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A Quantile Regression Analysis of Growth and Convergence in the EU: Potential Implications for Portugal

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abstract

This paper applies a quantile regression approach to examine the growth and convergence process of fourteen EU member states over the period 1986-2009. From the results of the estimation of an accounting growth regression we conclude that an increase in the weight of the non-tradables sector and a loss of (price) competitiveness are especially harmful for growth for under-performing countries, while these benefit the most from physical capital accumulation and are less negatively affected by an increase in government consumption. Additionally, technological convergence is felt less strongly by low-growth member states. The variables retained are robustly related to growth at all quantiles, but the quantitative importance of the respective coefficients differs across quantiles in some cases. Given the changes in growth rhythms that Portugal recorded throughout the period under analysis, we derive some potential implications from these results for a better understanding of the Portuguese growth and convergence process after European integration. Our findings suggest that, given the growth deceleration that the Portuguese economy has been experiencing since the late 1990s, policies to enhance growth should pay more attention to promoting competitiveness and changing the specialization pattern away from the non-tradables sectors, as well as to increasing investment.

JEL Classification: C23; O47; O52

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1. Introduction

In 1986, Portugal (and Spain) joined the European Economic Community (EEC) that later became the European Union (EU). During the 25 years that ensued, European integration proceeded at a fast pace with the signature of the Single European Act in 1986 and the Treaty of the European Union in 1992, the single market was established in 1993, and the euro was introduced in 11 countries in 1999, Portugal included. Accession by Portugal to the EU was accompanied by a growth acceleration of the Portuguese economy relative to the previous decade, 1974-1985. Over this period, following political and economic turmoil, the Portuguese economy became almost stagnant, undergoing two IMF interventions in 1978-79 and 1983-85. From 1986 to 1998, the Portuguese economy enjoyed a phase of sustained economic growth in which real convergence with the core European economies took place. This convergence process was accompanied by the implementation of better macroeconomic policies (associated with the process of nominal convergence on the way to the euro in the 1990s), structural reforms, especially in the financial, labour and product markets, but also investments in physical and human capital, and technology enhancing factors (e.g. Barros and Garoupa, 1996; Duarte and Simões, 2002; Vamvakidis, 2002; Lains, 2003; Freitas, 2006; Mateus, 2006; Santos Pereira and Lains, 2010). Yet this expansionary phase did not last, and since 1999 Portugal has been experiencing a stagnation/divergence period highlighting the need for further structural reforms to recover the ground lost during the last almost 15 years (see Alexandre *et al.*, 2014).

This paper applies quantile regression analysis to estimate an empirical growth model for a sample of fourteen EU member states over the period 1986-2009 in order to get a better understanding of the changes in the Portuguese convergence process and in its growth rhythm. Our main aim is to identify the relevant growth determinants for Portugal, as a member of the EU, adding to the literature by applying an estimation methodology we believe more suitable for the period and countries under analysis, the quantile regression technique. This estimation approach allows for the identification of different impacts of the explanatory variables across the growth rate distribution. Given the changes in growth rhythms registered over the period under analysis in the EU, and particularly in Portugal, this seems a suitable approach. According to Mello and Perelli (2003), quantile regression is a suitable estimation methodology in a growth context as it allows to capture countries' heterogeneity and assess how policy variables affect countries according to their position on the conditional growth distribution. In fact, the quantile regression estimator gives, potentially, one solution to each quantile. In terms of policy implications, as suggested by Barreto and Hughes (2004), it may the case that, due to the presence of other (un-modelled) factors countries grow slower (or faster) relative to the conditions suggested by the variables that are included in the model. This happens because the factors that are not included in the estimated model create an unfavourable (more favourable) environment for the impact of the included growth determinants. Quantile regression analysis allows us to identify those growth determinants that do not have the expected notable effect on growth and hence determine the policy implications specifically for under-performing versus over achieving countries in terms of output growth. We also depart from the previous literature on growth and convergence in the EU by focusing on a more recent period (1986-2009) that is usually missing from older analysis or is included in a longer time frame in more recent studies (e.g. Soukiazis and Castro, 2005; Castro, 2011).

We first review the recent growth and convergence process of the Portuguese economy focusing on the period 1986-2009, the 25 years since Portugal joined the EEC, now EU, and comparing it with the average EU14 economy[1]. We start by presenting some descriptive data on convergence

1 Together with Portugal this group, composed of the member countries in the European Union prior to the accession of the ten candidate countries on 1 May 2004, is usually known as EU15. The EU15 includes the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom. The EU14 includes all the previous countries except Luxembourg.

and growth for Portugal relative to the aggregate of reference, the EU14. This comparison highlights the two different phases in terms of growth and convergence that Portugal experienced after European integration. We next apply quantile regression analysis to estimate an empirical growth model for the EU14 sample. The empirical model includes the factors driving convergence and growth highlighted by the theoretical predictions and empirical evidence developed in the economic growth literature over recent decades (e.g. Doppelhofer, Miller, and Sala-i-Martin, 2004; Durlauf, Johnson, and Temple, 2005; Sala-i-Martin, 1997). Finally, we derive some potential implications of our results for a better understanding of the Portuguese growth and convergence process after European integration.

The results from the estimation of our preferred models indicate that slow growers are negatively affected in a quantitatively more important way by a loss in price competitiveness and an increase in the share of the non-tradables sector, while fast-growing countries suffer more from an increase in government consumption. As for expected positive growth effects, these are confirmed for physical capital accumulation and are higher for under-performing countries. Finally, technological catch-up/convergence seems to be a generalized phenomenon across the conditional growth distribution, as long as countries possess the necessary absorptive capacity in the form of educational human capital. However, for the first of our two preferred models there is an indication that this effect is weaker for under-performing economies. On a normative level and as far as the Portuguese economy is concerned, given its uneven growth performance in the recent past and in particular the growth slowdown it has been experiencing since the turn of the century, our results suggest that more attention should be paid to policies aimed at restoring competitiveness and changing the specialization pattern, as well as increasing investment.

The remainder of this paper is organized as follows. Section 2 describes the developments in terms of output and productivity indicators for Portugal over the last 25 years relative to the EU14 and the USA. Section 3 attempts to assess which factors are the most relevant to explain the growth performance of the fourteen EU member states over the period 1986-2009 by estimating an appropriate growth regression specification using quantile regression techniques. Some potential implications of the results obtained for the specific case of Portugal are next derived. Finally, Section 4 offers some conclusions.

