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ORIGINAL ARTICLE

Gross domestic product growth, volatility and regime changes nexus: the case of Portugal

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Abstract This paper provides evidence of the behavior of GDP growth volatility in Portugal over the period from 1961 to 2016 with the main objective of measuring the degree of asymmetry of GDP growth rates volatility across the business cycles and its persistence over time. The methodological setting benefits from the most recent developments that recommend the consideration of structural changes in both the mean and variance and asymmetric reactions of volatility to positive and negative shocks. The results document structural changes and significant reductions of GDP growth rates volatility consistent with the "Great Moderation" phenomenon and reveal that the impact of negative shocks on volatility exceeds that of positive shocks more than 4 times over the sample period. Moreover, these asymmetries follow a rather stable pattern over the sample period, suggesting that the Portuguese economy has not been able to reduce its growth vulnerability to cyclical fluctuations.

Keywords GDP · Volatility · Structural change · GARCH · Portugal

JEL Classification C22 · E23 · E32

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1 Introduction

Since the mid-1980s, gross domestic product (GDP, hereafter) in developed nations has exhibited lower volatility over the business cycle. This phenomenon has been referred to as the "Great Moderation" (Bodman 2009).

This empirical evidence has, however, triggered out a deep discussion on the linkage between growth rates and volatility, whose conclusions are far from being consensual. On the one hand, a positive relationship is suggested by the perspective that agents choose to invest in riskier and hence more volatile assets only if the associated risk is offset by the expected rates of return (Black 1987), while "Schumpeterians" postulate that the economic instability generated by the process of "creative destruction" would improve the economic efficiency and thereby the long term growth. Evidence of a positive relationship is found, for instance, in Grier and Tullock (1989), Caporale and McKiernan (1996, 1998).

On the other hand, suspicions of a negative relationship are raised by the idea that higher volatility is associated to higher uncertainty which, in turn, causes constraints to investments and it is found in Ramey and Ramey (1995) and Martin and Rogers (2000), among other studies. Finally, no significant relation between growth and volatility is found in other studies. (See, *inter alia*, Speight 1999; and Grier and Perry 2000).

The lack of consensus on this issue rests on the implications of growth volatility on the countries' economic development. The importance of getting rigorous knowledge of the growth volatility behaviour constitutes the motivation of this paper, given its relevance as an information tool for policy design. However, this issue poses a particular challenge as real GDP growth involves a long run perspective over which structural changes in volatility are very likely to occur. Their occurrence has been, in fact, widely documented in the literature. For example, Kim and Nelson (1999), McConnell and Perez-Quiros (2000), Blanchard and Simon (2001), and Ahmed et al. (2004), among others, document a structural change in the volatility of U.S. GDP growth, while Stock and Watson (2003), Bhar and Hamori (2003), Mills and Wang (2003), and Summers (2005) report a structural break in the volatility of the output growth rate for Japan and other G7 countries, although the break occurs at different times.

The task of modelling GDP growth volatility is not new in the literature. However, the modelling attempts have consisted on the estimation of stable (exponential) generalized autoregressive conditional heteroskedasticity ((E)*GARCH*, hereafter) models, excluding the possible occurrence of structural breaks in the output growth and/or the respective unconditional or conditional variances. Among others, there are the studies of Hamori (2000), Engle and Bollerslev's (1986), Ho and Tsui (2003), and Fountas et al. (2004) whose results suggest strong volatility persistence. However, this conclusion is challenged by several studies, according to which structural changes may confound persistence estimation in *GARCH* models, and it can result from instability of the constant term of the conditional variance (i.e., nonstationarity of the unconditional variance). Neglecting such changes can generate spuriously measured persistence with the sum of the estimated autoregressive parameters of the conditional variance heavily biased towards one. Among others, we may mention Diebold (1986), Lamoureux and Lastrapes (1990), Hamilton and Susmel (1994), Kim et al. (1998), Mikosch and Stărică (2004); Hillebrand (2005); Kim and Nelson (1999); Bhar and Hamori (2003); Mills and Wang (2003); and Summers (2005). The evidence reported in these studies is towards the idea that ignoring regime changes in the mean and/or unconditional variance can bias upward *GARCH* estimates of persistence in variance while the use of dummy variables to account for such shifts reduces the degree of *GARCH* persistence. With this paper, we intend to contribute to the literature on this thematic by providing accurate evidence of the behaviour of GDP growth volatility in Portugal, after having identified the timing of structural changes both in the mean and variance.

