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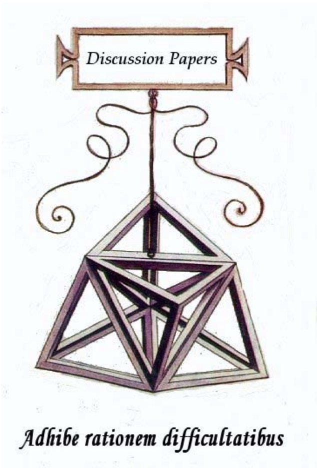

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On the Determinants of Growth Volatility: a Nonparametric Approach

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On the Determinants of Growth Volatility: a Nonparametric Approach

Abstract

We propose a model where the growth rate volatility of a country is explained by structural change and the size of the economy. We test these predictions by means of nonparametric techniques. Growth volatility appears to (i) decrease with total GDP, (ii) increase with the share of the agricultural sector on GDP. Trade openness can also play a role in conjunction with total GDP. In accordance with our model, the explanatory power of per capita GDP, a relevant variable in other empirical works, vanishes when we control for these variables.

Classificazione JEL: O11, O40, C14, C21.
Keywords: growth volatility, structural change, nonparametric methods.

Contents

I. Introduction

The relationship between growth rate volatility (*GRV* henceforth), income levels and other explanatory variables has recently started to receive attention. Contributions can be divided into two main groups. The first highlights that development is accompanied by a sharp reduction in *GRV* (see Acemoglu and Zilibotti (1997) and Pritchett (2000)), while the second refers to a negative relationship between the *size* of an economy and *GRV* (see Canning *et al.* (1998)). In addition, Acemoglu *et al.* (2003) highlight another possible causal explanation of volatility based on the lack of strong "institutions" (which may, e.g., enforce property rights, reduce corruption and/or political instability), while Easterly *et al.* (2000) focus on the development of the financial sector as a cause for the reduction in volatility.

The aim of this paper is to identify the main determinants of growth volatility of a country. This can be relevant for a better understanding of the development process, especially in low-income countries, as well as for the design of economic policies aiming at stabilizing the growth path in underdeveloped economies. In fact, a high volatility may be associated to low long-run growth, as documented in Ramey and Ramey (1995).

Since development is generally intended as an increase in per capita GDP, a first possible empirical investigation regards the relationship between *GRV* and per capita GDP. In this context, we also analyze structural change, a typical phenomenon associated to development. In fact, a plausible explanation of the reduction in *GRV* as development proceeds, resides in the decreasing weight of sectors with more volatile output, like agriculture and primary sectors, with respect to sectors with less volatile output, like manufacturing and services.[1] Differently, the increase in the number of sectors (or productive units) associated to a growing size of the economy is the most common explanation of the relationship be-

[1]So far the literature on structural change has not paid attention to this issue (see e.g. Pasinetti (1981)).

tween the size of the economy and *GRV*. In this case, a reduction in aggregate *GRV* may derive from averaging an increasing number of sectoral growth rates, since idiosyncratic shocks to each sector would tend to cancel out by the law of large numbers.

In this paper we introduce a simple analytical framework and then test for the existence of these relationships in a large sample of countries from Maddison (2001)'s dataset. In particular we focus on the effect of three variables on *GRV*: (i) the level of per capita GDP (*GDP* henceforth) as proxy for the level of development, (ii) the share of agriculture on GDP (*AS* henceforth) as proxy for structural change and (iii) total GDP (*TGDP* henceforth) as proxy for the size of the economy. We also consider a measure of trade openness (*TR* henceforth), to proxy the effective dimension of an economy which may not be entirely captured by *TGDP* only.

Individually, we find an inverse relationship between *GRV* and both *GDP* and *TGDP*, and a positive relationship between *GRV* and *AS* as we expected, although some nonlinearities appear in the latter case. *TR* shows a nonlinear behaviour, but we argue that the effect of this variable on *GRV* has to be evaluated jointly with *TGDP*. However, the effect of *GDP* on *GRV* vanishes when it is considered jointly with *TGDP*, *TR* and *AS*.

These findings agree with the predictions of our model, in which *GRV* is explained by structural change and by the size of the economy.

From the theoretical point of view, our work is also related to papers such as Scheinkman and Woodford (1994) and Horvath (1998), which study the emergence of aggregate fluctuations from local shocks. None of them is however explicitly concerned with structural change. Acemoglu and Zilibotti (1997) study an economy where an increasing number of sectors allows for a diversification of investment, and is associated to a reduction in aggregate *GRV*. A direct implication is that risk-adverse agents, by investing in more productive and more risky sectors, determine an increase in the growth rate. Hence their approach differ from ours as we focus on the specificity of the sectors (agricultural sector vs other sectors) and not only on their number. Moreover, they do not explicitly interpret the number of sectors as a proxy of the size of the economy. Differently, Acemoglu *et al.* (2003) argue that growth volatility is one negative macroeconomic consequences of poor institutions. In particular, the mechanisms ensuring the stability of governments, the enforcement of property rights and the mediation of social cleavages, are conducive to good macroeconomic performances, which include low levels of growth volatility. They do not consider the structural transformation of the economy.

In our empirical analysis we follow the Canning *et al.* (1998)'s approach, where all observations are pooled and then partitioned in classes. We measure *GRV* for each class of *GDP*, *AS* and *TGDP* as the standard deviation of growth rates associated to the observations in each class. We estimate by nonparametric methods (this is a crucial difference with respect to Canning *et al.* (1998)) the relationship between *GRV* and our explanatory variables, exploring in particular the effects of their interactions. Here *GDP* appears to play no role in the explanation of *GRV* when *AS*, *TGDP* and *TR* are included in the regression. We carefully controlled the robustness of our results with respect to different ways of computing *GRV*.

The paper is organized as follows. Section II. proposes a simple model to explain the growth volatility of a multisector economy. Section III. contains a nonparametric analysis of *GRV*; Section IV. concludes.