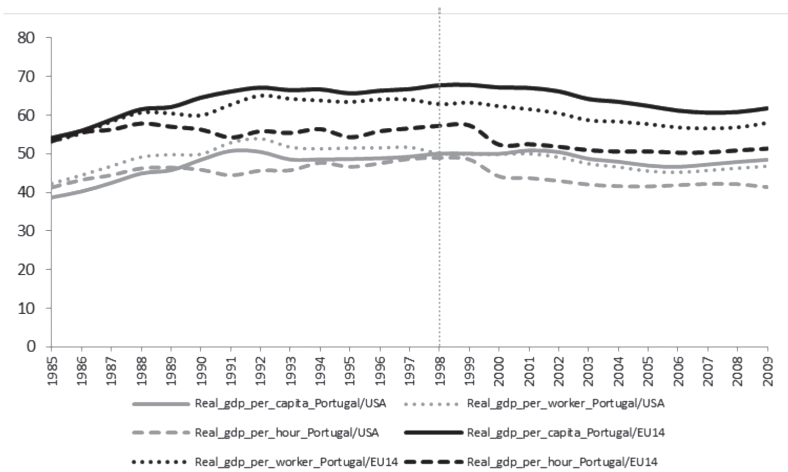
2. The different phases of Portuguese growth and convergence following EU accession

In an initial approach to the growth and convergence performance of the Portuguese economy after EU accession, Figure 1 shows the variation over time of real GDP *per capita*, per worker and per hour worked relative to either the aggregate of reference, the EU14 (black lines), or the USA (grey lines), the usual benchmark in terms of productivity and technological development comparisons, from 1985 until 2009. All variables are measured in purchasing power parities. The figure suggests that the period we are analysing can be broken down into two sub-periods according to the behaviour of Portuguese per capita income. As can be seen, Portugal joined the EC in 1986 with a low relative real GDP per capita standing at a little less than 55% of the EU14 average. From 1986 up until 1992 the situation improved with Portugal standing at 65% of the EU average in 1992. The 1992-93 crisis brought progress to a temporary halt, but in 1998-99 relative real GDP per capita was 66%. From 1999 onwards, however, Portugal embarked in a period of stagnation during which its GDP per capita remained largely unchanged relative to the EU average, and in 2009 it stood only at 62%.

As far as productivity growth and convergence is concerned, a driving force of output growth and convergence (e.g. Hall and Jones (1999); Jones (2002); Jones and Fernald (2014)), Figure 1 presents the evolution of two measures of labour productivity relative to the EU14 and the USA, real GDP per worker and real GDP per hour worked. In both cases it is evident the low relative productivity levels of the Portuguese economy, and the almost absence of convergence over the period under analysis. Relative real GDP per worker increased from 52.2% in 1985 to 58.7% in 2009, reaching a maximum of 63.2% in 1992 but decreasing in almost every year from then onwards. Relative real GDP per hour worked stood at 52.8% in 1985 and decreased to 51.5% in 2009, reaching a maximum of 57.2% in 1988.

The trends relative to the USA in terms of the three macroeconomic performance measures under analysis are practically the same as those registered relative to the EU14. At the end of the period under analysis Portugal was still 38 percentage points below the EU14 average, and 52 points below the United States in terms of real GDP *per capita*, and even further away in terms of labour productivity.

Figure 1: Relative Real GDP per capita, Per Worker and Per Hour Worked (EU14 or USA =100) 1985 -2009



Source: Authors' computations based on data from the PWT 7.0

Table 1 contains information on real GDP *per capita*, per worker, per hour worked, and Total Factor Productivity (TFP) annual average growth rates for the period 1986-2009, detailing the previous information from Figure 1. For the whole period, Portugal grew faster than the EU14 average and the USA in terms of all the measures considered, except for real GDP per hour worked. However, the Portuguese growth and convergence process in terms of real GDP *per capita* after EU membership was not uniform. In fact it can be divided into two periods: 1986-1998, a convergence period during which growth in the Portuguese economy accelerated and Portugal grew faster than the EU14 average (and the USA), 3.87% and 2.21%, respectively; and a stagnation/divergence period from 1999 onwards when its growth rate slowed down to figures lower than the reference group average, 0.17% and 1.15 %, respectively. The differences across the two sub-periods are even more striking in terms of the labour productivity and TFP measures.

Although the real GDP measures and TFP growth rates declined from one period to the next in Portugal, the EU14 and the USA (except real GDP per hour worked in this case), the change in growth rhythms in Portugal additionally reversed the positive growth differential with the EU14 and the United States it had registered before 1999. The TFP (and real GDP per hour worked) growth gap between the United States and the EU14 in the second period was also considerable. This comparison highlights the well-known dichotomy between the productivity performance of the US economy and that of the EU before and after 1999. Before 1999 US TFP and real GDP per hour worked were growing less than in the EU but the situation reversed in the following decade. As a result, the EU almost ceased to converge with the United States in terms of productivity levels (see Figure 2). Portugal's case is even more striking than that of the EU14 since productivity fell dramatically after 1999, even registering negative growth values in the cases of real GDP per worker and TFP.

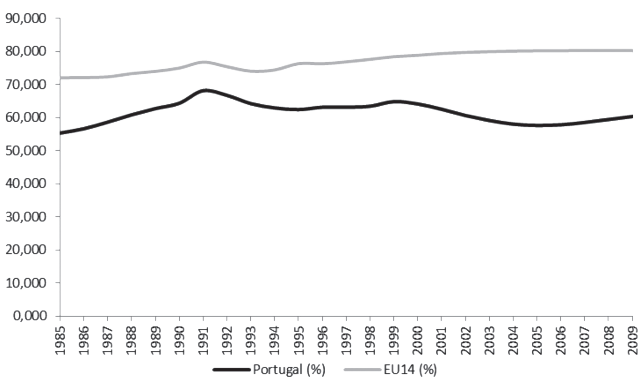
Table 1: Real GDP per capita, Per Worker and Per Hour Worked and TFP Average Growth Rates (%) 1986-2009

	Real GDP *per capita*			Real GDP per worker			Real GDP per hour worked			TFP		
	1986-98	1999-09	1986-09	1986-98	1999-09	1986-09	1986-98	1999-09	1986-09	1986-98	1999-09	1986-09
Portugal	3.87	0.17	2.26	2.95	-0.22	1.59	2.48	0.06	1.41	1.93	-0.20	0.98
EU14	2.21	1.15	1.81	1.84	0.69	1.37	2.22	1.22	1.76	1.13	0.12	0.68
USA	2.05	0.49	1.45	1.96	0.43	1.37	1.45	1.66	1.60	1.06	0.60	0.91

Note: TFP growth rates are relative to the EU15.
Source: Authors' computations based on data from the PWT 7.0 and AMECO.

Figure 2 contains TFP levels relative to the USA, the world technological leader, over the period 1985-2009, for Portugal and the EU14. In 1985, Portugal was almost 45 percentage points less productive than the USA, while the EU14 registered a relative TFP of around 72%. The situation in Portugal improved at a fast pace until 1992, when it reached a value of almost 67%. Since then however the situation deteriorated, and in 2010 relative TFP stood at 61.2%. The EU14 increased its situation only slightly over the whole period, standing still almost 20 percentage points below the USA in 2009. The potential for technological catch-up both for Portugal but also for the average EU14 country therefore does seem to exist.