Another relevant issue is that earlier studies assume a symmetric relationship between volatility and growth over business cycles. However, there is no a priori reason to believe that the sign (and size as well) of the volatility-growth relation is the same whether the economy is in contraction or expansion. By the contrary, we argue that it is conceivable that the sign of the volatility-growth relation depends on business cycle phases. In this context, several contributions have tried to clarify the nature of the growth-volatility relationship in a limited set of countries OECD countries (see, among others, Fang and Miller 2008, 2009; Fang et al. 2008; and Fountas and Karanasos 2006) or the trade-off between the variability of inflation and output gap (Lee 1999, 2002, among others). This study also contributes to the literature by providing evidence on the asymmetric impact of good and bad news on growth volatility.

In short, the possible evidence of structural changes in output growth volatility, combined with its asymmetric behaviour are the innovative aspects considered in this paper whose general goal is to provide empirical evidence on the growth-volatility nexus for Portugal. Specifically, this paper intends to analyse the degree of symmetry/asymmetry of GDP growth volatility across different phases of the business cycle and its persistence over the sample period.

Our motivation also lies on the relevance of this study for a small open country like Portugal, whose economy has been strongly impacted by international shocks, such as the oil shocks of the 1970s and 1980s, and domestic structural changes that have resulted from national and international arrangements such as the transition to a democratic regime in 1974, the adhesion to the European Union in 1986 (former European Economic Community), the currency change from the Escudo to the Euro in 2000, and the external financial assistance programs in the 1970s, 1980s and more recently, in 2011. Given the structural impacts of those events and the economy vulnerability resulting from its exposure to external economic evolution, the knowledge of the growth-volatility nexus is of extremely importance for the design of short- and long-term policies.

By using an asymmetric GARCH modelling framework, accounting for the existence of structural changes endogenously determined in both the mean and variance, we report evidence of the "Great moderation" in Portugal, characterized by a decline in GDP growth rates and associated volatility. Asymmetric behaviour of growth volatility seems to emerge over the business cycle with higher (lower) volatility being associated to negative (positive) output gaps. The impact of negative shocks on volatility exceeds that of positive shocks more than four times over the sample period and this asymmetric pattern has been stable over time as revealed in a time disaggregate analysis

Accordingly, the paper is organized as follows. Section 2 presents a preliminary data analysis. Section 3 reports the methodological background and empirical results. Finally, section 4 reports the main conclusions.

2 The Portuguese gross domestic product: data, basic evidence and structural changes

2.1 Data sources and descriptive statistics

This paper uses quarterly GDP real growth rates in Portugal and spans a period of major events that impacted on the Portuguese economy, from 1961:1 to 2016:2 (the last quarter for which data are available). The data come from the OECD statistical database, which can be accessed online at www.oecd.org/.

Figure 1 illustrates the growth rate trajectory and it clearly shows a decreasing trend both in the mean and volatility since the 1970s. After the high and increasing growth phase of the 1960s, Portuguese GDP growth enacted, on average, a decreasing growth path since the mid-1970s, notwithstanding the occurrence of up- and downswings in the 80s and 90s.

Simple quantitative measures of the GDP growth rate are summarized in Table 1. Portugal has recorded an average growth rate of 3.19% per annum, with the highest value of 12.00% in 1973 and the minimum value of −6.30% in 1975. The output volatility, measured by the standard deviation is equal to 3.58. The skewness measure is close to zero, while the kurtosis is close to three, which means that the distribution

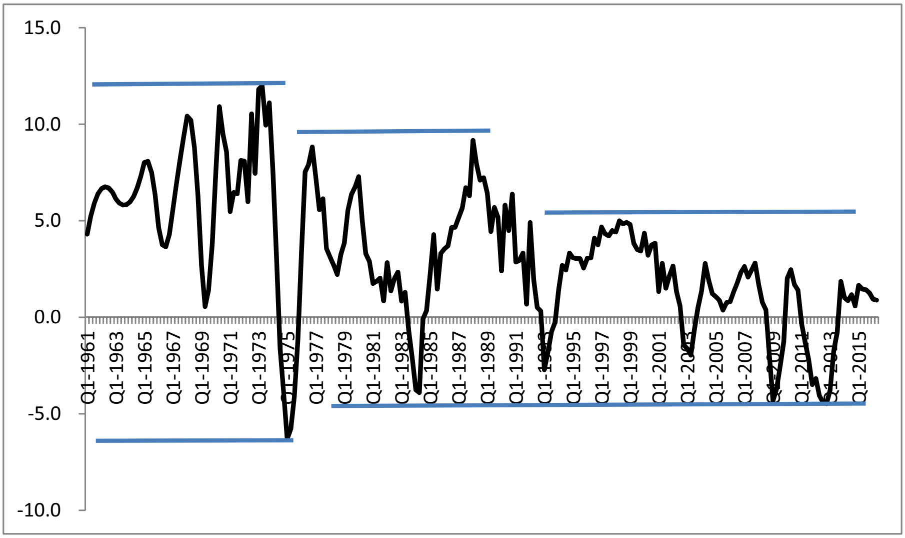

Fig. 1 Evidence of trend and volatility of GDP growth. Note: the horizontal blue lines are intended to highlight the decreasing trend in the series' volatility. Source: Authors' calculation

seems to be approximately symmetric and mesocurtic. Unsurprisingly, the Jarque-Bera statistic does not reject normality. Finally, the Ljung-Box statistic suggests autocorrelation in the growth rates and time varying variance.[1] These results suggest the estimation of autoregressive conditional heteroskedastic (ARCH, hereafter) models which attend to the existence of autocorrelation and heteroskedasticity in growth rates.