II. A Basic Analytical Framework

In this section we present a simple model to highlight the key factors which can account for *GRV* in a country. In particular our focus is on the composition of output and the size of the economy.

Consider an economy with N_t sectors, where t indexes time. Sector i's output grows according the following rule:

$$y_t^i = y_{t-1}^i \left(1 + g_t^i \varepsilon_t^i\right) ,$$

where y_t^i is output in period t of sector i, g_t^i is the exogenous growth rate of sector i, and ε_i^t is a random shock.

We assume that random shocks are normally distributed with mean 1 and variance $\left(\sigma^i\right)^2$, that is:

$$\varepsilon_t^i \sim N\left(1, \left(\sigma^i\right)^2\right).$$

Let Γ_t be the $N_t \times N_t$ covariance matrix, where γ_t^{ij} is an element. Notice that assuming a nonzero covariance among shocks is a simple way to model sectoral interdependence.[2] We assume that the autocorrelation of the shocks is zero, that is $cov\left(\varepsilon_t^i, \varepsilon_{t-1}^i\right) = 0$, $\forall i = 1, ..., N_t$ and $\forall t$. Finally, we assume that $\sigma^{i-1} \geq \sigma^i$, $i = 2, ..., N_t$, that is we order sectors on the basis of *GRV*.[3]

Notice that shocks are assumed to be normally distributed for analytical convenience. In fact, this allows us to measure aggregate *GRV* by the standard deviation of the aggregate growth rate. If we relax this assumption, measuring *GRV* of a country can become complex. We return on this point in the section devoted to the empirical analysis.

Let Y_t be aggregate output in period t, that is:

$$Y_t = \Sigma_{i=1}^{N_t} y_t^i.$$

Therefore the aggregate growth rate is given by:

$$\mu_t = \frac{Y_t - Y_{t-1}}{Y_{t-1}} = \frac{\Sigma_{i=1}^{N_t} y_{t-1}^i \left(1 + g_t^i \varepsilon_t^i\right)}{\Sigma_{i=1}^{N_t} y_{t-1}^i} - 1 = \Sigma_{i=1}^{N_t} \alpha_{t-1}^i g_t^i \varepsilon_t^i, \qquad (1)$$

where $\alpha_{t-1}^i = \frac{y_{t-1}^i}{\Sigma_{i=1}^{N_t} y_{t-1}^i}$ is the share of output of sector i with respect to total output, so that $\Sigma_{i=1}^{N_t} \alpha_{t-1}^i = 1$, $\forall t$.

[2] Horvath (1998) shows that a multisector model with intermediate goods and idiosyncratic shocks to individual sectors can generate an aggregate dynamics for certain structures of sectoral outputs' correlation.

[3] Grossman and Kim (1996) endogenize the different volatility of sectors on the basis of rent-seeking theory. Here, we argue that these sectors are intrinsically more subject to random shocks, e.g. changes in terms of trade, climatic changes and the like.

From definition (1) we have that the expected value and variance of μ_t are given by:

$$\bar{\mu}_t = E_t[\mu_t] = \Sigma_{i=1}^{N_t} \alpha_{t-1}^i g_t^i \tag{2}$$

$$\bar{\sigma}_t^2 = E_t\left[\left(\Sigma_{i=1}^{N_t} \alpha_{t-1}^i g_t^i \eta_t^i\right)^2\right], \tag{3}$$

where $\eta_t^i = \varepsilon_t^i - 1$. Trivially, η has the same properties of ε, but its mean is equal to 0 (that is $\eta_t^i \sim N\left(0, \left(\sigma^i\right)^2\right)$). It follows that μ_t is normally distributed, that is $\mu_t \sim N\left(\bar{\mu}_t, \bar{\sigma}_t^2\right)$. From (3) we obtain the following expression for $\bar{\sigma}_t^2$:

$$\bar{\sigma}_t^2 = \Sigma_{i=1}^{N_t} \left(\alpha_{t-1}^i g_t^i \sigma^i\right)^2 + \Sigma_{i=1}^{N_t} \Sigma_{j=1, j\neq i}^{N_t} \alpha_{t-1}^i \alpha_{t-1}^j g_t^i g_t^j \gamma_t^{ij}, \tag{4}$$

where $\gamma_t^{ij} - 1$ is the covariance between η_t^i and η_t^j.

The functional form of Equation (4) does not allow for a simple identification of the effects of the elements on the right-hand side on $\bar{\sigma}_t^2$, except for g_t^i. An increase of g_t^i, *ceteris paribus*, increases both $\bar{\mu}_t$ and $\bar{\sigma}_t^2$, i.e. $\frac{\partial \bar{\sigma}_t^2}{\partial g_t^i} > 0$, $\forall i$. However, the effects of the other variables involved, in particular the number of sectors N_t and of structure of economy $\left(\alpha_{t-1}^1, ..., \alpha_{t-1}^{N_t}\right)$, may not be so easily identifiable.

To proceed, suppose that Y_t comes from the agricultural sector A (sector 1), and from the rest of economy R (sectors $2, ..., N_t$), which includes secondary and tertiary sectors (we will use this distinction in the empirical analysis). Denoting by α_A and α_R the shares from the two macrosectors, equation (4) becomes:

$$\bar{\sigma}_t^2 = \left(\alpha_{t-1}^A g_t^A \sigma^A\right)^2 + \left(\alpha_{t-1}^R g_t^R \sigma_t^R\right)^2 + \alpha_{t-1}^A \alpha_{t-1}^R g_t^A g_t^R \gamma_t^{AR}. \tag{5}$$

It is plausible to assume that $\gamma_t^{AR} = 0$ because shocks to A and R are likely to be of different nature and uncorrelated.[4] Therefore we have:

$$\bar{\sigma}_t^2 = \left(\alpha_{t-1}^A g_t^A \sigma^A\right)^2 + \left[\alpha_{t-1}^R g_t^R \sigma_t^R\right]^2. \tag{6}$$

Generally, a change in α_{t-1}^A and $\alpha_{t-1}^R = 1 - \alpha_{t-1}^A$, and/or a change in the number of sectors N_t have an ambiguous effect on aggregate variance. Let us analyse first the role of N_t.