Figure 2: TFP Relative to the USA (%) 1985-2009



Note: EU14 does not include Germany.
Source: Authors' computations based on data from the World Productivity Database, UNIDO

In summary, average growth in Portugal slowed down considerably in the second sub-period under analysis so that the expansionary phase enjoyed in the first years following EU accession seems to have made further reforms less pressing and thus productivity remained weak. There are a number of potential important factors that may explain the slowdown in output and productivity. First, factor accumulation might not have been adequate concentrating on less productive investments (infrastructures; residential investment) and the educational attainment levels of the labour force might not have registered the necessary upgrade. Second, the dimensions shaping the dynamics of technology did not show the necessary improvements. Third, and directly related to the availability of low skilled workers, there might have been an excessive specialization towards relatively unskilled labour-intensive activities. This might also have prompted firms to use less advanced technologies. Finally, the regime of macroeconomic stability achieved in preparation to joining the European Monetary Union (EMU) was put into question by the lack of fiscal consolidation in the years following EMU membership. In the next section we take into account some of these issues when we estimate a growth accounting regression for the sample of fourteen EU member states with some potentially important growth and convergence determinants selected according to the relevant literature. Based on our findings for the whole sample we then derive some potential implications for the specific case of Portugal.

3. Empirical model, methodology and results

We replicate here estimations of empirical growth models that have been carried out in a large number of empirical growth studies in order to better identify the relevant growth determinants for our sample of fourteen EU member states taking into account parameter heterogeneity. We accomplish this by applying a quantile regression approach. The factors driving growth and convergence included in our empirical model are those highlighted by the theoretical and empirical literature on growth and convergence that developed over recent decades (e.g. Doppelhofer, Miller, and Sala-i-Martin, 2004; Durlauf, Johnson, and Temple, 2005; Sala-i-Martin, 1997; Barreto and Hughes, 2004; Crespo-Cuaresma, Foster, and Stehrer, 2011). Our ultimate goal is to derive potential implications of the results obtained for a better understanding of the growth and convergence process of Portugal as a member of the EU.

3.1. Growth accounting regression specification

We estimate what is known in the literature as a growth accounting regression (e.g. Benhabib and Spiegel (1994)) that encompasses the neoclassical, technological diffusion, and endogenous growth models explanations. As Crespo-Cuaresma, Foster, and Stehrer (2011) point out this implies that it is not possible to establish a single clear link between the selected variables and a unique growth theory since the same variable can have an important role in different growth theories[2].

The estimated growth accounting regression is given by equation (1):

$$\Delta ly_{it} = \beta_0 + \beta_1 \left(hcap_{it} \times dist.frontier_{it} \right) + \beta_2 inov_{it} + X'_{it} \beta_x + \varepsilon_{it} \qquad (1)$$

where the real GDP per capita annual growth rate (Δly_{it}) depends on technological catch-up/convergence (*dist.frontier*) that is facilitated by human capital (*hcap*), taken as the main determinant of absorption capacity; the activity of the R&D/innovation sector (*inov*); and a vector X that includes a set of control variables found to be relevant growth determinants in previous theoretical and empirical growth models through factor accumulation and productivity/efficiency gains; α_0 is the constant term and ε the error term.

2 For example, exogenous growth models emphasize the importance of human capital for growth through factor accumulation to be used in final goods production (see Mankiw, Romer, and Weil, 1992), while more recent endogenous growth models emphasize its importance for productivity growth (Lucas, 1988; Romer, 1990b; Nelson and Phelps, 1966).

The choice of the explanatory variables was determined by theoretical predictions and previous empirical evidence, the convenience of a parsimonious specification and the availability of annual data for the EU14 countries, a necessary condition for the estimation with quantile regression techniques (see Table 2). The expectations concerning growth and real convergence of the Portuguese economy after EU membership are supported by exogenous and technological diffusion growth models predictions (e.g. Solow, 1956; Mankiw, Romer, and Weil, 1992; Nelson and Phelps, 1966; Barro and Sala-i-Martin, 1997). According to exogenous growth models, poorer countries grow faster than initially richer countries through faster factor accumulation since marginal productivities are higher in the former. However, catch-up only occurs if the countries possess the same structural characteristics. In technology diffusion models, real convergence occurs through technological catch-up of the followers, where imitation is less costly than innovation. This assumption implies that the growth rate of technology will be higher in the countries further away from the technological frontier, as long as they show adequate absorptive capacity, namely in what concerns educational attainment. An economy must possess a certain number of characteristics, known as social or absorptive capacity, in order to catch-up to the richer/leader countries and fully exploit the advantages of its technological backwardness (e.g. Nelson and Phelps, 1966; Abramovitz, 1986) and to be able to innovate. The convergence and growth benefits from the absorption of technology from abroad are bound to be exhausted as countries close the technological gap and so the focus must be on growth through innovation, as predicted by endogenous growth models (e.g. Romer, 1990a; Romer, 1994; Jones, 1995; Jones, 2005).

Particular attention will be paid to absorptive capacity, in the form of the skill level of the workforce, and innovation efforts. The estimation of a growth accounting regression allows us to identify the innovation and technological diffusion growth effects in the EU sample of countries. This methodological strategy seems adequate for a sample of developed countries that nonetheless exhibit differences in their productivity paths, pointing to different intensities of innovation and imitation activities among EU countries. We consider the USA as the technological leader in order to emphasize the technological convergence mechanism for the sample. Additionally, the increase in international trade and the specialization pattern associated with the integration process, as well as macroeconomic stability achieved mainly in preparation for the euro, might also help to explain the output dynamics of the Portuguese economy relative to its European counterparts (e.g. Kormendi and Meguire, 1985; Frankel and Romer, 1999; Bassanini and Hemmings, 2001; Bassanini and Scarpetta, 2001; Alcalá and Ciccone, 2004). The concerns with the relationship between the size of government and economic growth will also be addressed (e.g. Barro, 1990; Karras, 1997).

Recent studies on growth and convergence in the EU include, for instance, Soukiazis and Castro (2005) and Castro (2011). The main concern of these studies is to assess whether the rules associated with EMU membership undermined economic growth in Europe, in particular the Maastricht criteria budgetary rules and those associated with the Stability and Growth Pact. They conclude however that it is not possible to detect any significant influence of the change occurred in policy settings on growth, namely a negative one as predicted by some authors (e.g. Thirlwall, 2000; Hein and Truger, 2005). In this particular study we depart from these earlier studies by adopting a growth accounting specification and considering a larger number of potential explanatory variables, although we use some common regressors such as initial output, investment in physical capital, human capital, trade openness, inflation, or government consumption. In any case, within the framework we consider not all are found to be relevant growth determinants. Our time coverage and estimation methodology also differ from the ones considered in these previous studies.