2.2 Identification of structural changes

The analysis of structural changes is of considerable importance as the consequences of not considering their existence in the specification of an econometric model are dramatic for statistical inference and the estimates credibility (see, for example, Perron 1989, 1997; Leybourne and Newbold 2003).

Given that the search for only one structural break may be too restrictive over the period under analysis, in which several economic and political arrangements have taken place, and attending the econometric advances on unit root tests with structural changes that emerged in the literature after Perron's (1989) influential article, we use the Bai and Perron (1998, 2003) test sequential procedure (BP, hereafter) to estimate multiple break dates without prior knowledge of the time they may have occurred according to the procedure next described.

We estimate an AR(3) model for the growth rate series, which proves to be adequate to capture the series dynamics.[2] After identifying the breaks in the mean, we identify the breaks in the variance by applying the BP test to the conditional mean of the squared value of the residuals. The test procedure adopted in this paper tests, in a sequential way, the hypothesis of m breaks against $m + 1$ breaks conditional on finding m breaks. If the null of no break versus one break is rejected, the break date is estimated by least squares and the sample is divided into two subsamples according to the estimated break date and a test of parameter constancy is performed on both subsamples. This procedure is repeated on a sequential basis increasing m, that is the number of breaks, until we fail to reject the alternative of an additional break. With this procedure, we search for up to four breaks and use a level of significance of 5%.[3]

The results of the BP test on the mean and variance are reported in Table 2. We also report the results of structural stability test. The sequential procedure reveals significance up to $m = 3$. Given the existence of one break, the statistic value of F (2/1) = 4.7381 is statistically significant, which suggests the existence of a second break. In the next test, the statistic F (3/2) = 5.7177, is again significant, and therefore it is suggested the occurrence of a third break. Finally,

[1] The Ljung-Box statistic suggests autocorrelation when applied to growth rates, and time-varying variance when applied to squared rates.

[2] We use the Schwartz Bayesian Criterion to determine the best order of the model. The residuals of the AR(3) specification do not exhibit autocorrelation. The model selection procedure and the diagnostic test are not fully reported here but details are available upon request.

[3] To our knowledge, the null distribution of the BP test statistic applied to OLS residuals has not been derived. Therefore, we use in this paper, the original distribution, as in Bai and Perron (1998, 2003). We are grateful to an anonymous referee for this remark.

Table 1 Summary statistics of GDP real growth rates

Mean	3.192
Standard Deviation	3.577
Maximum value	12.002
Minimum value	−6.303
Skewness	−0.108
Kurtosis	2.885
Jarque-Bera statistic	0.560 [0.755]
LB Q(36)	902.74 [0.000.]
LB Q^2(36)	976.03 [0.000]

Source: OECD and authors' calculation

the statistic F (4/3) = 0.9038 is not statistically significant. In short, we identify three breaks in the mean at 1973:2, 1981:4 and 2002:2. Through an identical procedure we identify two breaks in the growth rate variance at 1974:4 and 1992:1

In columns (3), (4) and (5) we report the results of structural stability tests for the mean and the unconditional variance of the growth rate considering the subperiods dictated by the breaks identified by the previous test. We use t-statistic tests for the equality of means under unequal variances for pairs of subsamples, and variance-ratio statistic tests for the equality of the unconditional

Table 2 Regime changes and stability tests for the mean and variance of GDP growth rates

Statistics	Break test in		Stability test in		
	Mean (1)	Variance (2)	Subperiod (3)	Mean (4)	Variance (5)
F(1/0)	23.8680*	5.4355*	Subperiod 1 vs Subperiod 2	7.0263 [0.0001]	4.7781 [0.0036]
F(2/1)	4.7381*	7.3617*	Subperiod 2 vs Subperiod 3	5.1884 [0.0007]	5.2342 [0.0008]
F(3/2)	5.7177*	4.3146	Subperiod 1 vs Subperiod 3	5.9152 [0.0008]	6.3105 [0.0003]
F(4/3)	0.9038	–	Subperiod 3 vs Subperiod 4	4.7808 [0.0012]	–
Break dates	1973:2 1981:4 2002:2	1974:2 1992:1	Subperiod 1 vs Ssubperiod 4	5.0985 [0.0007]	–

