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Modeling Parameter Heterogeneity in Cross-Country Growth Regression Models*

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Abstract

Given the failure of the conventional linear Solow growth model to establish reliable results in the analysis cross-country growth performance, this paper proposes a new framework using the concept of hierarchy of time-scales. By hierarchy of time scales, I mean that slower moving variables such as culture, play a major role in determining medium moving variables such as institutions, and which in turn play a major role in determining faster moving variables such as the conventional determinants of economics growth. This approach provides a systematic way of thinking about the heterogeneity in the cross-country growth performance. In the context of the Solow growth model the hierarchical approach suggests a local generalization of the Solow growth model in the form of a semiparametric varying parameter model along the lines of Hastie and Tibshirani (1992). Using the varying coefficient model, this paper studies two examples. In the first example the parameters of the model vary according to initial human capital while in the second they vary according to a measure of ethnic diversity. The results suggest that there exists substantial parameter heterogeneity in the cross-country growth process.

Keywords: Empirical Growth, Heterogeneity, Hierarchy of Time-Scales, Varying Parameters.
JEL Classification: C14, C21, C50, N10

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1 Introduction

Empirical growth research has become one of the dominant areas of macroeconomics. Yet, despite the vast research, there seems to exist remarkably little confidence in the body of results and the implications of the conventional empirical methods of growth analysis. A typical example is Pack (1994), pp. 68-69, who describes several problems with cross-country growth regressions:

> "...The production function interpretation is further muddled by the assumption that all countries are on the same international production frontier...regression equations that attempt to sort out the sources of growth also generally ignore interaction effects...The recent spate of cross-country growth regressions also obscures some of the lessons that have been learned from the analysis of policy in individual countries."

One of the major reasons for this general mistrust of the conventional cross-country linear regression models is the assumption of parameter homogeneity. Parameter homogeneity means that the parameters of the model are assumed to be country-invariant. An example that indicates the problem is Brock and Durlauf (2001), pp. 8-9:

> "A second problem with conventional growth analyses is the assumption of parameter homogeneity. This seems to be a very implausible assumption. Does it really make sense to believe that the effect of a change in the level of civil liberties index on growth in the United States is the same as that for Russia?...Our contention is that the assumption of parameter homogeneity seems particularly inappropriate when one is studying complex heterogeneous objects such as countries..."

Parameter homogeneity makes the linear Solow growth model theoretically uncompelling as well as statistically misspecified. At a theoretical level the linear growth model is unsatisfactory for several reasons. First, a wide range of recent nonlinear growth models explicitly suggest that the parameters of a linear growth regression, which depends only on the stocks of capital and labor, will not be constant across countries. Example include Romer (1986), Azariadis and Drazen (1990), Galor and Zeira (1993), Durlauf (1993), Lucas (1993), Durlauf (1996). Each of these theories suggests that, from the perspective of a local linear approximation of the growth process, different countries will be characterized by different parameters. Second, a range of new growth theories has emerged that suggests additional covariates beyond those originally proposed by Solow can induce nonlinearities. Galor (1996) suggests that the introduction of new variables can induce polarization, persistent poverty, and clustering across countries. For instance, Durlauf and Quah (1999) identified more than 80 variables used by various researchers ranging from market distortions, geographical regions, source endowments, climate, institutions, politics, war etc. Third, the assumption of Cobb-Douglas production function of the Solow growth model is questionable. Duffy and Papageorgiou (2000) and Masanjala and

Papageorgiou (2001) find evidence in favor of a CES production function rather than the standard Cobb-Douglas specification. This is important given that a Cobb-Douglas production function is a necessary condition for the linearity of the Solow growth model.

Evidence of statistical mispecification has recently been developed by a number of studies that suggests the assumption of a single linear model when applied to all countries is invalid. Instead, they find evidence which is consistent with multiple steady-state equilibria that classify the countries into different convergence clubs. Durlauf and Johnson (1995) employs a tree-regression approach to uncover multiple regimes in the data while Hansen (2000) proposes a threshold regression model that leads to a formal test for the presence of a regime change. Liu and Stengos (1999) and Kalaitzidakis et al (2001) employ an additive semiparametric partially linear model to identify nonlinear growth patterns. Canova (1999) uses a predictive density approach, Desdoigts (1999) employs an exploratory projection pursuit (density estimation) while Kourtellos (2001) uses a projection pursuit regression. Finally, Brock and Durlauf (2001) provide a systematic account of the econometric problems associated with the Solow growth model and they argue that these problems are forms of violations of an exchangeability assumption.

This paper approaches the topic of cross-country growth analysis using the concept of a hierarchy of time scales. By hierachy of time scales, I mean that slower moving variables such as culture, economic aspirations, play a major role in determining medium moving variables such as institutions, property rights, and which in turn play a major role in determining faster moving variables such as the conventional determinants of economics growth (for example saving rates). This approach is inspired by the ideas expressed in Inglehart (1997), North (1997), and Brock (2001)[1]. From the perspective of economic growth these ideas seem to suggest that current conventional growth models of Solow, Barro, Lucas, etc. are unable to explain the heterogeneity of growth rates that we observe because these models ignore structures embedded in the current institutional framework operating in each country which in turn are determined by a system of beliefs (e.g. culture) operating in each country.

Here, the hierarchical approach suggests a local generalization of the Solow growth model in the sense that the Solow model applies to all countries but the aggregate production function varies across countries. In effect, this local generalization can facilitate a bridge between hierarchical models and modern growth theories. Theories such as Azariadis and Drazen (1990) suggest that countries that are identical in their structural characteristics but differ in initial conditions may cluster around different steady state equilibria in the presence of increasing returns to scale from some factor of production, market imperfections, non-convexities in the production function, etc. In other words, the introduction of initial conditions such as level of

[1] A similar approach has been successfully used in Ecology by Holling (1992) and others in the testing of Holling's Textural Hypothesis. The idea is that slow moving variables such as landscape determine the distribution of body size distributions in ecological data sets. The analogy is clear. The "landscape" corresponds to slow moving variables such as growth related cultural and institutional characteristics. The faster moving variables correspond to conventional determinants of growth such as saving rates.

initial human capital, initial income distribution, non-convexities, externalities and capital market imperfections may lead to the emergence of club convergence (see Galor (1996)). These considerations suggest that if we index the countries by an interesting dimension such as initial conditions then, near steady state, the Solow model can provide a good approximation for countries with similar initial conditions.

In this paper, the local generalization of the Solow growth model takes the form of a semiparametric varying coefficient model along the lines of Hastie and Tibshirani (1990). It is semiparametric in the sense that it imposes no assumptions on the functional form of the coefficients. Two important examples are studied. The first example builds on Durlauf and Johnson (1995) who used initial human capital as a source of thresholds in the growth process. In this example the parameters of the Solow growth model vary smoothly with an unknown function of initial human capital. The second example builds on Easterly and Levine (2000) who used ethnic diversity to explain Africa's poor growth. In this case the parameters of the model vary smoothly with an unknown function of ethnic diversity.