Table 2: Proxies Used for Growth and Convergence Determinants in the Estimations

Determinant	Proxy	Source
Convergence (*dist.front*)	Total factor productivity ratio of the follower relative to the leader, the USA (both in index numbers).	World Productivity Database AMECO
Absorption capacity (*hcap*)	Average years of secondary schooling of the population aged 25 and over; Average years of total schooling of the population aged 25 and over.	Barro and Lee (2010)
Innovation (*inov*)	Total R&D spending (% GDP);	OECD
	Scientific journals articles (number per thousand people);	World Bank
	Patents (number per thousand people);	OECD
	Average years of tertiary schooling of the population aged 25 and over.	Barro and Lee (2010)
Control variables:	Investment share (% GDP);	PWT 7.0
(*X*)**:**	Non-tradables sector share (% GDP)	OECD
- factor accumulation;	Openness ratio;	PWT 7.0
- structural change;	Real exchange rate;	PWT 7.0
- macroeconomic stability	Public Consumption (% GDP);	PWT 7.0
	Public debt (% GDP);	Eurostat
	Public expenditures (% GDP);	Eurostat
	Tax burden (% GDP).	Eurostat

3.2. Empirical Methodology

We use a quantile regression approach, originally proposed by Koenker and Bassett (1978), in order to assess the influence of growth covariates on economic growth, conditioned by the location of the dependent variable at different parts of its distribution. Applying this methodology to growth regressions has several advantages. We can test for differentiated effects of the covariates at different parts of the growth rate distribution that otherwise would be collapsed on the mean estimates obtained through, for example, OLS estimators. Galton's fallacy (see Friedman, 1992), a major critique to the technique of regression to the mean, and consequently to standard convergence equations estimations, can also be addressed through the quantile regression methodology. Furthermore, it allows for deeper investigation of the reasons for different patterns of growth and convergence (divergence) experienced by EU economies over the period 1986-2009. Traditional econometric methods such as OLS are based on mean estimates of the parameters ignoring the distribution characteristics of the variable representing the phenomena under analysis. They thus give a synthetic picture of the effects of covariates that might be very misleading. The quantile regression approach proposed by Roger Koenker (see Koenker and Bassett, 1978; Koenker and Hallock, 2001; Koenker, 2005) tries to overcome this problem by estimating the effects of covariates over the whole distribution of the variable to be explained. Quantile regression methods allow heterogeneous marginal effects of the covariates on the conditional outcome distribution. They thus provide one method of capturing parameter heterogeneity across countries by allowing for the presence of heterogeneous effects across different quantiles of the conditional growth distribution.

Denoting the vector of *k* regressors in equation (1) by *Z*, the quantile regression model can be written as:

$$\Delta ly_{it} = Z'_{it}\beta_\tau + \varepsilon_{\tau it} \qquad (2)$$

where Z_{it} is a $k \times 1$ vector containing the independent variables, β_τ is an unknown $k \times 1$ parameter vector associated with the τ^{th} quantile and $\varepsilon_{\tau it}$ is an unknown error term. It is assumed that $\varepsilon_{\tau it}$ satisfies the constraint $Quant_\tau(\varepsilon_{\tau it} \mid Z_{it})=0$, such that the errors have zero conditional mean, though no other distributional assumptions are required. The coefficient for a regressor *k*, $\beta_{\tau k}$, can be interpreted as the marginal change in the τ^{th} conditional quantile of Δly_{it} due to a marginal change in *k*.

The τ^{th} quantile regression, $0<\tau<1$, solves the following minimization problem:

$$\min_{\beta_\tau} \frac{1}{n}\left(\sum_{it:\Delta ly_{it} \geq Z'_{it}\beta_\tau} \tau \left|\Delta ly_{it} - Z'_{it}\beta_\tau\right| + \sum_{it:\Delta ly_{it} < Z'_{it}\beta_\tau} (1-\tau)\left|\Delta ly_{it} - Z'_{it}\beta_\tau\right| \right) \qquad (3)$$

Quantile regression thus allows us to trace the entire distribution of the growth rate of real output per capita, conditional on the regressors included. In our study of growth dynamics, the influence of the different growth determinants is thus investigated by running a set of τ quantile regressions. In other words, we estimate τ growth accounting regressions, each of which measures the influence of each explanatory variable at a different quantile of the growth distribution.

The growth empirics literature has benefitted from the quantile regression methodology for several reasons: its estimators are robust to outliers in terms of growth and it gives information on the (degree of) importance of policy and state variables according to the conditional growth distribution. In terms of policy implications, as suggested by Barreto and Hughes (2004), it may be the case that, due to the presence of other (un-modelled) factors countries grow slower (or faster) relative to the conditions suggested by the variables that are included in the model. This happens because the factors that are not included in the estimated model create an unfavourable (more favourable) environment for the impact of traditional growth determinants. Quantile regression analysis allows us to identify those growth determinants that do not have the expected notable effect on growth and hence determine the policy implications specifically for under-performing versus over achieving countries, in terms of output growth. Additionally, these estimators are robust to the presence of outliers as far as the dependent variable is concerned, a characteristic of output growth rates across countries. In fact, Mello and Perelli (2003) point out that the distribution of average GDP growth rates is skewed to the right. This literature has by now many contributions, some of the most representative are (see Table 3): Mello and Novo, 2002; Mello and Perelli, 2003; Barreto and Hughes, 2004, Canarella and Pollard, 2004, Miles, 2004, Osborne, 2006, Laurini, 2007, Foster, 2008, Dufrénot, Mignon, and Tsangarides, 2010, and Crespo-Cuaresma, Foster, and Stehrer, 2011). A general conclusion from Table 3 is that the results concerning the influence of many growth determinants vary across quantiles and, even when a variable is found to be robust across quantiles, the estimated impact on growth of that variable is often found to differ (quantitatively) across the quantiles. This applies irrespective of the number and type of countries considered, time period of the analysis, and the set of growth determinants included.

We use in this paper a variant of Koenker's method proposed by Canay (2011), which proved that when fixed effects are location shift variables, influencing all quantiles in the same way, a two-step estimator is consistent and asymptotically normal when the number of individuals and time periods goes to infinity. As a first step, the fixed effects are obtained in accordance with the model to be estimated. As they are constant across the distribution of the variable to be explained, we can simply retain the parameters obtained in the estimation of its conditional mean. The difference to the mean of these coefficients' values is subtracted to the dependent variable and we are thus able to apply the quantile regression methodology to our model with only one intercept[3].

3 We use Koenker (2012b). See also Koenker (2012a).

Table 3: Summary of Selected Empirical Growth Studies Applying Quantile Regression Analysis

Authors	Sample	Methodology	Dependent Variable	Explanatory variables	Main results
Mello and Novo (2002)	98 countries in the Barro-Lee data set. 1960-1985.	Quantile regression.	Growth rate of real GDP per capita.	Initial income. Investment share. Human capital. Population growth. Real government consumption. Number of revolutions and coups. Number of assassinations.	Only the top 35% quantiles exhibit a negative relationship between growth and initial income. Changes in human capital have a stronger impact on the GDP growth rate for fast-growing countries than for slow-growing countries.
Mello and Perrelli (2003)	100 countries. 1960-1985	Quantile regression.	Growth rate of real GDP per capita.	Initial GDP per capita. Proxies for human capital. Ratio of real government consumption expenditure to real GDP. Proxies for political instability. Measure of market distortions. Average share of investment to real GDP. Average growth rate of the total population.	Concavity pattern of the regression quantile process on the initial income coefficient. The quantile processes for the secondary school enrolment, proxies for political instability, and market distortions are relatively stable around the OLS estimate. The quantile regression process for the investment variable is positive for all the quantiles but it decreases from $\tau = 30\%$ to $\tau = 70\%$, and then it increases again. The quantile regression for the coefficient on population growth increases non-linearly across the quantiles.
Barreto and Hughes (2004)	119 countries. 1960-1990	Quantile and OLS regression of 7770 different models to select the robust growth determinants.	Growth rate of real GDP per capita.	50 different variables from Levine and Renelt (1992) and Barro and Lee (1994).	For over achieving countries, the determinants of growth are trade, social infrastructure, government expenditure share, investment share and investment prices as well as a few demographic variables. For under-performing countries, the most significant determinants of growth are latitude, social infrastructure, civil liberties and liquid liabilities.
Canarella and Pollard (2004)	86 countries. 1960-2000	Quantile regression applied to the MRW model.	Growth rate of real GDP per person of working age.	Initial income. Investment share. Average fraction of working age population in secondary school. Rate of growth of the working age population. Regional dummies.	Convergence does not apply to countries in the lower quantiles. Countries whose growth rates are in the higher quantiles respond differently to investment in human and physical capital than do countries whose growth rates are in the lower quantiles.
Miles (2004)	77 countries. 1970-1998	Quantile regression.	Growth rate of real GDP per capita.	Initial real GDP per capita. Average years of secondary schooling. Interaction term between human capital and initial per capita GDP. Investment share. Population growth. Regional dummies.	Human capital has a larger marginal benefit for countries that have experienced fast growth, but little significant impact on slow growing nations. Varying size and statistical significance of coefficients for the other explanatory variables.