* significant at 5% level; p-values in square brackets. Subperiod 1 spans the period from 1961:1 to 1973:2 for the mean and 1961:1 to 1974:2 for the variance; Subperiod 2 spans the period from 1973:2 to 1981:4 for the mean and 1974:3 to 1992:1 for the variance; Subperiod 3 spans the period from 1982:1 to 2002:2 for the mean and 1992:2 to 2016:2 for the variance; Subperiod 4 spans the period from 2002:3 to 2016:2 for the mean

Source: Authors' calculation

variances. The results suggest that the mean growth rate in each subperiod differs significantly, given the statistical significance of the test statistic. Therefore, these results allow us to reject the null hypothesis of equal means. In Portugal the mean growth rate drops from 6.76% in the period before 1973:2 to 3.46% in the period from 1973:3 to 1981:4 and it continues falling down in the periods 1982:1–2002:2 and 2002:3–2016:2 to 3.06% and 0.03%, respectively. There are also significant reductions of the growth rate standard deviation from 1.38 in the period before 1974:4 to 1.23 in the period 1975:2–1992:1 and to 0.78 in the period 1992:2–2016:2.

Figure 2 reports the GDP growth rate and highlights the break dates in the mean and the variance. The horizontal lines denote the mean growth rates in each regime, whereas the grey areas identify the regimes for the variance.

3 On GDP volatility modelling: methodology and empirical results

This section provides the methodology and the models specifications that best describe the conditional mean and conditional variance of GDP growth rates, along with the empirical results. The objective is to provide empirical evidence of the volatility dependence upon the business cycle and the time varying nature of such relationship.

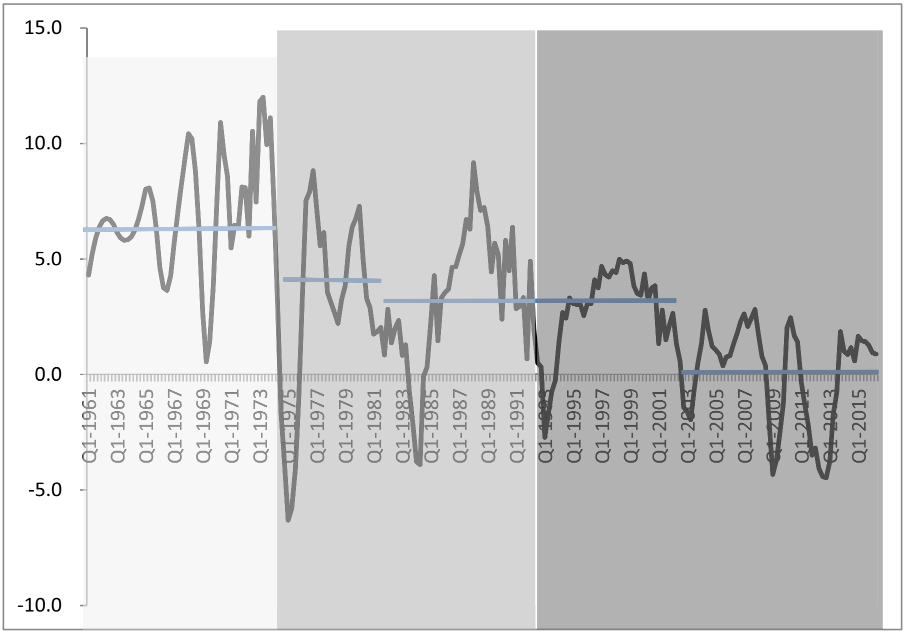

Fig. 2 GDP growth and structural breaks in the mean and variance. Note: The solid horizontal lines represent the mean growth rates in the four regimes: 6.8% in the first; 3.5% in the second; 3.1% in the third and 0.0% in the fourth. The three regimes in the variance are represented with grey areas. Source: Authors' calculation

3.1 Methodology framework

The *ARCH* models are design to model and forecast conditional variance. In each case the variance of the dependent variable is specified to depend upon past values of the dependent variable using some formulae. A general *ARMA(r,s)-GARCH(p,q)* process is specified as follows,

$$\Phi(L)y_t = \mu + \Theta(L)u_t + \delta h_t \tag{1}$$

$$B(L)h_t = \varpi + A(L)u_t^2 \tag{2}$$

where,

$$\Phi(L) = 1 - \sum_{j=1}^{r} \varphi_j L^j; \quad \Theta(L) = -\sum_{j=1}^{s} \theta_j L^j; \quad B(L) = 1 - \sum_{i=1}^{p} \alpha_i L^i \quad A(L) = \sum_{i=1}^{q} \beta_i L^i.$$