[4]For a discussion of the relationship between $\bar{\sigma}^2$ and Γ see Horvath (1998).

Number of Sectors and Growth Volatility Some authors argue that the size of an economy, in terms of number of sectors or units of production, may affect aggregate *GRV* (e.g. Scheinkman and Woodford (1994)). In our model, the possible negative correlation between *GRV* and N can derive from an inverse correlation between σ^R and N. We can identify simple conditions under which $d\sigma^R/dN < 0$. Assume that $g_t^i = g^R$, $\gamma_t^{ij} = 0$, $\alpha_0^i = \frac{1}{N_0-1}$, for $i, j = 2, ..., N_t$ and $\forall t$. Then, from Equation (4) written with respect to R, we have:

$$\left(\bar{\sigma}_t^R\right)^2 = \left(\frac{g^R}{N_t - 1}\right)^2 \left[\Sigma_{i=2}^{N_t} \left(\sigma^i\right)^2\right],$$

that is $\left(\bar{\sigma}_t^R\right)^2$ is decreasing in N_t and increasing in g^R, given that $\sigma^{i-1} \geq \sigma^i$.

Hence, the higher is the number of sectors in R, the lower is the variance of its growth rate, if the covariance between sectors is negligible (this is an application of the law of large numbers). If the size of an economy is positively related to the number of sectors N, then the size of an economy and its growth volatility are inversely related. Moreover, higher g^R leads to higher *GRV* but, if the output of some sectors has a strong positive correlation with the output of others, then *GRV* can nonetheless increase if the latter effect is stronger than the effect of the increase in N.[5]

To conclude, if $\sigma^R = \sigma^R(N)$, where $d\sigma^R/dN < 0$, then from Equation (6) we obtain:

$$\frac{\partial \bar{\sigma}_t^2}{\partial N_t} = \left[\alpha_{t-1}^R g_t^R\right]^2 \frac{d\left(\sigma^R\right)^2}{dN_t} < 0. \tag{7}$$

We show below that this relationship finds an empirical support when we proxy for N by the dimension of the economy.[6]

[5] An example can be the emergence of a financial sector, whose output is correlated to many sectors through the capital market. This remark could introduce the very interesting question whether *GRV* remains stable over time given, for instance, the same level of *GDP*. For example, the development of a global capital market may increase the interdependence among sectors and possibly *GRV*, without implying an increase in the level of *GDP*.

[6] Notice that to isolate the effect of N_t, we ruled out the presence of structural change but, clearly, the two factors interact.

Composition of Output and Growth Volatility In a typical process of growth and structural change, primary sectors grow less than industrial and service sectors. This implies that the share of sectors with higher variance declines over time. The overall result would be a decrease in aggregate *GRV*, as the latter is a weighted sum of sectors' variances, and weights are proportional to sectors' shares.

From Equations (1) and (6) we have:

$$\bar{\sigma}_t^2 = \left(\alpha_{t-1}^A g_t^A \sigma^A\right)^2 + \left[\left(\bar{\mu}_t - \alpha_{t-1}^A g_t^A\right)\sigma^R\right]^2 .$$

Calculations lead to:

$$\frac{\partial \bar{\sigma}_t^2}{\partial \alpha_{t-1}^A} > 0 \Leftrightarrow \alpha_{t-1}^A > \frac{\bar{\mu}_t}{g_t^A}\left[1 + \frac{\left(\sigma^A\right)^2}{\left(\sigma^R\right)^2}\right]^{-1} = \bar{\alpha}. \tag{8}$$

This means that for $\alpha_{t-1}^A < \bar{\alpha}$ ($\alpha_{t-1}^A > \bar{\alpha}$) *GRV* is decreasing (increasing) in the share of the agricultural sector α^A. That is, the relationship between α_{t-1}^A and $\bar{\sigma}_t^2$ is U-shaped. Moreover, if $\sigma^R = \sigma^R(N)$ and $d\sigma^R/dN < 0$, then the threshold value $\bar{\alpha}$ decreases in N_t.[7]

To summarize our results consider the following equation, derived from Equation (6):

$$\bar{\sigma}_t^2 = \left(\bar{\mu}_t \sigma^R\right)^2 + \left(\alpha_{t-1}^A g_t^A\right)^2 \left[\left(\sigma^A\right)^2 + \left(\sigma^R\right)^2 - \frac{2\sigma^R}{\alpha_{t-1}^A g_t^A}\right]. \tag{9}$$

In Equation (9) aggregate variance depends on two terms: the first term captures the effect of the variance of the "rest of the economy", which we argue depends negatively on the number of sectors N (see Equation (7)); the second term represents the effect of the share of agriculture α^A, whose sign depends in a non-trivial way on the interaction with N, via σ^R (see condition (8)). Notice finally that *GDP* does not play any role in the model. In our empirical analysis we estimate Equation (9).

[7]Notice that the U-shaped relation between α_{t-1}^A and $\bar{\sigma}_t^2$ resembles the relation between the variance of a portfolio and the share of the more volatile asset. In the problem of portfolio choice, the variance of portfolio decreases with the share of the more volatile asset until a positive threshold value is reached, then increases.