Table 3: Summary of Selected Empirical Growth Studies Applying Quantile Regression Analysis (cont.)

Authors	Sample	Methodology	Dependent Variable	Explanatory variables	Main results
Osborne (2006)	Barro-Lee dataset. 1960-1995	Quantile regression applied to the level of output not the growth rate.	Real GDP per capita.	Real non-residential capital per worker. Country's population's average schooling. Average annual rate of inflation. Government consumption less education and defense spending as a percentage of GDP. Political instability. Measure of democracy. Black market premium. Export to import relative prices. Openness of the economy. Proxy for financial sophistication. Measure of inequality.	Physical and human capital have a positive impact across quantiles but the dimension of the effect of human capital is higher for higher quantiles. The significance of the other variables differs across quantiles. For the statistically significant variables, the differences in the magnitude of the estimated coefficients is most compelling with respect to education, openness, and financial development.
Laurini (2007)	Brazilian municipalities. 1970-1996	Nonparametric quantile smoothing splines.	Per capita income growth.	Initial income per capita.	Convergent lower and higher incomes and divergent intermediary incomes.
Foster (2008)	75 trade liberalising countries. 1960-2003	Quantile regression.	Real per capita GDP growth.	Initial GDP per capita. Investment share. Average years of secondary schooling in the population over 15. Population growth. Dummy variable capturing trade liberalisation episode.	Countries experiencing the lowest rates of per capita GDP growth benefited the most from trade liberalisation. The coefficient estimates for investment tend to be fairly similar across the quantiles. For population growth the coefficient is positive at low quantiles, but tends to become negative and significant at higher quantiles.
Dufrénot, Mignon, and Tsangarides (2010)	75 developing countries. 1980-2006	Quantile regression.	Real per capita GDP growth.	Initial GDP per capita. Indicator of trade openness. Investment share. Population growth. Government's balance as share of GDP. Terms of trade growth. Inflation rate.	Openness has a higher impact on growth among low-growth countries relative to high-growth countries, with significantly larger short-run and long-run effects.
Crespo-Cuaresma, Foster, and Stehrer (2011)	255 NUTS2 European regions 1995-2005	Quantile regression with Bayesian Model Averaging (BMA)	Growth rate of real GDP per capita.	35 potential determinants of growth (e.g. initial GDP per capita; skill endowment; GFCF; infrastructures; geography; technology)	The set of robust variables differs across quantiles. The size of the parameters on a specific set of variables varies across quantiles.

3.3. Results

Our empirical strategy consisted in first regressing two groups of equations of type (1) depending on the interaction term representing the absorption capacity of the follower country: either average years of secondary schooling of the population aged 25 and over (*lhcs*) or average years of total schooling of the population aged 25 and over (*lhct*). Additionally, we estimated equation (1) considering different proxies for innovation and different control variables. All the proxies for innovation (see Table 2) revealed not to be statistically significant or the signs were not the right ones according to theoretical predictions. Also, the results did not show any improvement when we included different control variables. The tax burden was not statistically significant or it presented a positive sign that might reflect a pro-cyclical budget policy. The same applies to the openness ratio, but in this case the sign was negative. On the contrary, the real exchange rate was always significant with the predicted theoretical sign, negative[4].

We ended up with a small number of growth equations (A1 and A2) all of them without the innovation component. In these two models the convergence coefficient (interacted with *lhcs* or *lhct*) was always statistically significant with the expected sign, negative, and robust to the consideration of different sets of explanatory variables. The control variables that proved to be statistically significant are: public consumption (% GDP), *lkg*; the investment share (% GDP), *lki*; the real exchange rate, *lp*; and the non-tradables sector share (% GDP), *lnt*. Public consumption always presented a negative estimated coefficient.

Our two preferred growth regressions thus result from the estimation of models of type A1 and A2. In both cases we consider as the proxy for absorptive capacity to interact with technological catch up, *lhcs*. This result is in accordance with previous studies that find that to fully exploit the growth benefits from technological backwardness countries need a sufficient level of education at the secondary level (e.g. Simões (2009)). Model A1 includes as control variables (all in logs): public consumption (*lkg*), the investment share (*lki*), and the real exchange rate (*lp*). Model A2 includes one more regressor from the control variables set: the non-tradables sector share, *lnt*. Table 4 contains some descriptive statistics for these variables, for the whole sample and for Portugal alone.

Table 4: Summary Statistics for the Variables Included in Models A1 and A2

	EU14				Portugal			
	Min.	Average	Max.	Coef. Var.	Min.	Average	Max.	Coef.Var.
Δly (%)	-10.8	1.9	9.4	1.377	-3.7	2.5	8.4	1.123
hcs (years)	1.486	3.525	8.263	0.296	1.486	1.941	2.445	0.147
tfpr (index)	71.18	99.08	111.5	0.054	91.26	97.97	103	0.039
kg (% GDP)	5.67	9.99	17.27	0.239	5.67	5.93	6.36	0.028
ki (% GDP)	13.81	21.59	32.47	0.166	19.22	27.26	32.47	0.11
p (index)	52.63	101.7	155.8	0.199	52.63	78.04	99.8	0.165
nt (% GDP)	40.58	50.89	65.07	0.081	47.94	53.66	58.02	0.063

Notes: *Δly* - real GDP per capita annual growth rate; *tfpr* - distance to frontier; *hcs* - average years of secondary schooling; *kg* - public consumption share; *ki* - investment share; *p* - real exchange rate; *nt* - non-tradables sector share.

In what follows, we interpret the main results derived from models A1 and A2 through the inspection of the tables of results and the plots of the covariates estimates for different quantiles of the distribution of the dependent variable, the growth rate of real GDP *per capita*. In Tables 5 and 6 OLS results are displayed first. Subsequently, Tables 5 and 6 report the estimated vector β_τ

4 We also tested for the influence of some financial proxies, such as the interest rate banking spread, but the results were never statistically significant.