Let $\{u_t\}$ be a real-valued time series stochastic process generated by $u_t = e_t h_t^{1/2}$, where $\{e_t\}$ is a sequence of independent, identically distributed (*i.i.d.*) random variables with zero mean and unitary variance; h_t is positive with probability one and is a measurable function of $\sum_{t-1}$ which in turn is the sigma-algebra generated by $\{u_{t-1}, u_{t-2}, \ldots\}$. That is, h_t is the conditional variance of the errors $\{u_t\}$, $(u_t|\sum_{t-1}) \sim (0, h_t)$. This turns the current variance depending upon three factors: a constant, past news about volatility, which is taken to be the squared residual from the past (the *ARCH* terms), and past forecast variance (the *GARCH* terms). For the remaining, r and s correspond to the order of the *ARMA* process for the conditional mean; and p and q correspond to the order of the *GARCH* process for the conditional variance.

The dependency of the nature of the volatility-growth relation on the business cycle phase requires the use of methods that account for this asymmetry. One of those methods to describe this asymmetry in variance is the *T-GARCH* model, which was introduced independently by Zakoian (1994) and Glosten et al. (1994). The model for the variance is given by,

$$B(L)\ h_t = \varpi + A(L)\ u_t^2 + C(L)\ u_t^2, \tag{3}$$

where $C(L) = \sum_{i=1}^{q} \beta_{i+1} I_{t-1} L^i$ and $I_{t-i} = 1$ for $u_t < 0$ and zero otherwise.

The *T-GARCH* specification allows the impacts of lagged squared residuals to have different effects on volatility depending on their sign. While good news, given by $u_{t-i} > 0$, have an impact of α_i, bad news, expressed by $u_{t-i} < 0$ will have an impact of $\alpha_i + \sum_{i=1}^{q} \beta_{i+1}$. Significant values for the leverage effect coefficients suggest asymmetries, with negative (positive) shocks having a greater impact upon volatility whether $\sum_{i=1}^{q} \beta_{i+1} > 0$ $\left(\sum_{i=1}^{q} \beta_{i+1} < 0\right)$.

Another approach to investigate whether fluctuations in GDP volatility are associated with GDP growth is to estimate an exponential *GARCH (EGARCH)* in which the variance formulation captures asymmetric responses in the conditional variance (Nelson 1991). Generalizing, the formulation for the conditional variance for an *EGARCH(p,q)* process is as follows:

$$B(L)\ln(h_t) = \varpi + C(L)z_t, \tag{4}$$

where $z_{t-i} = \beta_1 \frac{u_{t-i}}{\sqrt{h_{t-i}}} + \beta_2 \left[\frac{|u_{t-i}|}{\sqrt{h_{t-i}}} - E\left| \frac{u_{t-i}}{\sqrt{h_{t-i}}} \right| \right]$; $C(L) = \sum_{i=1}^{q} c_i L^i$ and $B(L) = \prod_{i=1}^{p} (1-\alpha_i L)$, with $c_i = 1$.

3.2 GARCH modelling: the main features of GDP growth volatility

For modelling purposes, we follow the standard Box-Jenkins ARIMA modelling procedure. For the model identification, our decision on the models' order is based on the analysis of the sample autocorrelation and the sample autocorrelation functions, and the use of the Schwartz Information Criterion (SIC, hereafter). The models' adequacy is further assessed by performing diagnostic tests on the estimation residuals. The identification and estimation procedures have led to the following specifications for the GARCH, TGARCH and EGARCH models:Model *ARMA*(2,3):

$$\left[1-\Phi_1 \sum_{i=1}^{2} L^i\right] y_t = \mu + \sum_{k=1}^{3} \eta_k DM_k + \sum_{j=1}^{3} \theta_j L^j u_t; \tag{5}$$

Model *ARMA*(2,3) − *GARCH* (1,1):

$$[1-\alpha_1 L]h_t = \omega + \beta_1 L u_t^2 + \psi_1 DV1 + \psi_2 DV2; \tag{6}$$

Model *ARMA*(2,3) − *TGARCH* (1,1)

$$[1-\alpha_1 L]h_t = \omega + \beta_1 L u_t^2 + \beta_2 I_{t-1} L u_t^2 + \psi_1 DV1_t + \psi_2 DV2_t; \tag{7}$$

Model ARMA(1,3) − EGARCH(1,1):

$$(1-\alpha_1 L)\, Ln(h_t) = \omega + z_{t-1} + \psi_1 DV1_t + \psi_2 DV2_t; \tag{8}$$

where *DM*1, *DM*2 and *DM*3 are dummy variables to reflect the regime changes in the mean: *DM*1 = 1 in 1973:3 – 1981:4 and *DM*1 = 0 otherwise; *DM*2 = 1 in 1982:1 – 2002:2 and *DM*2 = 0 otherwise; *DM*3 = 1 in 2002:3 – 2016:2 and *DM*3 = 0 otherwise; *DV*1 and *DV2* are dummy variables to reflect the regime changes in the variance: *DV*1 = 1 in 1974:3 – 1992:1 and *DV*1 = 0 otherwise; *DV*2 = 1 in 1992:2 – 2016:2 and *DV*2 = 0 otherwise. The results are provided in Table 3.[4]

[4] The analysis of sample (partial) autocorrelation functions and SIC values are not provided here, but are available upon request.