This modeling strategy can also be formalized in terms of exchangeability arguments. It is equivalent to assuming that the regression parameters of the Solow growth model are exchangeable, conditional on initial human capital in the first model and ethnic diversity in the second model. Here, conditional exchangeability means that the model incorporates all the relevant information about the growth process. This stronger assumption allows a researcher to judge the overall specification of the model, which is not limited to the specification of the regression function; for more see Brock and Durlauf (2001).

My findings suggest that there exists substantial heterogeneity across countries. This heterogeneity is reflected in the effect of Solow-type variables on growth, which appears to vary substantially with initial human capital and ethnic diversity. In particular, my results are suggestive of the presence of two steady state equilibria in the growth process with respect to initial human capital. This is consistent with the twin peaks found by Quah (1997) in the cross-country limiting distribution of income. What is more, my results suggest that ethnic diversity may not necessarily be a bad thing. For countries with moderate levels of ethnic diversity, the relationship between growth rate and ethnic diversity is positive. Furthermore, very low or very high levels of ethnic diversity can induce divergence.

2 Revisiting the Conventional Approach

The standard approach to cross-country growth analysis as illustrated by Barro (1991, 1997), Barro and Sala-i-Martin (1995), and Mankiw, Romer and Weil (1992) and extended by Evans (1993), Islam (1995) and Lee, Pesaran and Smith (1997) to panel data[2], has focused on the (parameter invariant) linear regression model.

$$g_i = \boldsymbol{\beta}'\mathbf{X}_i + \boldsymbol{\beta}_W'\mathbf{W}_i + u_i, \quad i = 1, ..., n \tag{1}$$

where g_i is real per capita growth in economy i over a given time period, $\mathbf{X}_i$ is a $p+1$ dimensional vector of the p variables suggested by the Solow growth model (Solow 1957) and a constant. These variables are common across different studies that use the Solow model as a baseline model to build up more involved theories. According to the basic Solow theory, the vector of explanatory variables $\mathbf{X}_i$ consists of the log of $y_{i,0}$, the real per capita income of the country at the beginning of the period over which growth is measured, the log of $s_{k,i}$, the savings rate for physical capital accumulation out of real output, and the log of $(n_i+\rho+\delta)$, where n_i is the population growth rate of country i and ρ and δ represent common rates of technical change and depreciation of human and physical capital stocks, respectively. Following common practice I assume that $(\rho + \delta) = 0.05$. $\mathbf{W}_i$ is a q-dimensional vector of additional country specific covariates that augments the basic Solow model. It usually includes proxies for the unobservable variables of technology level and technological growth. In practice however, vector $\mathbf{W}$ includes any covariates a researcher believes are important and as a result the empirical model cannot be linked to any theoretical model. An exception of this practice is the work by Mankiw, Romer and Weil (1992) where the variables used in the empirical analysis were explicitly suggested by the theoretical model. In particular, they augment the original Solow growth model with the log of $s_{h,i}$, which is the analogous savings rate for human capital. The variable u_i is the non-systematic (error) term.

A typical conclusion of this literature is given by Barro (1997):

> "...Growth differences between countries depend first on each country's existing level of output. If a country's current output is below its steady-state level of output, there is a catching-up process, which occurs mainly through technological transfer. Each year's growth eliminates some 2.5 percent of the gap between actual and steady-state output", Barro (1997), pp.vii.

Interestingly, Solow (1986) is skeptical about the model that bears his name and is widely used to explain cross-country growth differences:

> "...One model is supposed to apply everywhere and always. Each country is just a point on a cross-section regression, or one among several essentially identical regressions, leaving only grumblers to worry about what is exogenous and what is endogenous, and whether simple parameterizations do justice to real differences in the way the economic mechanism functions in one place or another.", Solow (1986), Economica, 53, S23-34.

[2] Panel data approaches to growth have addressed the problem of parameter heterogeneity by allowing for fixed effects or random effects. However, in the context of cross-country growth comparisons these methods are of limited scope because they condition out the variation that underlies why some countries are rich, and others poor. A similar point is made by Quah (2000).

A careful rereading of Solow's original work shows that Solow developed his model based on stylized facts from the most developed countries and these stylized facts were not interpreted as universal properties for every country in the world. In contrast, the current literature imposes very strong homogeneity assumptions on the cross-country growth process as each country is assumed to have an identical (and Cobb-Douglas) aggregate production function. In effect, this assumption translates into country invariant regression parameters in the standard cross-country growth equation. This is surprising given that modern growth theories suggest that different countries should be described by different aggregate production functions. Parente and Prescott (2000) argue that although countries may share the same production function, there exist political, legal, and other barriers across countries that are put in place to protect the interest of groups involved in current production process. These barriers prevent countries from using their same production function potential and keep the economy inside its production possibility frontier. Brock, Magee, and Young (1989) provide a similar argument and study internal political organization that gives rise to this kind of "rent seeking" behavior that prevents economies from being on the same efficiency frontier across countries. This discussion suggests that the assumption of constant parameters cannot be interpreted as a global property for every country in the world. Therefore one should explicitly account for parameter heterogeneity rather than using the linear model (1) as a framework in modelling all types of cross-country growth differences.

3 Data

In this paper, I use a balanced panel dataset for 85 countries (see table 1) averaged over three periods: 1960 to 1969, 1970 to 1979 and 1980 to 1989. The explanatory variables I consider is the standard set variables suggested by the Solow growth theory (see Mankiw, Romer and Weil (1992)) plus a measure of ethnic diversity. They include (*i*) *gpop*, logarithm of average growth rate of the population plus 0.05 for depreciation; (*ii*) *inv*, logarithm of average proportion of real investments (including government) to real GDP; (*iii*) h_0, logarithm of adult literacy rates defined as the fraction of population over the age of 15 that is able to read and write in 1960; (*vi*) y_0, logarithm of initial per capita income; (*v*) *eth*, logarithm of ethnic fractionalization.

This measure of ethnic fractionalization was used by Easterly and Levine (1997) to explain Africa's poor growth. It measures the probability that two randomly selected individuals in a country belong to different ethnolinguistic groups. Ethnic diversity may increase polarization and thereby hinder coordination for the provision of public goods; see Alesina and Drazen (1991), Shleifer and Vishny (1993), Person, Roland, and Tabellini (1997). Ethnic diversity may also create positive incentive for growth-reducing policies, such as financial repression and overvalued exchange rates, that promote rent-seeking behavior; see Alesina and Spalaore (1997), Alesina, Baqir, and Easterly (1999), Alesina and Ferrara (2000).