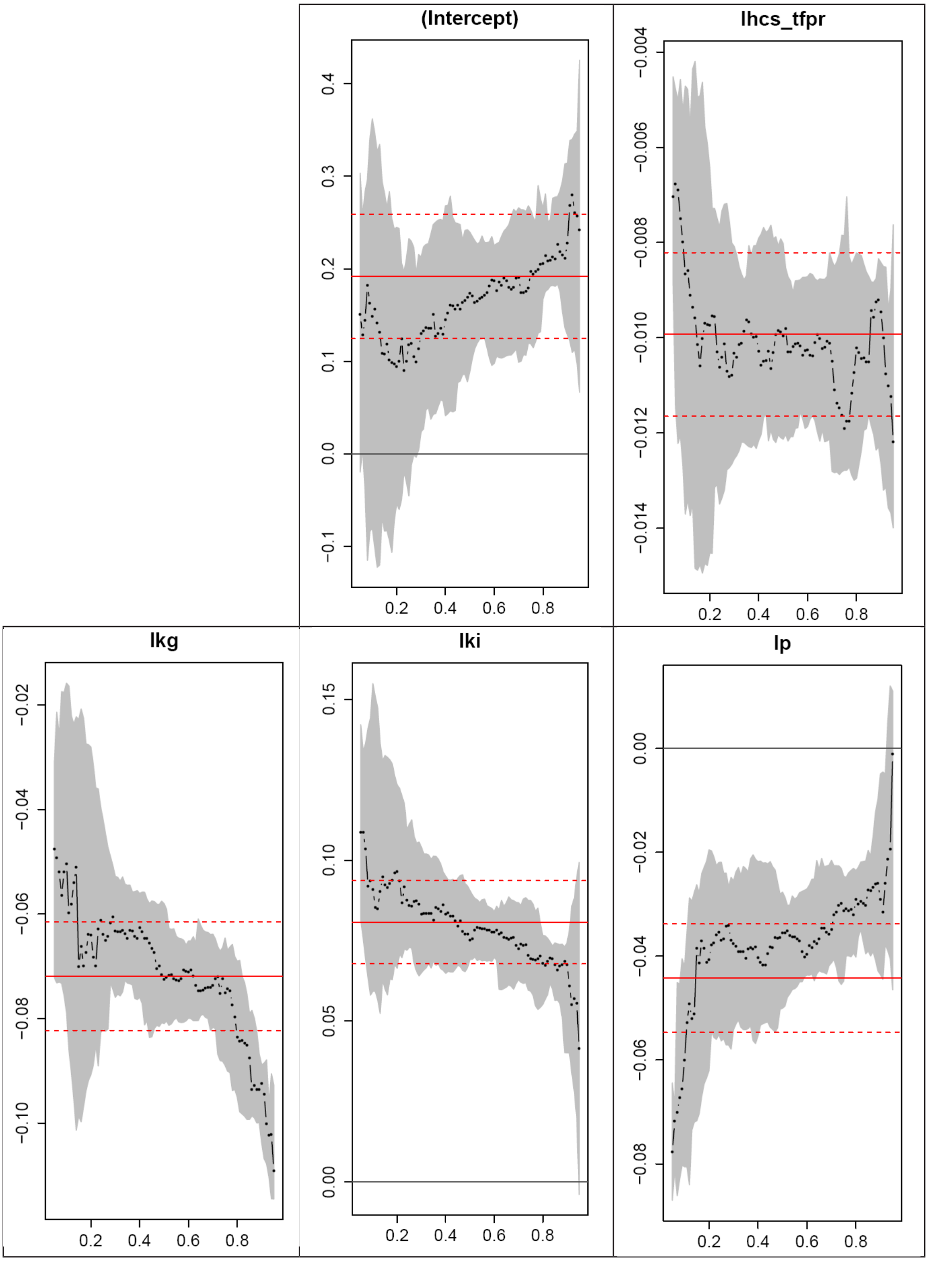
corresponding to the 10th, 25th, 50th, 75th and 90th quantiles of the conditional growth distribution for the preferred specifications of the estimated A1 and A2 models, respectively.

Table 5: Quantile Regression Estimates - Model A1

	Mean regression (OLS)	Quantiles				
		τ=0.1	τ=0.25	τ=0.5	τ=0.75	τ=0.9
Intercept	0.1918	0.1483	0.1181	0.1734	0.1968	0.2280
	(0.0409)	(0.1160)	(0.055)	(0.0401)	(0.0435)	(0.0700)
lhcs_tfpr	-0.0099	-0.0087	-0.0104	-0.01	-0.0119	-0.0095
	(0.0010)	(0.0025)	(0.0015)	(0.001)	(0.0011)	(0.0016)
lkg	-0.0719	-0.0504	-0.0639	-0.0726	-0.0751	-0.0924
	(0.0063)	(0.0142)	(0.0090)	(0.0058)	(0.0060)	(0.0094)
lki	0.0807	0.0909	0.0859	0.0752	0.0695	0.0676
	(0.0079)	(0.0225)	(0.0110)	(0.008)	(0.0087)	(0.0143)
lp	-0.0442	-0.0600	-0.0369	-0.0355	-0.0312	-0.0290
	(0.0063)	(0.0138)	(0.0084)	(0.0058)	(0.006)	(0.0076)
Adjusted R^2	0.759					

Notes: *Δly* - real GDP per capita annual growth rate; *tfpr* - distance to frontier; *hcs* - average years of secondary schooling; *kg* - public consumption share; *ki* - investment share; *p* - real exchange rate. Variables are in logs. Standard errors in parenthesis.

Figure 3: Plots of the Quantile Regression Results - Model A1



Notes: *Δly* - real GDP per capita annual growth rate; *tfpr* - distance to frontier; *hcs* - average years of secondary schooling; *kg* - public consumption share; *ki* - investment share; *p* - real exchange rate. Variables are in logs.

According to the results presented in Table 5 and Figure 3, the signs of the estimated coefficients of the different regressors considered in model A1 do not change across quantiles. But the results also show that the quantitative importance of the β-coefficients differ across the growth rate distribution. The estimated coefficient of the technological gap interacted with human capital (*lhcs_tfpr*) is always negative as expected, implying that the countries that are further away from the technological frontier (the USA) grow faster, provided they have the necessary absorptive capacity in the form of average years of secondary schooling. However, the magnitude of this effect is not the same across quantiles with the under-performing countries in terms of growth benefitting less from the technological diffusion mechanism, while the other growth quantiles exhibit a technological catch-up coefficient similar to that estimated for the mean (at a 90% confidence interval for the mean coefficient). The regressions referring to the lower quantiles of the conditional growth distribution analyse the technological convergence hypothesis for the low-performing countries in the sample, i.e. for the economies whose growth performance has been more sluggish than it could have been expected based on the conditions suggested by the variables that are included in the model. The results presented in Table 5 and Figure 3 thus indicate that when we focus on the lower quantiles of the distribution, low-performing countries register slower rates of technological convergence than over-performing economies.

As for public consumption, the coefficient is negative for all the growth quantiles, implying that for our sample of fourteen European countries an increase in the size of government will reduce growth. This is in line with the theoretical predictions of Barro (1990), according to whom when a government increases ‘utility-enhancing’ public consumption while reducing ‘production-enhancing’ public spending, growth rates fall, and is also in line with the results from a recent study by Acosta-Ormaechea and Morozumi (2013). Additionally, a stronger negative effect is found for over-achieving countries, or equivalently for the economies that experienced the highest growth rates. In this case, the interpretation of this finding is the following. The regressions that refer to the upper quantiles of the conditional growth distribution focus on the countries that have been particularly dynamic in the period, corresponding to those economies whose growth rate has been faster than it could have been expected based on the variables included in the model. From the results presented in Table 5 it is possible to see that the fast-growing economies have been more severely hampered in their growth performance by an increase in government consumption.