Table 3 Time varying volatility and symmetric responses of volatility: 1961:1–2016:2 (Regime shifts in the mean at 1973:2, 1981:4 and 2002:1; regime shifts in the variance at 1974:2 and 1992:1)

Parameters	ARMA(2,3) (1)	ARMA(2,3)-GARCH(1,1) (2)
μ	3.207*** [0.0001]	1.072*** [0.0000]
η_1	−0.589* [0.0714]	−1.033*** [0.0001]
η_2	−0.628* (0.0601)	−0.684*** [0.0000]
η_3	−0.771** [0.0452]	−0.774*** [0.0000]
ϕ_1	0.208*** [0.0005]	0.933*** [0.0000]
ϕ_2	0.399*** [0.0000]	0.415*** [0.0000]
θ_1	0.106** (0.0492)	0.9367*** [0.0000]
θ_2	0.218** (0.0311)	0.863*** [0.0000]
θ_3	0.252* (0.0832)	0.917*** [0.0000]
ϖ	–	0.0031 [0.6217]
α_1	–	0.458*** [0.0017]
β_1	–	0.352*** [0.0000]
Ψ_1	–	0.229* [0.0695]
Ψ_2	–	0.0361* [0.0992]
R^2	0.913	0.922
J-B	43.441*** [0.0000]	3.707 [0.1566]
Skewness	0.213	−0.026
Kurtosis	5.125	3.634
LM ARCH (1)	3.267* [0.0721]	0.008 [0.9286]

p-values in square brackets; * indicates statistical significance at 10% level; ** indicates statistical significance at 5%; *** indicates statistical significance at 1%

Source: Authors' calculation

We start by estimating an ARMA model as the baseline model in order to assess the evidence of volatility persistence. The results, reported in column 1, suggest that all coefficients estimates are statistically significant at the 10% level or less. Excess kurtosis explains the significant value of the Jarque-Bera statistic, which consequently rejects residual normality. The diagnostic tests on the residuals do not report evidence of residual autocorrelation, but reveal significant persistence in the squared residuals.[5] The Lagrange Multiplier test (LM, hereafter) for ARCH shows a significant non-captured structure in the second moment.

To address these issues and allow for time varying conditional variance, a *GARCH* modelling procedure of the squared residuals is followed. The corresponding results are reported in column 2 along with the residuals diagnostic tests. The coefficients' estimates in the conditional mean specification are significant at the 1% level or less and the process stability is guaranteed in the conditional variance specification. Both the coefficient of the lagged squared residual and the coefficient of the lagged conditional variance term are highly statistically significant and their sum is very close to one, which implies that shocks to the conditional variance are quite persistent. The dummies' coefficients are significant at the 10% level. The model specification fully captures the persistence in volatility as demonstrated by the non-significant value of the *LM* statistic.

3.3 Volatility asymmetries: the cyclical features of volatility and the business cycle dependence

After having identified the main issues on volatility major changes, e.g. their timing and nature, and having estimated the model that best describes its behaviour, the analysis of the volatility behaviour over business cycles different phases is of empirical relevance for the design of the policy-decision process.

Volatility is represented in Fig. 3, together with GDP annual growth rates. The evolution of volatility reveals trend changes over the sample period, which confirms the previous conclusions of subsection 2.2. We also notice that periods of positive growth seem to be characterized by a negative relationship between growth rates and volatility. This is confirmed by the increase of the volatility series standard deviation from 1135.75 in periods of positive growth rates to 1259.26 in periods of negative rates. Finally, this cyclical pattern seems to suggest the existence of potential asymmetries in volatility associated to the business cycle and therefore, it may suggest that negative and positive shocks to the economy may impact differently on growth volatility. Therefore it seems that the asymmetry of the business cycle may account for part of the increase in measured volatility during recessions.

[5] The results of these tests are not reported in Table 3 for space reasons but are available upon request.

