMM</th>
<th>OU-CEV (γ &gt; 0.5)</th>
<th>Ait-Sahalia Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>OU</td>
<td>OU</td>
<td>OU-CEV (γ &gt; 0.5)</td>
<td>OU-CEV (γ &gt; 0.5)</td>
</tr>
<tr>
<td>α</td>
<td>0.1096 (0.2900)</td>
<td>0.0319 (0.4391)</td>
<td>0.1119 (0.4391)</td>
</tr>
<tr>
<td>μ</td>
<td>1.0949 (0.0400)</td>
<td>2.7457 (0.0000)</td>
<td>1.0747 (0.0108)</td>
</tr>
<tr>
<td>σ</td>
<td>0.0490 (0.0000)</td>
<td>0.0227 (0.4450)</td>
<td>0.0448 (0.4450)</td>
</tr>
<tr>
<td>γ</td>
<td>-</td>
<td>0.5271 (0.0000)</td>
<td>-</td>
</tr>
<tr>
<td>t_{1/2}</td>
<td>25.2973</td>
<td>86.9150</td>
<td>24.7774</td>
</tr>
</tbody>
</table>

The rate of mean reverting α for the standard Ornstein-Uhlenbeck method is statistically significant only for the case of using the method of Ait-Sahalia, even that the size of the coefficient is close.

![Graphs showing Bayesian estimation of the Arithmetic Ornstein-Uhlenbeck process and Objective function surface from GMM estimation](image-url)
4. Conclusions

In this paper I addressed the random walk hypothesis of the permanent income theory (RW-PIH) for Romanian economy in a new vision based on a continuous time approach. In the literature exists several econometric ways to test for the implications raised by the new RW-PIH theory advocated by Hall (1978), among which perhaps the most used is the class of unit roots test. As pointed out by Cochrane in successive works, the use of unit roots test for stationarity could provide ambiguous information from different reasons. In that sense, here I switch to a continuous environment that allows for a much larger view on what we call stationarity in discrete time. For example, the population of a stochastic process may follow an Ornstein-Uhlenbeck style process, but because the short sample counterpart we found signs for non-stationarity in discrete time. For this purpose I have restored three methods to fit an Ornstein-Uhlenbeck process on the Romanian non-durable goods consumption, in order to identify some important stochastic properties of the underlined series. Also in the current paper I emphasized the following problem: in the emerging countries, heteroskedasticity of the shocks which affect the data generating process for consumption may be due to the sharp switching to different states caused by several types of jumps and not necessarily to the way in which the agents set their decisions.

Acknowledgements

This work was co-financed from the European Social Fund through Sectoral Operational Programme Human Resources Development 2007-2013; project number POSDRU/107/1.5/S/77213 „Ph.D. for a career in interdisciplinary economic research at the European standards”.

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