The explanatory variables also include a couple of time dummies for 1960's and 1970's. Income growth rates, g, reflect the change in the log of income per capita over the 1960s, the 1970s, and 1980s. With the exception of adult literacy rates, the data were obtained from the World Bank's Global Development Network Growth Database developed by Easterly and Yu (2000). Adult literacy rates were obtained from data are from the World Bank's World Report. Table 1 also presents the relative ranks of countries with h_0 and eth in ascending order. Figure 1 presents kernel density estimates of the variables used along with the 95% confidence intervals. The quartic kernel , $k(x) = \frac{15}{16}(1 - x^2)^2 I(\mid x \mid \leq 1)$ was used and the bandwidth was based on the Silverman's rule of thumb.

4 Varying Coefficient Model

One way to model parameter heterogeneity is to locally generalize (1) into a varying coefficient model:

$$g_i = \boldsymbol{\gamma}(z_i)'\mathbf{X}_i + u_i \tag{2}$$

where $\boldsymbol{\gamma}(z_i)$=($\gamma_1(z_i)$,$\gamma_1(z_i)$,...,$\gamma_{p+1}(z_i)$)$'$ is a smooth function that maps the scalar index z_i into a set of country-specific Solow parameters. Hastie and Tibshirani (1990) studied this type of model. The term local captures the idea that a Solow model applies to each country, but the parameters of the aggregate production function vary according to a slower moving variable such as country's initial conditions and country characteristics. In other words, although the Solow model can be an inappropriate specification when applied to all countries, it can still be a good approximation locally for a each country.

Following Durlauf, Kourtellos, and Minkin (2001), z_i may be interpreted as a measure of "development" of a country. By modelling parameter heterogeneity in this way, one can classify the variables in the vector of additional controls Z in terms of their time-scales. In general, slower moving variables will define a "development" index, which will be used to characterize parameter heterogeneity. For instance, if one believes that ethnic diversity causally affects growth (Easterly and Levine (1997)), then an ethnic diversity variable can be introduced as a "development" index rather than be appended linearly as an additional regressor. Furthermore, this local generalization of the Solow growth model provides a framework within which one can bridge the gap between cross-country regression models and modern theories. For example, if one wants to evaluate Azariadis and Drazen (1990), particularly their assumption that there exist threshold capital externalities, then one needs to investigate whether the measure of "development" $\boldsymbol{\gamma}(z_i)$ behaves as a step function with respect to a capital stock. Moreover, the varying coefficient model allows the variables of initial human capital and ethnic diversity to affect the growth of income in two ways. First, they can affect the growth process directly as an additive component, which is reflected in the varying intercept. And second, they can affect the growth process indirectly by affecting the effect of the Solow-type variables on growth, which is reflected in the varying parameters. Here, the "development" index, z_i takes the form of initial human capital and ethnic diversity. The vector $\mathbf{X}_i$ reflects the basic Solow type variables. The varying coefficient model (2) is characterized by the assumptions[3]:

$$E(g_i \mid \mathbf{X}_i = \mathbf{x}_i) = \boldsymbol{\gamma}(z_i)'\mathbf{x}_i \tag{3}$$
$$Var(g_i \mid \mathbf{X}_i = \mathbf{x}_i) = \sigma^2(z_i). \tag{4}$$

The sampling model is assumed to be a random sample $\{g_i, \mathbf{x}_i\}_{i=1}^n$ drawn from a distribution $F_{g,X}$. I also assume that the data matrix $\mathbb{X}$ has a full rank.

4.1 Estimation Issues

The varying parameter formulation (2) is very appealing since the parameter functions can easily be estimated by a simple local regression; see Fan and Zhang (1999, 2000)). Particularly, for each given point z_0, I approximate the functions $\gamma_j(z)$, $j = 1, \dots p$, by local polynomials of odd[4] order as

$$\gamma_j(z) \approx \sum_{l=0}^{q} c_{jl}(z - z_0)^l \tag{5}$$

for sample points z in a neighborhood of z_0. This results in the following weighted local least squares problem:

$$\min_{c_{jl}'s} \sum_{i=1}^{n} \left[g_i - \sum_{j=1}^{p} \sum_{l=0}^{q} c_{jl}(z_i - z_0)^l X_{ij} \right]^2 K_h(z_i - z_0) \tag{6}$$

where $K_h(\cdot) = \frac{1}{h} K\left(\frac{\cdot}{h}\right)$ and $K(\cdot)$ is the Epanechnikov kernel $K(z) = \frac{3}{4}(1 - z^2)I(\mid z \mid \leq 1)$.

Let $\mathbf{g} = (g_1, \dots, g_n)'$, $\mathbf{W} = diag\left(\frac{1}{h}K(\frac{z_1 - z_0}{h}), \dots, \frac{1}{h}K(\frac{z_n - z_0}{h})\right)$, and

$$\mathbf{X}_q = \begin{pmatrix} X_{11} & \cdots & (z_1 - z_0)^q X_{11} & \cdots & X_{1p} & \cdots & (z_1 - z_0)^q X_{1p} \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ X_{n1} & \cdots & (z_n - z_0)^q X_{n1} & \cdots & X_{np} & \cdots & (z_n - z_0)^q X_{np} \end{pmatrix} \tag{7}$$

I estimate the varying parameters $\gamma_j(z), j = 1, \dots, p + 1$ by adopting a local linear approximation $q = 1$. Higher order fits are necessary for the selection of the bandwidth discussed subsequently. The solution of the problem (6) is then given by

$$\widehat{\gamma}_j(z) = e'_{2j-1,2p}(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1)^{-1}\mathbf{X}_1'\mathbf{W}\mathbf{g} \tag{8}$$

where $e_{k,m}$ denote the unit vector of length m with 1 at the k_{th} position.

The conditional variance is estimated by a normalized weighted residual sum of squares

$$\widehat{\sigma}^2(z) = \frac{\sum_{i=1}^{n} (g_i - \widehat{g}_i)^2 K_h(z_i - z)}{tr\{\mathbf{W} - \mathbf{W}\mathbf{X}_1(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1)^{-1}\mathbf{X}_1'\mathbf{W}\}} \tag{9}$$

[3] Notice that z is not random

[4] Odd order polynomial fits outperform even order polynomial fits; see Fan and Gibjels (1996).

where

$$\widehat{\mathbf{g}}_i = (\widehat{g}_1, \ldots, \widehat{g}_n)' = \mathbf{X}_1(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1)^{-1}\mathbf{X}_1'\mathbf{W}\mathbf{g} \tag{10}$$