III. Nonparametric estimation

We use data on *GDP* and *TGDP* from Maddison (2001)'s database and data on agriculture and trade from the World Bank's *World Development Indicators 2002*. Our sample includes 119 countries for the period $1960 - 1998$.[8] As noted, we proxy for the structure of the economy by the share of the agricultural sector in aggregate value added, *AS*, and measure the *effective* dimension of the economy, related to the number of sectors N in the model, both by the *total* GDP (*TGDP*) *and* trade openness (*TR*), which is the ratio of the sum of imports and exports to GDP. The latter, jointly with *TGDP*, would provide a more exact measure of the extent of the overall market for an economy.[9]

III.A. The methodology of empirical investigation

To study the relationship between *GRV* and the levels of our variables (*GDP*, *AS*, *TGDP* and *TR*) we pool all the observations from the sample and partition them into classes. Then, we measure *GRV* by the standard deviation of growth rates or growth rates residuals corresponding to the observations in each class (in the following we discuss this point in more details).

This procedure is also adopted in Canning *et al.* (1998) and Acemoglu and Zilibotti (1997). With respect to previous studies we estimate the relationships between *GRV* and our variables by nonparametric methods. These techniques have some advantages: first, they allow to uncover the possible nonlinear effects, whose presence is shown to be pervasive in economic growth (see, e.g. Kalaitzidakis et al.(2001) and Fiaschi and Lavezzi (2003b)). Moreover, they al-

[8] Data on *GDP* and *TGDP* are in 1990 international dollars. Not all observations on agriculture and trade openness were available for each country for all years. See Appendix A for the country list.

[9] In general, as noted by Easterly *et al.* (2000), p. 10, the effect of trade openness is ambiguous: trade may reduce volatility for the reason just discussed, but it may also increase it by making a country more vulnerable to external shocks. We remark that a relevant issue is the *composition* of trade. For instance, a high level of trade openness associated to a concentration of export in few goods (e.g. primary or oil) may result in a positive relation between trade openness and growth volatility.

low to model in more general terms the interactions between the explanatory variables, which are crucial in our model and appear to be non-trivial as remarked.

As we said above *GRV* in each class can be calculated by the standard deviation of growth rates or growth rates residuals. In general, the possible cross-country heterogeneity imposes the adoption of some simplifying assumptions on the growth dynamics of different countries. To fix the idea consider the following very simple definition of the growth rate of country j, g_t^j:

$$g_t^j = f^j\left(X_t^j\right) + \lambda_t + u_t^j,$$

where $f^j\left(X_t^j\right)$ is the nonstochastic part of the growth rate of country j and is a function of a $(k \times 1)$ vector of variables X_t^j (e.g. saving rate, human capital, etc.),[10] λ_t is a random shock affecting all countries in period t, normally and independently distributed with zero mean and standard deviation σ_λ^2, and u_t^j is a idiosincratic random shock with zero mean and variance $\sigma_u^2 = \sigma\left(Z_t^j\right)$, where Z_t^j is a $(q \times 1)$ vector of variables affecting the growth volatility of country j (e.g. in our model the share of agriculture on total output, the number of sectors, etc.).

The aim is to estimate the function σ. Clearly, taking an estimate which considers the variance of the single time series of country j is inconsistent (in fact Z_t^j is likely to change over time), as well as restricting the estimate for each country to a shorter period (the estimate is poorly significant). In the literature, in order to achieve this goal (and maintain the analysis as simple as possible) three different methods have been proposed:

1. suppose that $f^j\left(X_t^j\right) = \gamma^j$, that is the growth rate of each country has a country-specific element (possibly different from country to country). Then the equation to be estimated becomes

$$g_t^j = \gamma^j + \lambda_t + u_t^j. \tag{10}$$

[10] In our theoretical model growth determinants are not considered.

Canning *et al.* (1998) pool the residuals from a panel estimation of Equation (10) and partition them into different classes on the basis of the level of *TGDP*. In other words, they are assuming that Z_t^j includes only one variable, i.e. *TGDP*. For each class they compute the standard deviation of residuals, which results to be an estimate of σ_u^2 conditioned on the level of *TGDP*. Finally, they estimate the function σ by a linear regression. A similar procedure is also followed by Acemoglu and Zilibotti (1997).

2. Suppose that $f^j\left(X_t^j\right) = f^j\left(g_{t-s}^j, ..., g_t^j, ..., g_{t+w}^j\right)$ and $\lambda_t = 0$, that is the growth rate is some function of its past and future values. Then the equation to be estimated becomes:

$$g_t^j = f^j\left(g_{t-s}^j, ..., g_t^j, ..., g_{t+w}^j\right) + u_t^j. \tag{11}$$

In particular, here we propose to estimate the function f^j by the Hodrick-Prescott filter, and then compute *GRV* as the standard deviation of the growth rate residuals with respect to the smoothed series. Head (1995) computes the growth volatility as the standard deviations of a H-P filtered series of observations on *TGDP*.

3. Suppose that $f^j\left(X_t^j\right) = f\left(X_t^j\right)$ and $\lambda_t = 0$, that is the growth process of each country is assumed to be the same:

$$g_t^j = f\left(X_t^j\right) + u_t^j. \tag{12}$$

Assuming that X_t^j and Z_t^j include only one variable, e.g. the level of *GDP* or of *AS*, etc. pooling and partitioning all observations into different classes of that variable provides an estimate of σ. In particular, here and in Fiaschi and Lavezzi (2003) we use a non-parametric approach to estimate σ.

Each method imposes strong assumptions on the analysis. In particular, the first method assumes a structure of growth dynamics that can be misleading in the calculation of residuals. For example, a country with a smooth growth dynamics, but a huge structural break within the period of observation will appear as a high growth volatility country. The second method ignores that there exists common shock to all countries. The third method has the drawback that the calculation of the residuals is conditioned on only one variable at a time.

In the following we will show that our results are independent of which assumptions we make on the growth process.[11]

III.B. A first glance at data

To have an idea of the relationships between our variables and growth volatility, for each variable we pool the observations of all countries and partition them into classes with an equal number of observations (30). For variables *GDP* and *TGDP* we get 151 classes, for *AS* 109 classes, while for *TR* 125 classes. For each variable we consider the corresponding observations on *GDP* and calculate the associated growth rates. Finally we calculate *GRV* by the simple standard deviation of growth rates (corresponding to method 3 in section III.A.).