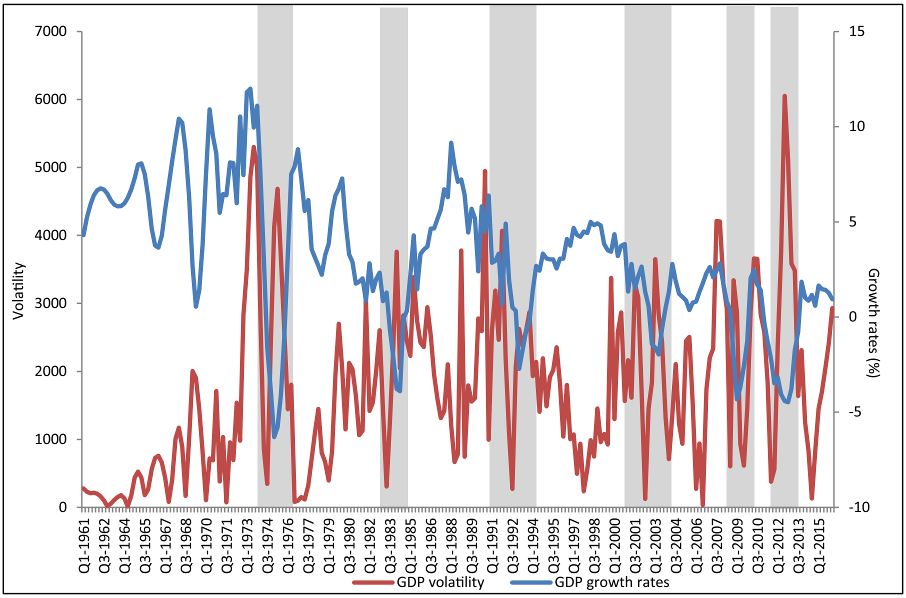

Fig. 3 Portuguese GDP volatility and the business cycle. *Note:* the shaded areas indicate periods of negative growth: 1974:2 – 1975:4; 1983:3 – 1984:3; 1993:1 – 1993:4; 2002:4 – 2003:3; 2008:4 – 2009:4; 2011:1 – 2013:4. Volatility is computed using the absolute value of the demeaned annual growth rate. Source: OECD and authors' calculations

To further conclude on this issue, we estimate *TGARCH* and *EGARCH* models and the results are reported in Table 4, along with the residuals diagnostic tests. Both models report statistical significant leverage effects, but the *EGARCH* specification outperforms the *TGARCH* specification, as it yields the highest log-likelihood and the lowest AIC and SIC values.[6] The results of the *EGARCH* model estimation suggest a positive leverage effect, which postulates a stronger impact of negative shocks on volatility. Specifically, the impact of good news on volatility amounts to 0.0676 while the impact of bad news is 0.3026, exceeding more than four times that of good news.

Therefore, the statistical significance of the positive leverage effect suggests asymmetric effects of positive and negative shocks, with negative shocks to GDP growth causing higher volatility than positive shocks, thereby increasing the degree of uncertainty during recessions.

3.4 The time varying asymmetric nature of volatility

Having detected a volatility change in GDP growth rates, further analysis is conducted to investigate whether the asymmetric effects exhibit a persistent

[6] The log-likelihood, AIC and SIC values are not reported here, but are available upon request.

Table 4 Time varying volatility and asymmetric responses of volatility: 1961:1–2016:2 (Regime shifts in the mean at 1973:2, 1981:4 and 2002:1; regime shifts in the variance at 1974:2 and 1992:1)

Parameters	ARMA(2,3)-TGARCH(1,1) (3)	ARMA(1,3)-EGARCH(1,1) (4)
μ	5.838*** [0.0000]	4.739*** [0.0018]
η_1	−1.993*** [0.0065]	−0.563 [0.1782]
η_2	−2.134*** [0.0000]	−1.136*** [0.0000]
η_3	−2.441*** [0.0000]	−1.674** [0.0453]
ϕ_1	0.458*** [0.0000]	0.443*** [0.0000]
ϕ_2	0.401*** [0.0000]	–
θ_1	0.836*** [0.0000]	0.932*** [0.0000]
θ_2	0.864*** [0.0000]	0.849*** [0.0000]
θ_3	0.918*** [0.0000]	0.909*** [0.0000]
ϖ	0.0021 [0.7310]	0.366*** [0.0007]
α_1	0.059*** [0.0000]	0.523*** [0.0000]
β_1	0.053*** [0.0091]	0.0676* (0.067)
β_2	0.153** (0.0451)	0.235** (0.033)
Ψ_1	0.216* [0.0717]	0.022* (0.088)
Ψ_2	0.039** (0.0772)	0.055** (0.041)
R^2	0.927	0.929
J-B	3.4859 [0.1750]	4.980 [0.1831]
Skewness	0.023	−0.103
Kurtosis	3.614	3.281
LM ARCH (1)	0.01581 [0.9000]	0.2871 [0.593]

Source: Authors' calculation

pattern over time, or the volatility decline is associated with a change of the business cycle asymmetric effects on volatility. The estimated results for the subperiods defined by the structural breaks, considering parsimonious specifications (lowest SIC), are reported in Table 5.