The estimated coefficient for the investment share is always positive, confirming the predictions of exogenous growth models that higher physical capital accumulation leads to faster growth (e.g. Solow, 1956; Mankiw, Romer, and Weil, 1992). The values of the estimated coefficient are higher for the under-performing countries. In fact, the results reported in Table 5 and Figure 3 indicate that the coefficient observed in the OLS regression is driven by the observations around or above the median of the conditional growth distribution. For the lower tails (τ = 0.1; 0.25), we find a higher growth influence of the investment rate.

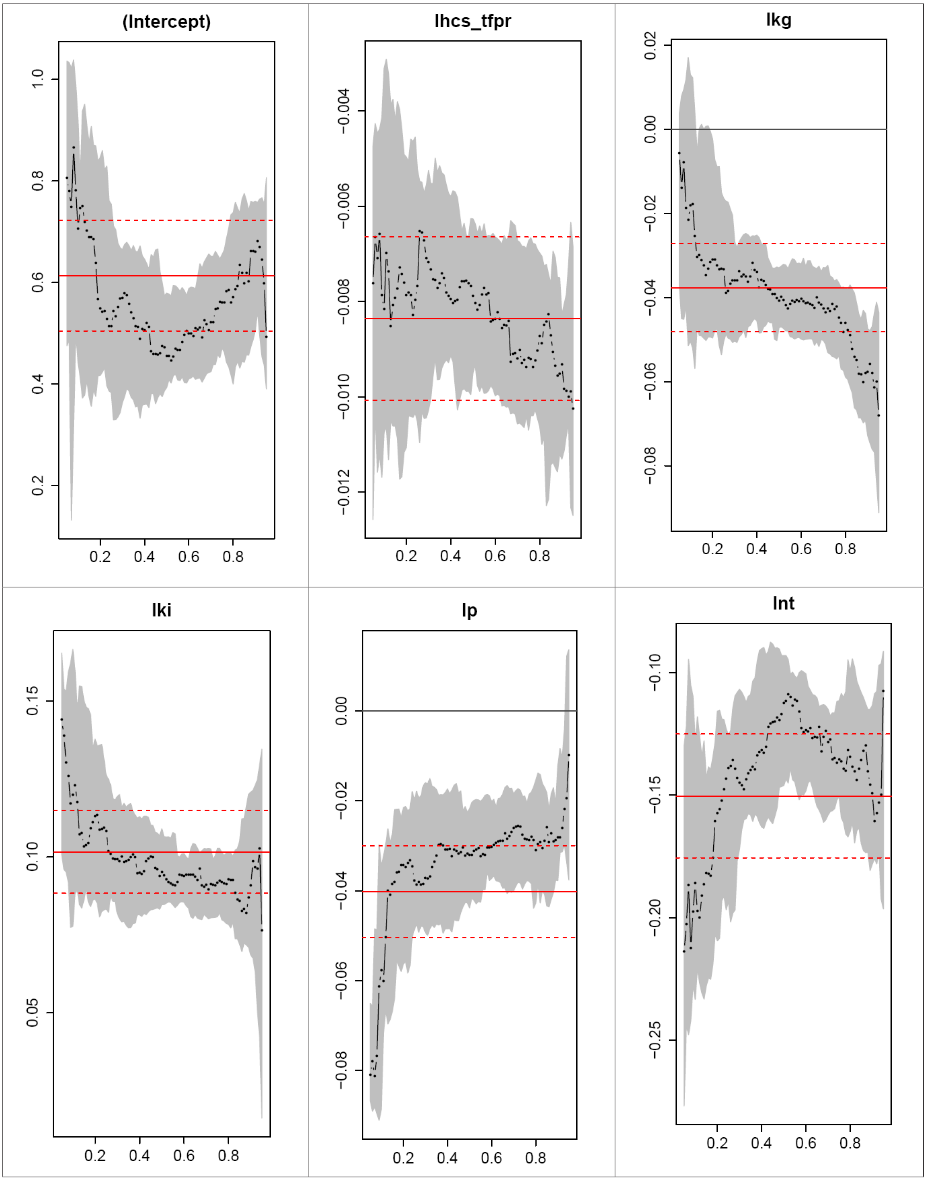
Finally, the estimated coefficient for the real exchange rate is negative as expected confirming the prediction that a decrease in price competitiveness is detrimental for growth. According to Rodrik (2008), an overvaluation of a currency is, among other things, usually associated with large current account deficits and balance of payments crisis, which are both damaging to growth. For the highest growth quantiles we find that the effect of a real exchange rate appreciation is felt less strongly (the estimated coefficient is close to zero) indicating that in these cases (price) competitiveness has a smaller growth influence, while the opposite applies at the left tail of the growth distribution. In the case of the real exchange rate, the coefficient observed in the OLS regression seems thus to be driven by the observations around the median of the conditional growth distribution.

Table 6: Quantile Regression Estimates - Model A2

	Mean regression (OLS)	Quantiles				
		τ=0.1	τ=0.25	τ=0.5	τ=0.75	τ=0.9
Intercept	0.6132	0.7056	0.5135	0.4548	0.5597	0.6597
	(0.0662)	(0.1533)	(0.093)	(0.0654)	(0.069)	(0.0957)
lhcs_tfpr	-0.0084	-0.0082	-0.0077	-0.0079	-0.0092	-0.0093
	(0.0010)	(0.0025)	(0.0015)	(0.0009)	(0.0010)	(0.0013)
lkg	-0.03763	-0.0182	-0.0334	-0.0408	-0.0429	-0.0578
	(0.0064)	(0.0152)	(0.0086)	(0.0058)	(0.0058)	(0.0077)
lki	0.1016	0.1198	0.1083	0.0951	0.0916	0.0907
	(0.0081)	(0.0200)	(0.0117)	(0.0081)	(0.0083)	(0.0122)
lp	-0.0402	-0.0577	-0.0378	-0.0321	-0.0284	-0.0281
	(0.0062)	(0.014)	(0.01)	(0.0061)	(0.0055)	(0.0079)
lnt	-0.1503	-0.186	-0.1390	-0.1124	-0.1355	-0.1493
	(0.0154)	(0.03)	(0.0209)	(0.0146)	(0.0151)	(0.0204)
Adjusted R^2	0.693					

Notes: *Δly* - real GDP per capita annual growth rate*; tfpr* - distance to frontier; *hcs* - average years of secondary schooling; *kg* - public consumption share; *ki* - investment share; *p* - real exchange rate; *nt* - non-tradables sector share. Variables are in logs. Standard errors in parenthesis.

Figure 4: Plots of the Quantile Regression Results - Model A2



Notes: *Δly* - real GDP per capita annual growth rate*; tfpr* - distance to frontier; *hcs* - average years of secondary schooling; *kg* - public consumption share; *ki* - investment share; *p* - real exchange rate; *nt* - non-tradables sector share. Variables are in logs.