Figure 1 reports the standard deviation of growth rates, *STD*, relative to the observations in a class against, respectively, the log of the average *GDP*, *AS*, *TGDP* and *TR* in that class, and report a nonparametric estimation of these relationships.[12]

[11] The approach adopted has however the drawback of ignoring the information on the growth path of individual countries, being based on the pooling of observations and on the measurement of *GRV* by the standard deviation within a class. For example, consider two countries whose *GDP* belongs to the same class, having constant growth rates but at very different levels. If we compute the standard deviation of growth rates for that *GDP* class, we would obtain a high value, wrongly indicating high *GRV*. In a companion paper (Fiaschi and Lavezzi (2003c)) we propose a method which overcomes this shortcoming. The method is based on the estimation of Markov transition matrices which detects transitions across growth rate classes. This procedure would correctly detect low volatility in the mentioned example. Growth volatility in this case is measured by *growth volatility indices*.

[12] All computation are performed by *R* (see R (2003)). The nonparametric estimate is obtained with the statistical package included in Bowman and Azzalini (1997). We used the standard settings suggested by the authors (i.e. optimal normal bandwidth). To test the robustness of this estimate, we ran an alternative nonparametric regression using the plug-in

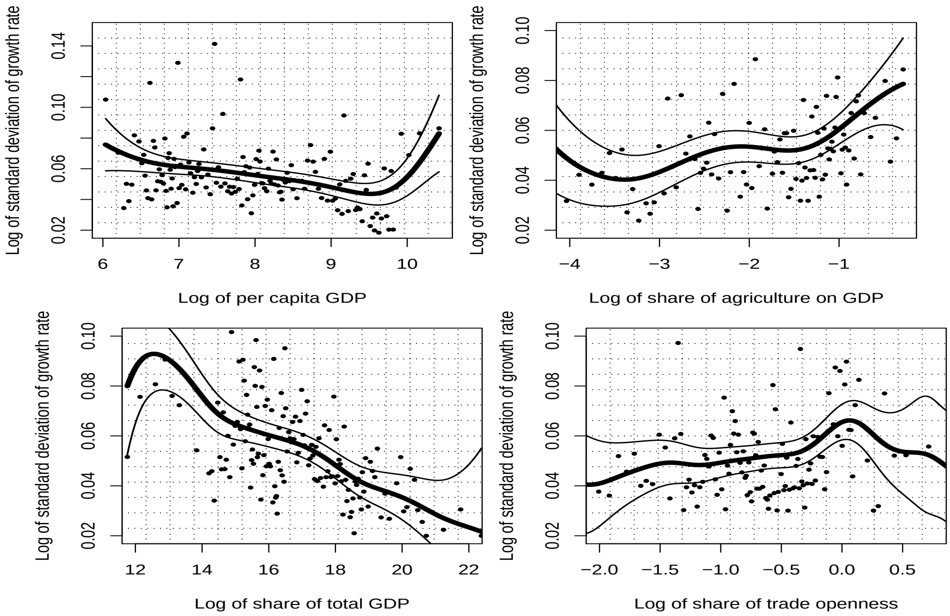

Figure 1: *GRV* estimated by *STD* vs, respectively, log of *GDP*, *AS*, *TGDP*, and *TR*

Figure 1 is the counterpart of Figure 1 in Acemoglu and Zilibotti (1997), where only cross-country variation in growth volatility is considered. They estimate an OLS regression and find a decreasing relationship between growth volatility and development, proxied by the initial level of *GDP*.

In our case, we see that *GRV* tends to fall with *GDP*. The high volatility at the lowest and, especially, highest *GDP* levels is associated with a much wider variability band, meaning that the estimate is not precise in those ranges. In Figure 1 growth volatility appears to be increasing with *AS*. This relation is not monotonic, but the variability band is tighter where the upward sloping portion is steeper, indicating that the estimation is more precise where the curve is sharply increasing. In Figure 1 *GRV* clearly decreases with *TGDP*, as the extreme portions of the estimate have a wide

method to calculate the kernel bandwidth, and obtained a similar picture. We refer to Bowman and Azzalini (1997) for more details. We report the variability bands representing two standard errors above and below the estimate. They give a measure of the statistical significance of the estimate (see Bowman and Azzalini (1997), pp. 29–30 for details on variability bands vs confidence bands). Data sets and codes used in the empirical analysis are available on the authors' websites (http://www-dse.ec.unipi.it/fiaschi and http://www-dse.ec.unipi.it/lavezzi).

variability band.

Finally, the relationship between *GRV* and *TR* in Figure 1 appears inversely U-shaped but the estimate of both decreasing parts has a wide variability band. As noted, the impact of *TR* on *GRV* does not interest us *per se*, but in conjunction with *TGDP* when we proxy for the effective size of an economy. In our view, the effective size of the economy increases if it is highly integrated with other economies.[13]

Figure 1 can be misleading in the understanding the true effect of our variables on *GRV*, because some variables show a high collinearity. In the next section we tackle this by performing a proper multivariate analysis by means of generalize additive models.

III.C. GAM estimation

To test the implications of Equation (9) we estimate the following generalized additive model:[14]

$$\begin{aligned} GRV_i = \beta_0 + \sum_{j \in P_1} s_j(x_{ji}) + \sum_{q \in P_2} \sum_{j \in P_3, j \neq q} s_{j,q}(x_{ji}, x_{qi}) + \\ + \sum_{k \in P_4} \sum_{q \in P_5} \sum_{j \in P_6, j \neq q \neq k} s_{k,j,q}(x_{ki}, x_{ji}, x_{qi}) + \epsilon_i \end{aligned} \tag{13}$$

where GRV_i is the growth rate volatility in class i, which can by estimated by one of the methods exposed in section III.A., $P_z \subseteq \{GDP, AS, TGDP, TR\}$, and $s_j(.)$, $s_{j,q}(.)$ and $s_{k,j,q}(.)$ are functions to be estimated nonparametrically. Functions $s_{j,q}(.)$ and $s_{k,j,q}(.)$ capture the effect of the interactions among the explanatory variables x_{ki}, x_{ji} and x_{qi}. Here *GDP* is considered to check the robustness of the results to its inclusion, and for comparison with existing results in the literature (remember that in our theoretical model *GDP* does not affect *GRV*).