Table 5 Time varying volatility and asymmetric responses of volatility in each regime of growth volatility

Parameters	1961:1 to 1974:2	1974:3 to 1992:1	1992:2 to 2016:2
	ARMA(3,3)-EGARCH(1,1)	ARMA(1,2)-EGARCH(1,1)	ARMA(2,2)-EGARCH(1,1)
μ	5.054*** [0.0000]	−5.135 [0.6616]	2.456** [0.0000]
η_1	−1.259*** [0.0000]	–	–
η_2	–	−1.225* [0.0504]	–
η_3	–	–	−1.26** [0.0106]
ϕ_1	0.593** [0.0481]	0.967*** [0.0000]	0.622*** [0.0000]
ϕ_2	−0.896* [0.08812]	–	0.0892* [0.0913]
ϕ_3	−0.052* [0.09192]	–	–
θ_1	0.015* (0.0621)	−0.190** [0.0000]	0.0915 (0.1548)
θ_2	0.926*** [0.0000]	0.973** [0.064]	0.0867*** [0.0011]
θ_3	−0.121*** [0.0000]	–	–
ϖ	0.429 [0.1870]	0.354*** [0.0003]	0.262*** [0.0011]
α_1	0.068* (0.089)	0.058* [0.0771]	0.042* [0.0093]
β_1	0.072** (0.0662)	0.045** [0.0227]	0.031** [0.0101]
β_2	0.106*** [0.0000]	0.062*** [0.0000]	0.041*** [0.0000]
R^2	0.787	0.814	0.849
$J-B$	1.437 [0.487]	0.178 [0.914]	0.794 [0.672]
Skewness	0.287	0.089	−0.221
Kurtosis	2.412	2.832	2.999
LM ARCH (1)	0.4027 [0.528]	0.3237 [0.3316]	0.566 [0.547]

η_1, η_2 e η_3 are the coefficients of the dummies variables *DM*1, *DM2* and *DM3* designed to reflect the regime changes in the mean in each regime of growth volatility: in the first regime *DM*1 = 0 in 1961:1 – 1973:2 and *DM1* = 1 in 1973:3 – 1974:2; in the second regime *DM*2 = 0 in 1974:3 – 1981:4 and *DM*2 = 1 in 1982:1 – 1992:1; in the third regime *DM*3 = 0 in 1992:2 – 2002:2 and *DM*3 = 1 in 2002:3 – 2016:2; p-values in square brackets; * indicates statistical significance at 10% level; ** indicates statistical significance at 5% level; *** indicates statistical significance at 1% level or less

Source: Authors' calculation

The results shed light on important issues. First, positive and negative shocks generate asymmetric effects on GDP growth volatility in all periods with negative shocks to GDP growth inducing higher volatility than positive shocks of identical magnitude. The impacts of positive shocks on volatility are 0.072, 0.045 and 0.031 in the first, second and third periods, respectively. In the same periods, the effects of negative shocks amount to 0.178, 0.107 and 0.072, respectively. Second, the effects' asymmetric pattern shows stability over time. In all periods, the effect of negative shocks is twice the effects of positive shocks.

4 Conclusions

This paper intends to model the volatility of real GDP growth rates in Portugal, using quarterly data over the last five decades. As both the mean and variance of growth rates paths are probably affected by international and domestic shocks to the Portuguese economy, we estimate generalized autoregressive conditional heteroskedasticity models considering the evidence of structural changes in both the mean and variance.

At the international level, events such as the occurrence of "the Great Moderation" phenomenon, which has translated into volatility declining across several countries, the financial crisis and oil shocks have generated significant impacts on the Portuguese economy. At the domestic level, the last decades have been characterized by political and economic shocks, such as the transition to democracy in the 1970s, the adhesion to the European Union in 1980s, the currency change in 2000 and several external financial assistance programs. The absence of information on how this changing environment impacted on output volatility in Portugal, together with the lack of consensus in the literature about the behaviour of volatility across the business cycle, attributed mostly by methodological issues, are open points in the research agenda that constitute an opportunity window for this research.

The results reveal a progressive "moderation" in Portugal, being characterized by a decline in both GDP growth rates and associated volatility. Asymmetric behaviour of growth volatility seems to emerge over the business cycle. The results suggest higher (lower) volatility associated negative (positive) output gaps. Furthermore, the impact of negative shocks on volatility exceeds that of positive shocks more than four times over the sample period. Furthermore, the analysis suggest that this asymmetric pattern has been stable over time as revealed in a time disaggregate analysis

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