The approximate asymptotic conditional variance of $\widehat{\gamma}_j(z)$, $\widehat{Var}(\widehat{\gamma}_j(z) \mid \Im))$, assuming local homoskedasticity can be estimated (see Fan and Zhang (2000)) by

$$e'_{2j-1,2p}\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\left(\mathbf{X}_1'\mathbf{W}^2\mathbf{X}_1\right)\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}e'_{2j-1,2p}\widehat{\sigma}^2(z) \tag{11}$$

where $\Im$ denotes the vector of the observed covariates

$$\Im = (x_{11}, \ldots x_{1n}, \ldots, x_{p1}, \ldots x_{pn}) \tag{12}$$

The conditional bias $\widehat{bias}(\widehat{\gamma}_j(z) \mid \Im)$ is estimated by $e'_{1,2p}\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\mathbf{X}_1'\mathbf{W}\widehat{\boldsymbol{\tau}}$ where the ith element of the $n \times 1$ vector $\widehat{\boldsymbol{\tau}}$ is given by

$$\sum_{j=1}^{p}\left[\frac{1}{2!}\widehat{\gamma}_j{}^2(z)(z_i - z)^2 + \frac{1}{3!}\widehat{\gamma}_j{}^3(z)(z_i - z)^3\right]X_{ij} \tag{13}$$

4.1.1 Confidence Intervals

Given the relatively small sample size and the heterogeneity involved in the specification of the conditional variance, this paper opts for bootstrap confidence intervals using the method of wild resampling. The basic idea is that the j_{th} resampled error u_j^* is drawn from the two point distribution

$$P\left(u_j^* = \frac{(1-\sqrt{5})}{2}\widehat{u}_j\right) = \frac{(5+\sqrt{5})}{10} \text{ and } P\left(u_j^* = \frac{(1+\sqrt{5})}{2}\widehat{u}_j\right) = \frac{(5-\sqrt{5})}{10}$$

where $\widehat{u}_j$ is the residual $\widehat{u}_j = g_j - \widehat{g}_j$.

4.1.2 Bandwidth Selection

The bandwidth selection is based on a variable bandwidth selection procedure proposed by Zhang and Lee (2000). In the case of unequally spaced data a variable bandwidth is necessary for estimating the parameter functions. Zhang and Lee show that the optimal variable bandwidth is superior to the theoretical optimal constant bandwidth and the bandwidth obtained by the cross-validation method.

The optimal variable bandwidth for the varying coefficient model is given by

$$\widehat{h}_{opt} = \arg\min_h \widehat{MSE}(\widehat{\boldsymbol{\gamma}}(z) \mid \Im) \tag{14}$$

where $\widehat{MSE}(\widehat{\boldsymbol{\gamma}}(z) \mid \Im)$ is a good estimator of the mean squared error $MSE(\widehat{\boldsymbol{\gamma}}(z) \mid \Im)$ defined by

$$MSE(\widehat{\boldsymbol{\gamma}}(z) \mid \Im) = \mathbf{b}'(z)\Omega(z)\mathbf{b}(z) + tr\left(\Omega(z)Cov(\widehat{\boldsymbol{\gamma}}(z) \mid \Im)\right) \tag{15}$$

where $\mathbf{b}(z) = bias(\widehat{\boldsymbol{\gamma}}(z) \mid \Im) = \left(bias\left(\widehat{\gamma}_1(z) \mid \Im\right), \ldots, bias(\widehat{\gamma}_p(z) \mid \Im)\right)$ and Ω is a matrix with $(i,j)th$ elements equal to $r_{ij}(z)$ with $r_{ij}(z) = E(X_iX_j \mid z = z)$, for $i,j = 1, 2, \ldots, p$.

Based on a second order Taylor approximation the conditional bias $\mathbf{b}(z)$ can be estimated by

$$\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\mathbf{X}_1\mathbf{W}\mathbf{X}_1^*\mathbf{s} \tag{16}$$

where $\mathbf{X}_1^*\mathbf{s} = \boldsymbol{\eta}$ is a $\mathbf{n}$ dimensional vector with i_{th} element equal to

$$\eta_i = \sum_{j=1}^{p}\left(c_{2j}(z_i - z_0)^2 + c_{3j}(z_i - z_0)^3\right)X_{ij}$$

with $\mathbf{c}_2 = (c_{21}, \ldots c_{2p})', \mathbf{c}_3 = (c_{31}, \ldots c_{3p})$, $\mathbf{s} = \left(\mathbf{c}_2' \otimes (1,0) + \mathbf{c}_3' \otimes (0,1)\right)'$, and

$$\mathbf{X}_1^* = \begin{pmatrix} (z_1-z_0)^2 X_{11} & (z_1-z_0)^3 X_{11} & \cdots & (z_1-z_0)^2 X_{1p+1} & (z_1-z_0)^3 X_{1p+1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ (z_n-z_0)^2 X_{n1} & (z_n-z_0)^3 X_{n1} & \cdots & (z_n-z_0)^2 X_{1p+1} & (z_n-z_0)^2 X_{1p+1} \end{pmatrix}.$$

Notice that $\mathbf{s}$ can then be estimated by using a local cubic polynomial regression ($q = 3$) with bandwidth h_*.

$$\widehat{\mathbf{s}} = \left(I_p \otimes (e_{3,3}, e_{4,3})'\right)\left(\mathbf{X}_3'\mathbf{W}_*\mathbf{X}_3\right)^{-1}\mathbf{X}_3\mathbf{W}_*\mathbf{g} \tag{17}$$

where $\mathbf{W}_* = diag\left(\frac{1}{h_*}K(\frac{z_1-z}{h_*}), \ldots, \frac{1}{h*}K(\frac{z_n-z}{h_*})\right)$. The initial bandwidth h_* is obtained by the minimizer of the integrated residual squares criterion (IRSC); see Fan and Gibjels (1996), pp.118-121.

Following (11) the conditional covariance $Cov(\widehat{\boldsymbol{\gamma}}(z) \mid \Im)$ is estimated by

$$\widehat{Cov}(\widehat{\boldsymbol{\gamma}}(z) \mid \Im) = \left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\left(\mathbf{X}_1'\mathbf{W}^2\mathbf{X}_1\right)\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\widehat{\sigma}_*^2 \tag{18}$$

where $\widehat{\sigma}_*^2$ is based on a cubic fit

$$\widehat{\sigma}_*^2 = \frac{\sum_{i=1}^{n}\left(g_i - \widehat{g}_{*i}\right)^2 K_{h_*}(z_i - z_0)}{tr\{\mathbf{W}_* - \mathbf{W}_*\mathbf{X}_3(\mathbf{X}_3'\mathbf{W}_*\mathbf{X}_3)^{-1}\mathbf{X}_3'\mathbf{W}_*\}} \tag{19}$$

with $\widehat{\mathbf{g}}_{*i} = (\widehat{g}_{*1}, \ldots, \widehat{g}_{*n})'$ and $\widehat{\mathbf{g}}_{*i} = \mathbf{X}_3(\mathbf{X}_3'\mathbf{W}_*\mathbf{X}_3)^{-1}\mathbf{X}_3'\mathbf{W}_*\mathbf{g}$.