[13] Our result on the ambiguous effect of trade openness on growth volatily provides some support to the remark of Easterly *et al.* (2000), p. 10.

[14] As we discussed above, in this paper we focus only on structural change and the size of economy. Hence we do not consider in the empirical analysis the covariance matrix Γ and growth rates of individual sectors.

Estimation by generalized additive model is particularly well-suited in this context because it is not affected by multicollinearity, a potential problem given the high correlation between *GDP*, *AS*, *TGDP* and *TR*.[15]

In the following we report the result of estimates where *TGDP* is used to define classes. The series of all other variables (*GDP*, *AS* and *TR*) are build by taking for each class of *TGDP* the corresponding observations of *GDP*, *AS* and *TR* and calculating the within-class average. In this way we obtain a dataset of 149×4 observations. The total number of classes is 149, because for two classes of *TGDP* we have not the corresponding observations for *AS* and *TR*.

As regards the calculation of *GRV*, we first show the results corresponding to method 3 of section III.A., then the results corresponding to the method 2 and 1. We suggest this order as method 3 utilizes "gross" data on growth rates, while the others take growth rates after deducting the effects of some other factors.

A potential problem in the analysis is the variable used to define the classes. In this respect we find a confirmation of our results when other variables are used to define classes.[16]

III.C.i. GRV *estimated by the standard deviation of growth rates*

Table 1 reports the estimate with classes defined on the basis of *TGDP*.[17]

[15] For example, the coefficient of correlation between *TGDP* and *AS* is -0.79, while for *TGDP* and *TR* it is equal to -0.69.

[16] Results obtained when classes are defined using the other variables are available upon request (alternatively, in the website you will find the code to get these results).

[17] The smooth terms $s(.)$ in Equation (13) are represented by penalized regression splines. The smoothing parameters are chosen to minimize the *Generalized Cross Validation* score (GCV) of the model, and the estimated degrees of freedom are computed as part of the minimization process (see Wood (2000) for more details). A lower GCV means a better fit.

Model	**1**	**2**	**3**	**4**	**5**	**6**
Constant	0	0	0	0	0	0
$s(TR, TGDP)$	0 (30.37)	-	0 (14.18)	-	-	0 (30.45)
$s(AS, TGDP)$	-	0.02 (19.99)	-	-	-	-
$s(AS, TR, TGDP)$	0 (7)	-	-	-	0 (22.15)	0 (7)
$s(TGDP)$	-	0 (8.52)	-	0 (4.10)	-	-
$s(AS)$	-	-	-	0.32 (1)	-	-
$s(TR)$	-	-	-	0.73 (1.02)	-	-
$s(GDP)$	-	-	-	-	-	0.42 (2.28)
GCV score(*10^{-4})	3.3733	3.5599	3.6217	3.6204	3.8237	3.4117
Deviance explained	0.65	0.57	0.45	0.38	0.49	0.66
Number of obs.	149	149	149	149	149	149

Table 1: Estimation of Equation (13). Dependent variable is *GRV*, classes defined in terms of *TGDP*. The p-value of the terms and the estimated degrees of freedom (in parenthesis) are reported.

For every estimated model we report the p-value for the approximate significance of each individual explanatory variable, the estimated degrees of freedom, the GCV score (the most important indicator of the goodness of fit of the model), and the value of deviance explained (an index comparable to R^2). Model 1 in Table 1 directly corresponds to Equation (9). From this equation we expected an effect on *GRV* from the number of sectors alone and from an interaction between N and *AS*. We consider the interaction between *TGDP* and *TR* as a proxy for N. These effects are indeed highly significant, and the specification of Model 1 produces the best results, in particular for the GCV score. The interaction between *TGDP* and *TR* and the interaction between these variables and *AS* account for 65% of the deviance of *STD*.

Models $2-6$ test the robustness of this result to alternative specifications. In Model 2 we check whether the inclusion of *TR* affects the results. We see that the GCV score increases while the deviance explained decreases, although the two variables are highly significant. Therefore we conclude that *TR* should be included.

In Model 3 we check for the relevance of *AS*, as its effect may be completely captured by the size of the economy. For instance, it is likely that an economy with a large agricultural share is quite underdeveloped and has a small size. However, with respect to the results of Model 1 we see that the exclusion of *AS* worsen the results.

Given that *TR* and *AS* are relevant, we check in Model 4 for the exclusion of their interactions. We can see that the only significant variable is *TGDP*, and that the results are worse than in Model 1. Hence, we conclude that the importance of *TR* and *AS* lies in their interactions. In Model 5 we check whether these variables are relevant when taken in one single interaction term, and conclude in the negative. Finally, in Model 6 we add *GDP* to our best specification, Model 1. We see that *GDP* is not significant, while the significance of the other terms is preserved.

Therefore, we argue that the effect of "development", when measured by *GDP*, on the decrease in *GRV* is broadly ascribable to our variables proxing for the size of the economy and structural change. Hence, it seems that other potentially relevant factors whose effect might be captured by *GDP* (e.g. the development of a financial system or of other "stabilizing" institutions), are not actually informative in presence of our variables.[18]

III.C.ii. GRV *estimated by the standard deviation of growth rates residuals*

In the following we report the estimates in the case we adopt method 1 or 2. We show that these results confirm the findings of the previous analysis.

Method 1 suggests to consider residuals from a panel regression of growth rates against a common component for each period and a country fixed effect, as described by Equation (10). *GRV* is therefore measured by the standard deviation of residuals for each class calculated on the basis of *TGDP*. Table 2 reports the results of

[18]However, we consider the subject for further research the explicit consideration of variables reflecting financial development.

estimations.