Contrary to the previous model, the estimates for model A2 (Table 6 and Figure 4) indicate that the technological convergence coefficients for the different quantiles are not significantly different from the mean coefficient. The absolute value of the estimated coefficient is also smaller when compared to the value obtained with model A1. As for the remaining coefficients, they exhibit paths and signs that are similar to those obtained with model A1. Finally, the coefficient of the non-tradables sectors share is significant and negative as expected across all quantiles since these sectors are protected from international competition, which makes them less efficient and productive. For instance, a competitive business environment fosters innovation aimed at reducing production costs and creating new products, and in this way enhances economic growth. Comparing the estimated coefficients across quantiles the resulting pattern points to a kind of an inverted-U shape. The coefficient is at its minimum for the median, while for the lower tail ($\tau = 0.1$) we find the highest negative growth influence of the real exchange rate. This variable shows again a strong negative influence upon the economies that are the best performers in terms of economic growth, although not as detrimental as the one for the under-performers.

In summary, we found evidence of parameter heterogeneity across quantiles in the sense that the size of the parameters on the set of variables found to be robust across quantiles with the expected sign, the interaction term between technological catch-up and absorptive capacity, investment, government consumption, the real exchange rate, and the share of the non-tradables sector, varies across quantiles. These results lead to different policy implications for over achieving versus under-performing countries, which is the case of Portugal since the turn of the century.

3.4. Potential implications for the Portuguese economy

As we have seen, the growth path of the Portuguese economy has not been uniform after EC accession, experiencing high growth rates between 1986 and 1998, but from 1999 onwards registering sluggish growth, that has deteriorated further with the financial and the global economic crisis. According to the growth regressions results, it is possible to argue that the high growth rates recorded by the economies located at the top of the growth distribution (as was the case of the Portuguese economy over the period 1986-1998) enabled by other factors not accounted for by the empirical model facilitated the development in the Portuguese economy of the non-tradables sector[5]. Although its influence is found to be detrimental to economic growth it is not felt as strongly in the higher growth quantiles relative to the lower tails of the distribution. At the same time, the lack of (price) competitiveness[6], which we also found to be growth detrimental, is again felt less strongly by over achieving countries in terms of output growth. There thus seems to have been a lack of concern by public decision makers with these features of the Portuguese economy throughout the first phase of European integration as the factors that are not included in the estimated model created an environment conducive to high growth relative to the conditions suggested by the variables that are included in the model (see Barreto and Hughes (2004) and Crespo-Cuaresma, Foster, and Stehrer (2011)).

As far as government consumption is concerned, although the negative impact is quantitatively more important at higher quantiles, a high growth context makes it easier for over achieving countries to accommodate an increase in the size of the respective governments without hampering in a sharp way their growth performance. However, if growth slows down, as has been the case for Portugal, the negative growth impact of an increase in government consumption, although lower in under-performing countries, will be more obvious. Thus, these countries will face greater growth difficulties in using stabilization policies to accommodate negative shocks such as the ones emanating from the recent financial and economic crisis. Additionally, the widely accepted/reliable technological convergence mechanism also seems to produce smaller effects during growth slowdowns. Furthermore, Portugal still presents low relative educational attainment levels (see Simões, Andrade, and Duarte, 2014; Carneiro, 2014; Teixeira *et al.*, 2014), a feature that undermines further its ability to benefit from its technological backwardness.

5 This is well documented in Alexandre and Bação, 2014, and Simões, Andrade, and Duarte, 2014.
6 Usually associated with the former specialization pattern and also a result of joining the EMU from the start with the associated real appreciation of the Portuguese Escudo (Bação and Duarte, 2014).

These relationships, combined with other un-modelled factors, created the conditions for the growth slowdown Portugal experienced over the last decade and make it more difficult to recover from stagnation. Given this context and the results found that indicate that the size of the impact of the variables considered vary across quantiles, the immediate policy implications that follow for the Portuguese economy are that more attention should be paid to incentives that allow for a change in the specialization pattern away from the non-tradables sector along with measures that induce a real exchange rate depreciation. Additionally, an increase in investment might also stimulate growth and allow for faster recovery since our results point to a quantitatively more important impact of this growth determinant for under-performing countries.

4. Conclusion

This paper applied a quantile regression approach to examine the growth and convergence process of fourteen EU member states over the period 1986-2009. The empirical growth models retained allowed us to identify a set of growth determinants with the expected influence, an interaction term between technological catch-up and absorptive capacity, investment, government consumption, the real exchange rate, and the share of the non-tradables sector. The quantitative importance of their influences was also found to vary across the growth rate distribution, confirming the importance of accommodating parameter heterogeneity in the empirical analysis of growth. The main findings can be summarized as follows: technological catch-up (interacted with absorptive capacity), government consumption, the real exchange rate and the share of non-tradables all have a negative growth impact, quantitatively higher for under-performing countries in the last two cases, but lower in the case of technological catch up. Government consumption is especially growth detrimental for over achieving countries. As for investment, it presents the expected positive growth influence, higher for slow growing countries.

We then derived some potential implications of the above described results for understanding the particular situation of the Portuguese economy. Portugal's accession to the EU was accompanied by important achievements in what concerns basic growth determinants performance (see Simões, Andrade, and Duarte, 2014). However, in terms of relative income per capita within the group of most advanced member states, the Portuguese economy is more or less in the same position it was immediately before European integration. After the initial expansionary phase that it enjoyed between 1986 and 1998, stagnation followed and the immediate future continues not to look good. Our findings suggest that the first phase of European integration (corresponding to the period 1986-1998), when Portuguese growth rates were located at the top of the distribution, allowed for the development of the non-tradables sector since although its influence is detrimental to economic growth it is not felt as strongly at the higher quantiles. At the same time, not enough attention seems to have been paid to the lack of (price) competitiveness (usually associated with the former specialization pattern), also found to be detrimental to economic growth, since again it is less important for fast growing economies. Additionally, when countries are growing fast they can accommodate in an easier way an increase in the size of government, even if its negative impact is higher. However, if growth slows down, as was the case for Portugal, they will face greater difficulties in using stabilization policies to accommodate negative shocks. All these relationships can therefore have contributed to the growth slowdown Portugal experienced during the second phase of European integration and make it more difficult to recover from stagnation and restore long-run growth, especially in a markedly adverse setting due to the current crisis. The technological convergence mechanism also seems to produce smaller effects during growth slowdowns, and absorption capacity, proxied by educational attainment, remains relatively low in Portugal. The most pressing policy measures that follow from our results thus involve incentives that allow for a change in the specialization pattern, associated with measures that increase competitiveness and promote investment.

While we have shown that there is evidence of parameter heterogeneity in the growth and convergence process of our fourteen EU member states over the period under analysis, further research is needed to understand why such parameter heterogeneity exists, namely which un-modelled factors create an environment that is conducive to high or low growth relative to the conditions suggested by the variables we included in the estimated model. Although quantile regressions identify differences between the behaviour of successful vs. less successful countries, they do not address the question of why some have been more successful than others. This question can only be addressed by including more potentially relevant variables in the empirical model. This calls also for the use of more sophisticated statistical methods to identify the set of robust growth determinants.

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