Finally the matrix Ω is also based on the local cubic fit with bandwidth h_*.

$$\widehat{r}_{ij} = e_{1,3}'(\mathbf{V}'\mathbf{W}_{0*}\mathbf{V})^{-1}\mathbf{V}'\mathbf{W}_{0*}\mathbf{U}_{ij} \tag{20}$$

where $\mathbf{W}_{0*} = diag\left(\frac{1}{h_{0*}}K(\frac{z_1-z_0}{h_{0*}}), \ldots, \frac{1}{h_{0*}}K(\frac{z_n-z_0}{h_{0*}})\right)$,

$$\mathbf{V} = \begin{pmatrix} 1 & z_1 - z_0 & (z_1-z_0)^2 & z_1 - z_0)^3 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & z_n - z_0 & (z_n-z_0)^2 & (z_n-z_0)^3 \end{pmatrix}$$

and

$$\mathbf{U}_{ij} = (X_{1i}X_{1j}, \ldots, X_{ni}X_{nj})'$$

then

$$\widehat{MSE}(\widehat{\boldsymbol{\gamma}}(z) \mid \Im) = \left(\widehat{\mathbf{s}}'\mathbf{X}_1^{*\prime}\mathbf{W}\mathbf{X}_1\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\right)\widehat{\Omega}\left(\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\mathbf{X}_1'\mathbf{W}\mathbf{X}_1^*\widehat{\mathbf{s}}\right) + tr\left(\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\left(\mathbf{X}_1'\mathbf{W}^2\mathbf{X}_1\right)\left(\mathbf{X}_1'\mathbf{W}\mathbf{X}_1\right)^{-1}\widehat{\Omega}\widehat{\sigma}_*^2\right). \tag{21}$$

4.2 Empirical Results

The first varying coefficient model I examine allows the parameters of the Solow growth model to vary according to a country's initial human capital. This generalizes the Solow growth model by allowing the parameters of the aggregate production function to vary according to initial human capital.

$$g_i = \gamma_1(h_{0i}) + \gamma_2(h_{0i})gpop_i + \gamma_3(h_{0i})inv_i + \gamma_4(h_{0i})y_{0i} + u_i \tag{22}$$

Figure 2a-d present the point estimates and associated 90% bootstrap confidence intervals for the varying parameter functions. The superimposed horizontal dashed line refers to the corresponding least square constant parameter from a linear regression.

Figure 2a shows the varying intercept of the model with as a "development" index. The results are quite revealing. The relationship between the logarithm of initial human capital, h_0, and growth is highly nonlinear. At lower levels of initial human capital and up to the level that corresponds to El Salvador, the relationship between initial human capital and growth appears to be negative. This relationship becomes positive once the economies achieve a threshold level of human capital higher than that of El Salvador. This pattern suggests the presence of a poverty trap with respect to the initial human capital. The constant parameter predicted by the Solow growth model is obviously misleading as it clearly cuts the bootstrap confidence intervals three times.

Figure 2b shows the varying parameter of population growth. This function suggests possible positive effects of population growth for most of the economies with low levels of initial human capital. This positive effect appears to taper off and finally becomes negative for economies with higher than a level of initial human capital, which corresponds to India. Again the constant parameter predicted by the Solow growth model clearly cuts the bootstrap confidence intervals twice. Figure 2c presents the investments parameter, which exhibits a quadratic shape. It suggests that the marginal effect of investments on growth is increasing for economies with lower levels of initial human capital and decreasing for economies with higher initial human capital. The marginal effect of investments on growth is the highest for the level of initial human capital that corresponds to Guatemala. The constant parameter predicted by the Solow growth model cuts the bootstrap confidence intervals at least three times. Figure 2d shows the varying parameter of initial income parameter. This function is negative suggesting that convergence hypothesis in the presence of different initial human capital is globally true. The parameter is increasing for economies with low initial human capital. Then it turns constant for economies with a level of initial human capital higher than that of Botswana. Figure 2g presents the conditional variance.

A more interesting exercise is to consider the partial predicted growth rates obtained by

$$\widehat{g}_i^*(h_{0i}, y_{0i}) = \widehat{\gamma}_1(h_{0i}) + \widehat{\gamma}_4(h_{0i})y_{0i} \tag{23}$$

Figure 2f shows a coplot of $\widehat{g}^*$ against y_0, given h_0. The dependence panels are the 3×3 array, and the given panel is at the top. On each dependence panel, $\widehat{g}^*$ is graphed against y_0 for those observations whose values of h_0 lie in a given interval.

The intervals are shown on the given panel; as we move from left to right through these intervals, we move from left to right and then bottom to top through the dependence panels. For very low and very high levels of initial human capital, the relationship between $\widehat{g}^*$ and y_0 is rather nonlinear with positive slope. All the other panels support the conditional linear structure of (23) with negative slope. Figure 2g shows a coplot of $\widehat{g}^*$ against h_0, given y_0. This suggests the presence of nonlinearities in the parameters especially for low income countries. These graphs are in contrast to the downward sloping line obtained by least squares estimation $\widehat{\gamma}_1^{0LS} + \widehat{\gamma}_4^{OLS} y_0$; see Barro (1997), pp.18. They are rather suggestive of the presence of two steady state equilibria in the growth process with respect to initial human capital consistent with the twin peaks found by Quah (1997) in the cross-country income distribution.

Figures 3a-g show the results for the varying coefficient model with eth as a "development" index.

$$g_i = \gamma_1(eth_i) + \gamma_2(eth_i)gpop_i + \gamma_3(eth_i)inv_i + \gamma_3(eth_i)y_{0i} + u_i \quad (24)$$

Figure 3a presents the varying intercept. It generally suggests that some ethnic diversity may not be a bad thing for growth. It suggests that there exist an optimal mix of ethnic diversity around which the economies may enjoy positive growth. However, high ethnic diversity or low ethnic diversity make the relationship between growth and ethnic diversity negative.. In particular, countries with a measure of ethnic diversity lower than a level, which corresponds to Colombia and higher than a level, which corresponds to France, the relationship between growth and ethnic diversity is negative. Figure 4b examines the varying parameter of population growth. As expected the effect of population growth is mostly negative. Figure 3b shows that higher ethnic diversity may also diminish the negative of population growth. Figure 3c also shows that the effect of investments does not vary substantially with ethnic diversity. One can also note that there is range of ethnic diversity in which the effect of investments is maximized. Figure 3d shows that the parameter of initial income is primarily negative. Interestingly, for very high or very low levels of ethnic diversity the parameter is positive. This suggests the possibility of divergence at extreme values for countries with levels of ethnic diversity below the one that corresponds to Saudi Arabia and above the one that corresponds to Malawi[5].