Model	**1**	**2**	**3**	**4**	**5**	**6**
Constant	0	0	0	0	0	0
$s(TR, TGDP)$	0	-	0	-	-	0.01
$s(AS, TGDP)$	-	0.29	-	-	-	-
$s(AS, TR, TGDP)$	0.018	-	-	-	0	0.03
$s(TGDP)$	-	0	-	0	-	-
$s(AS)$	-	-	-	0.20	-	-
$s(TR)$	-	-	-	0.96	-	-
$s(GDP)$	-	-	-	-	-	0.20
GCV score($*10^{-4}$)	3.378	3.382	3.440	3.425	3.641	3.392
Deviance explained	0.627	0.385	0.349	0.385	0.375	0.659
Number of obs.	149	149	149	149	149	149

Table 2: Estimation of Equation (13). Dependent variable is STD, estimated by the residuals of a panel regression. The p-value of the explanatory variables are reported.

We find that Model 1 is the best specification and again we see that the inclusion of GDP in Model 6 is not significant.

Method 2 suggests to consider residuals from a autoregressive process. We consider the Hodrick-Prescott filter, a widely used procedure to detrend data (see Cooley and Prescott (1995)).[19]

Model	**1**	**2**	**3**	**4**	**5**	**6**
Constant	0	0	0	0	0	0
$s(TR, TGDP)$	0	-	0	-	-	-
$s(AS, TGDP)$	-	0.01	-	-	-	0
$s(AS, TR, TGDP)$	0.02	-	-	-	0	-
$s(TGDP)$	-	0	-	0	-	0.02
$s(AS)$	-	-	-	0.22	-	-
$s(TR)$	-	-	-	0.63	-	-
$s(GDP)$	-	-	-	-	-	0.34
GCV score($*10^{-4}$)	2.864	2.793	2.964	2.987	3.072	2.886
Deviance explained	0.639	0.592	0.477	0.401	0.548	0.654
Number of obs.	149	149	149	149	149	149

Table 3: Estimation of Equation (13). Dependent variable is STD, estimated by the residuals of a Hodrick-Prescott filter. The p-value of the explanatory variables are reported

[19]In the filtering we set $\lambda = 100$, as it is standard in literature for annual data. We refer to Cooley and Prescott (1995) for more details on this filter.

Here it appears that the best model according to GCV score is Model 2, that is the model where TR is excluded. However, we see again that the inclusion of GDP in Model 2, which gives Model 6, is not significant.

Finally, in Appendices B we report the estimate in the case GRV is estimated by the variance of growth rates of each country along the period, while the values for the other variables are taken to be those corresponding to the beginning of the period (a method used for instance by Easterly *et al.* (2000)). This estimate appears to be little reliable for (i) the lack of data for low-income countries, (ii) the nonstationarity of growth paths of many countries in our sample (in fact only 38 out of 119 countries pass the Augmented Dicky-Fuller test at 10% level) and, overall, (iii) GRV is estimated over all the period, while variables are considered to the begin, so that the dynamics of the latter are not taken into account.

III.C.iii. Estimation of the individual effects

To disentangle the individual effects of individual variables is not an easy task. In the following we propose a procedure to have some intuition on the relationship between GRV and individual variables, given the results on the relevance of their interaction. We consider the estimate of our best model, that is Model 1, in the case GRV is estimated by the standard deviation of growth rates:

$$GRV_i = \hat{\beta}_0 + \hat{s}_{TGDP,TR}\left(TGDP_i, TR_i\right) + \hat{s}_{TGDP,TR,AS}\left(TGDP_i, TR_i, AS_i\right) + \bar{v}_i,$$

where $\bar{v}_i$ is the estimated error. To identify the effect of, e.g., AS we first estimate the following equations

$$\begin{aligned} TGDP_i &= \hat{s}_{AS}^{TGDP}\left(AS_i\right); \\ TR_i &= \hat{s}_{AS}^{TR}\left(AS_i\right), \end{aligned}$$

from which we obtain the fitted values of $\overline{TGDP}_i$ and $\overline{TR}_i$. We then estimate the effect of AS on GRV by:

$$\overline{GRV}_i = \hat{\beta}_0 + \hat{s}_{TGDP,TR}\left(\overline{TGDP}_i, \overline{TR}_i\right) + \hat{s}_{TGDP,TR,AS}\left(\overline{TGDP}_i, \overline{TR}_i, AS_i\right).$$

The same procedure is repeated for *TGDP* and *TR*. Figure 2 reports the estimated relationships between *GRV* and, respectively, *AS*, *TGDP*, and *TR*.