. Figure 3e presents the conditional variance for the varying coefficient model with eth as a "development" index. It appears to be u-shaped with the majority of the countries lie on the right hand of the function. Figures 3f-g show the coplots of $\widehat{g}^*$ against eth, given y_0 and coplots of $\widehat{g}^*$ against y_0, given eth, respectively. These graphs are also in contrast to the downward sloping line obtained by least squares estimation.

Overall the results from the varying parameter models suggest that there exist evidence of weak heterogeneity. In particular, the results although the linear Solow

[5]It is important to realize that this paper does not attempt to explain the relationship between ethnic diversity and growth. This question ought to take into account the interaction between ethnic diversity and quality of institutions. This will give a clearer picture of the relationship between ethnic diversity and growth. Here, ethnic diversity is rather used as an index that may characterize coefficient heterogeneity in the context of the Solow growth model.

growth model may be a good approximation for countries with high levels of initial human capital, it does not perform well for "poor" countries. A similar result appears to be true when the parameters vary according to ethnic diversity. Although the linear Solow growth model does not perform well globally, it provides a good approximation for countries with moderate levels of ethnic diversity.

5 Conclusion

This paper approaches the topic of cross-country growth analysis using the notion of hierarchy of time-scales, which provides a natural framework to model parameter heterogeneity. Here, the hierarchy of times-scales suggests a local generalization of the Solow model in the form of a varying coefficient model. In the context of a varying coefficient model, this paper studies two examples. In the first example the model allows the parameters to vary according to initial human capital while in the second the parameters vary according to a measure of ethnic diversity. In general, my results suggest that there exists substantial heterogeneity, which is suggestive of a poverty traps with respect to initial human capital. My results are also suggestive of twin-peakedness of the cross-country limiting income distribution found by Quah (1997). As regards, the effect of ethnic diversity the results show that ethnic diversity may not necessarily be a bad thing. There seems to exist some optimal level of ethnic diversity around which countries enjoy positive benefits on growth. Finally, I would like to point out that this paper makes does not make structural claims per se but rather structural claims in the literature are exaggerated.

This study can be extended in several ways. One may develop a misspecification test based an F-conditional exchangeability test along the lines of Frydman and Singer (1985) in order to test for unobserved heterogeneity in the context of hierarchical linear models. Given that the idea of "exchangeability" provides a precise definition of "comparability" of countries„ this test is very important for policy analysis. Another equally important issue is the openendedness of economic growth theories; see Brock and Durlauf (2001). This problem refers to the determination of variables to be included in the model. This is particularly important given that there is a large number of candidate variables relative to available data. Brock and Durlauf (2001) suggest that hierarchical linear model can provide the natural framework within which one can account for both problems: the variable selection and parameter heterogeneity. Therefore one can use variable selection techniques such as Bayesian model averaging in the context of hierarchical models.

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Table 1 Country List and their Rankings

rank lit60	Country	rank eth	rank lit60	Country	rank eth
1	Niger	74	44	Colombia	15
2	Burkina Faso	69	45	Venezuela, RB	25
3	Somalia	21	46	Dominican Republic	7
4	Saudi Arabia	17	47	Mexico	40
5	Cote d'Ivoire	81	48	Malta	20
6	Mauritania	44	49	Ecuador	54
7	Senegal	73	50	Thailand	67
8	Central African Republic	79	51	Zimbabwe	56
9	Benin	62	52	Hong Kong, China	5
10	Algeria	48	53	Korea, Rep.	3
11	Togo	71	54	Philippines	75
12	Burundi	6	55	Paraguay	28
13	Morocco	55	56	Guyana	59
14	Haiti	1	57	Greece	23
15	Nigeria	82	58	Jamaica	14
16	Pakistan	65	59	Chile	27
17	Congo, Rep.	66	60	Israel	35
18	Rwanda	29	61	Costa Rica	19
19	Botswana	53	62	Spain	49
20	Kenya	80	63	Uruguay	36
21	Malawi	63	64	Argentina	41
22	Egypt, Arab Rep.	8	65	Italy	10
23	Ghana	70	66	Canada	76
24	India	84	67	Trinidad and Tobago	58
25	Zambia	78	68	Barbados	37
26	Papua New Guinea	46	69	Ireland	9
27	Syrian Arab Republic	38	70	United Kingdom	43
28	Congo, Dem. Rep.	85	71	Australia	42
29	Guatemala	64	72	Austria	26
30	Madagascar	16	73	Belgium	57
31	Bolivia	68	74	France	39
32	Indonesia	77	75	Japan	2
33	Honduras	32	76	Luxembourg	30
34	El Salvador	33	77	Netherlands	24
35	Nicaragua	34	78	New Zealand	45
36	Singapore	47	79	United States	52
37	Malaysia	72	80	Denmark	12
38	South Africa	83	81	Finland	31
39	Myanmar	50	82	Norway	11
40	Mauritius	60	83	Sweden	22
41	Brazil	18	84	Switzerland	51
42	Peru	61	85	Iceland	13
43	Portugal	4			