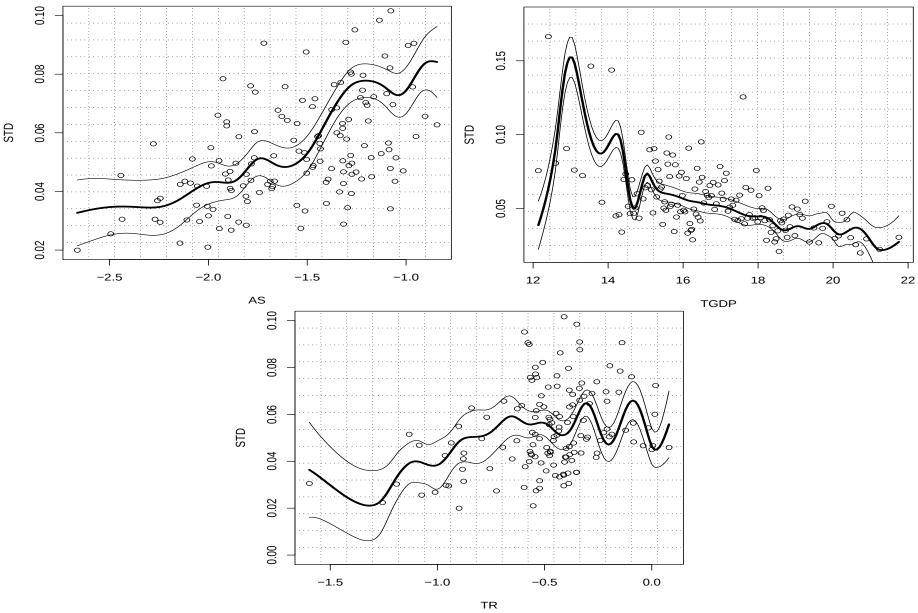

Figure 2: Estimation of *GRV* for, respectively, log of *AS*, *TGDP*, and *TR*

Figure 2 highlights that *GRV* has a significant positive correlation with *AS* (but notice the nonliearities); moreover, a clear negative relationship exists between *GRV* and *TGDP*, except for the lowest values of *TGDP* where the number of observations is low. Finally, the effect of *TR* on *GRV* appears to be relevant only for low values of *TR*, but its sign is ambiguous. In particular, it appears that the effect of *TR* on *GRV* is positive for low values of *TR*, and then becomes uncertain.

IV. Conclusions

This paper investigates the relation between growth volatility and the level of development, structural change and the size of the economy. We perform the econometric analysis by means of nonparametric techniques. Growth volatility appears to be negatively related to total GDP, proxy for the dimension of the economy. In particular it seems appropriate to consider as an additional control for the dimension of the economy the integration in the world markets although the latter, whene considered in isolation, has an ambiguous effect on volatility. Moreover, growth volatility appears to be negatively related to the share of agriculture on GDP, proxy for structural change. Finally, per capita GDP, proxing for the level of development, does not seem to add relevant information when the other variables are considered. A direction for further research may be an assessment of the explanatory power of other factors related to development and to growth volatility, like the growth of a financial sector, in relation to structural change.

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Appendix

A Country List

AFRICA	1 Algeria	2 Angola	3 Benin	4 Botswana
5 Cameroon	6 Cape Verde	7 Cent. Afr. Rep.	8 Chad	9 Comoros
10 Congo	11 Côte d' Ivoire	12 Djibouti	13 Egypt	14 Gabon
15 Gambia	16 Ghana	17 Kenya	18 Liberia	19 Madagascar
20 Mali	21 Mauritania	22 Mauritius	23 Morocco	24 Mozambique
25 Namibia	26 Niger	27 Nigeria	28 Rwanda	29 Senegal
30 Seychelles	31 Sierra Leone	32 Somalia	33 South Africa	34 Sudan
35 Swaziland	36 Tanzania	37 Togo	38 Tunisia	39 Uganda
40 Zambia	41 Zimbabwe	LATIN AMERICA	42 Argentina	43 Brazil
44 Chile	45 Colombia	46 Mexico	47 Peru	48 Uruguay
49 Venezuela	50 Bolivia	51 Costa Rica	52 Cuba	53 Dominican Rep.
54 Ecuador	55 El Salvador	56 Guatemala	57 Haiti	58 Honduras
59 Jamaica	60 Nicaragua	61 Panama	62 Paraguay	63 Puerto Rico
64 Trin. Tobago	OFF WESTERN	65 Australia	66 New Zealand	67 Canada
68 United States	WEST ASIA	69 Bahrain	70 Iran	71 Iraq
72 Israel	73 Jordan	74 Kuwait	75 Lebanon	76 Oman
77 Qatar	78 Saudi Arabia	79 Syria	80 Turkey	81 UAE
82 Yemen	83 W.Bank Gaza	EAST ASIA	84 China	85 India
86 Indonesia	87 Japan	88 Philippines	89 South Korea	90 Thailand
91 Bangladesh	92 Hong Kong	93 Malaysia	94 Nepal	95 Pakistan
96 Singapore	97 Sri Lanka	98 Afghanistan	99 Cambodia	100 Laos
101 Mongolia	102 North Korea	103 Vietnam	EUROPE	104 Austria
105 Belgium	106 Denmark	107 Finland	108 France	109 Germany
110 Italy	111 Netherlands	112 Norway	113 Sweden	114 Switzerland
115 UK	116 Ireland	117 Greece	118 Portugal	119 Spain

Table 4: Country list

B GAM estimation with cross-country data

In this Appendix we show the results of GAM estimations with cross-country data, restricting our analysis to the period 1970 − 1998 for lack of data on *TR* and *AS*. For each country we consider the standard deviation of growth rates for the period as *STD*, the value of per capita GDP in 1970 as *GDP*, the value of total GDP in

1970 for $TGDP$ and the average value of trade openness and the share of agriculture on GDP for the period $1970 - 1975$ as TR and AS (possible missing values have been removed). The available observations are only 87 (we would have only 58 observations if 1960 were the initial year, and the most of excluded countries are low income countries). Table 5 reports the results of GAM estimations.

Model	**1**	**2**	**3**	**4**	**5**	**6**
Constant	-	0	0	0	0	0
$s(TR, TGDP)$	-	-	0	-	-	-
$s(AS, TGDP)$	-	0.034	-	-	-	-
$s(AS, TR, TGDP)$	-	-	-	-	0	-
$s(TGDP)$	-	0	-	0	-	0
$s(AS)$	-	-	-	0	-	0.054
$s(TR)$	-	-	-	0.147	-	-
$s(GDP)$	-	-	-	-	-	0
GCV score(*10^{-4})	-	5.278	5.513	4.519	5.818	3.877
Deviance explained	-	0.506	0.217	0.484	0.308	0.601
Number of obs.	-	87	87	87	87	87

Table 5: Estimation of Equation (13). Dependent variable is STD. The p-value of the explanatory variables is reported

Results for Model 1 are not reported because the routine for the likelihood minimization could not reach convergence. From the other models it results that TR is not significant, but GDP is and Model 6 is the best in terms of GCV score. However, as already remarked, we do not consider this procedure as appropriate.

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