Figure 1

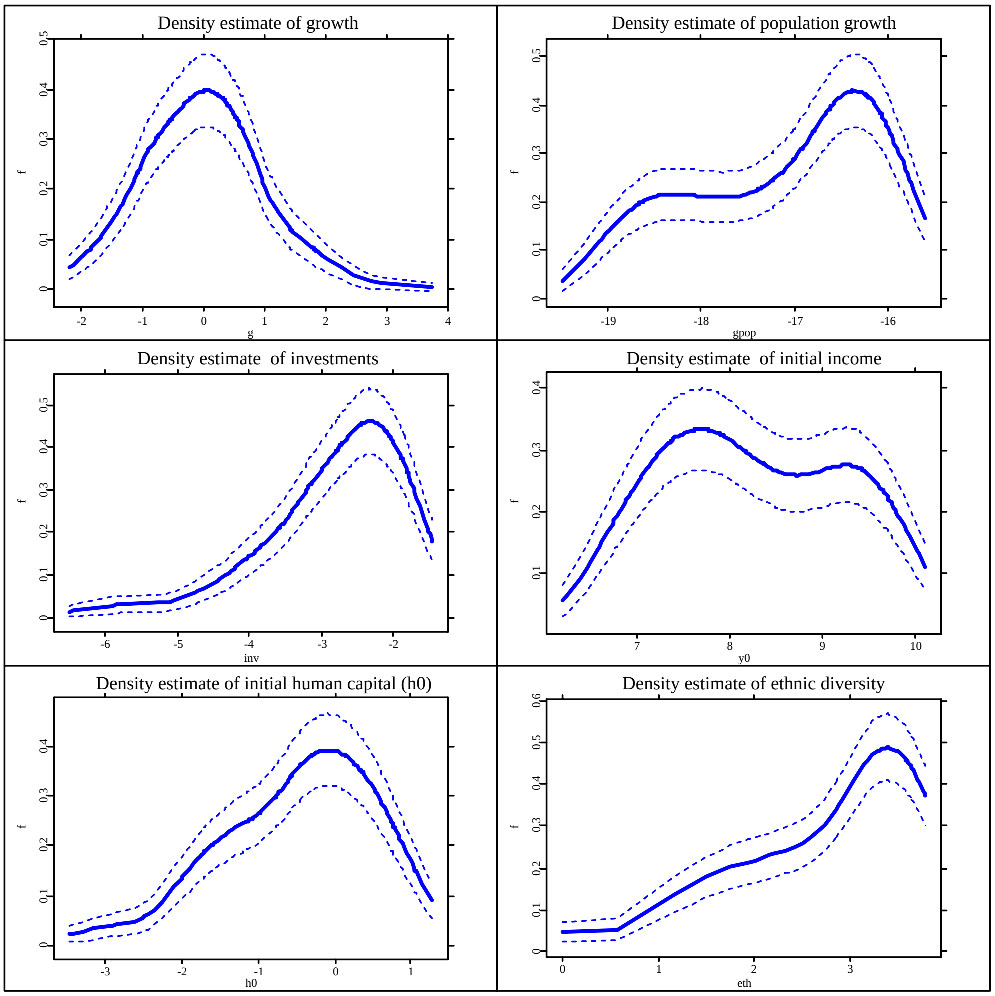

Density estimate of growth
f
g
Density estimate of population growth
f
gpop
Density estimate of investments
f
inv
Density estimate of initial income
f
y0
Density estimate of initial human capital (h0)
f
h0
Density estimate of ethnic diversity
f
eth

Figure 2a: intercept

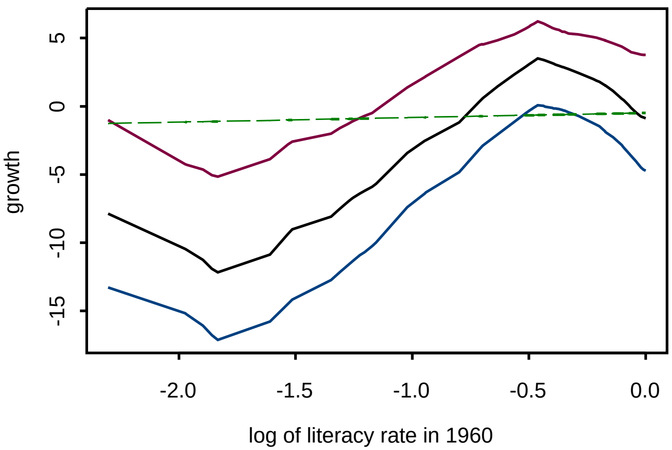


Figure 2b:
coefficient of log population growth

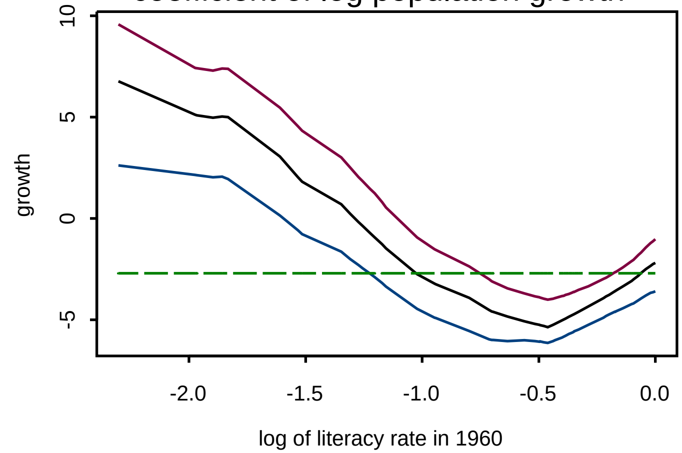


Figure 2c:
coefficient of log investments

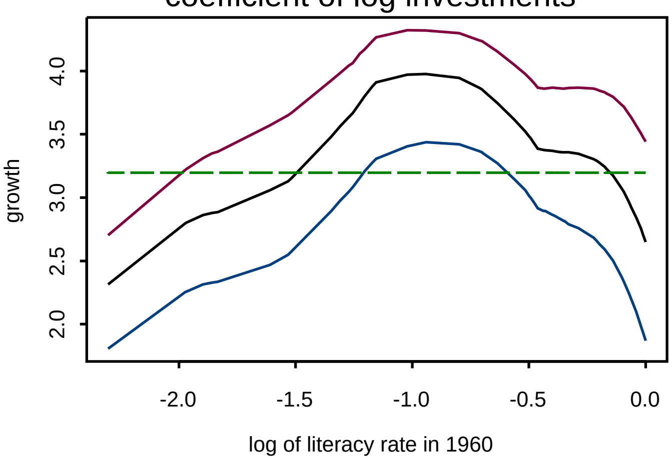


Figure 2d:
coefficient of log initial income

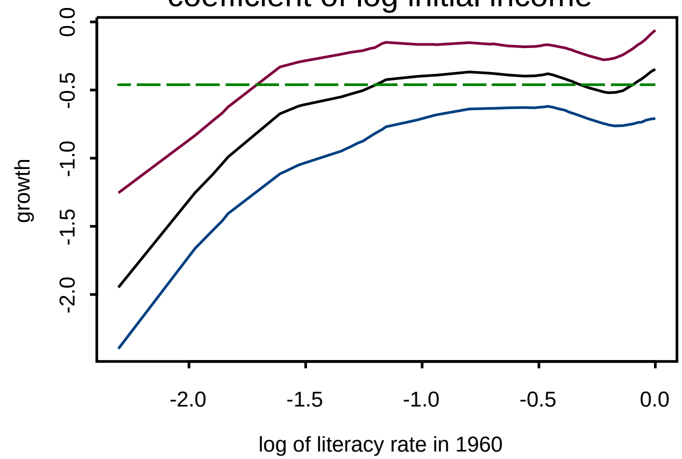
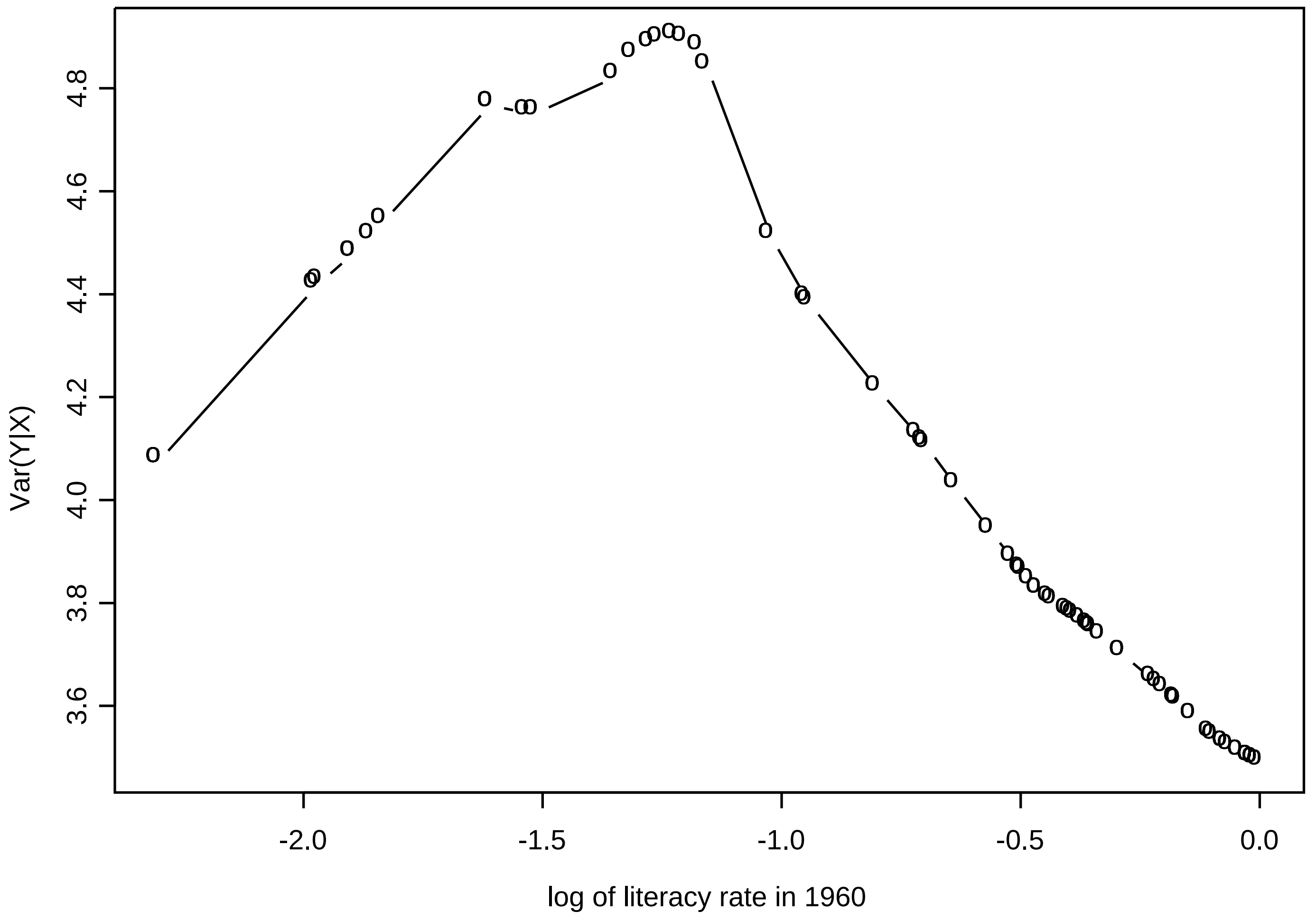


Figure 2e:
Conditional Variance



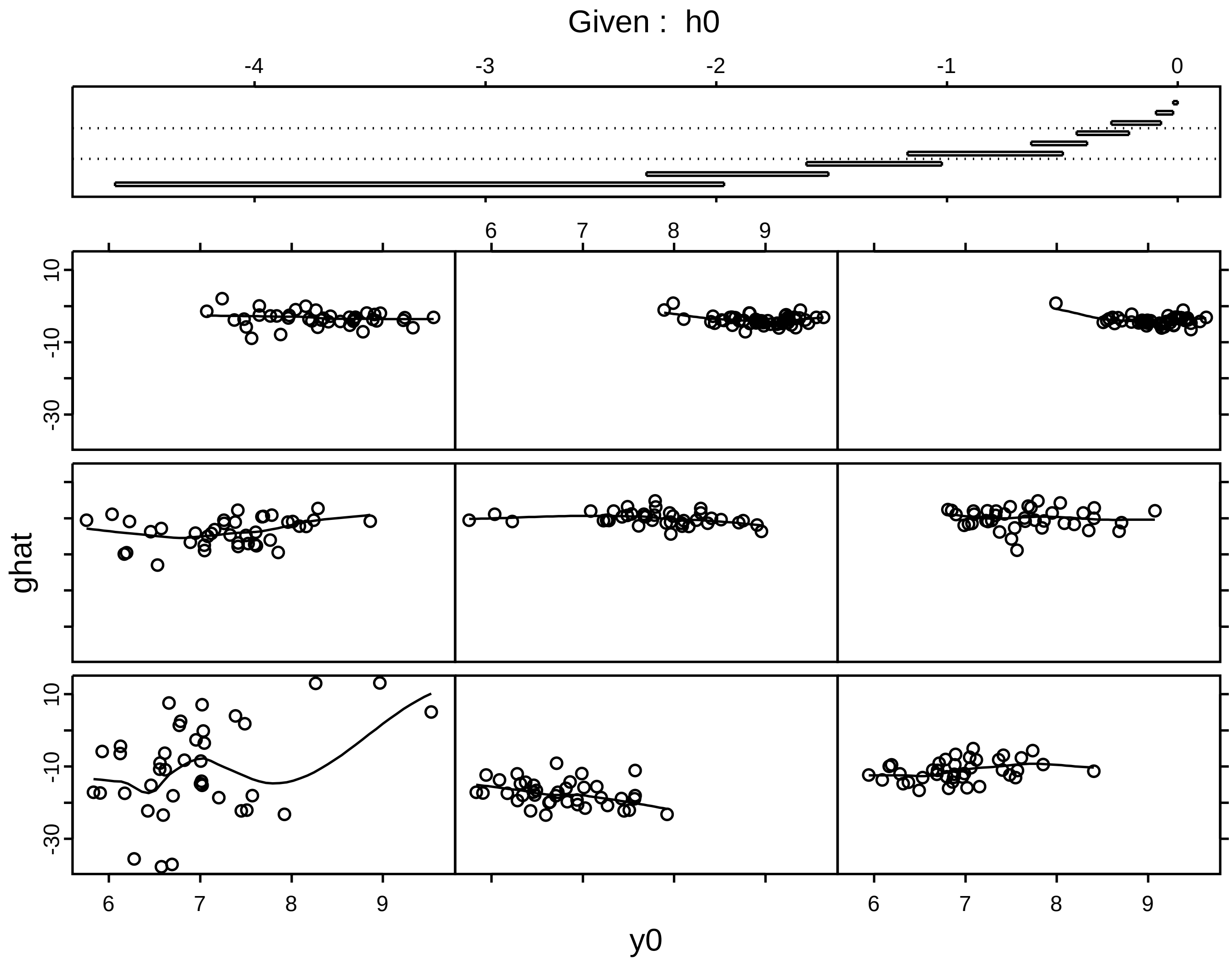


Figure 2f - predicted growth: ghat=gammahat1(h0)+gammahat4(h0)*y0

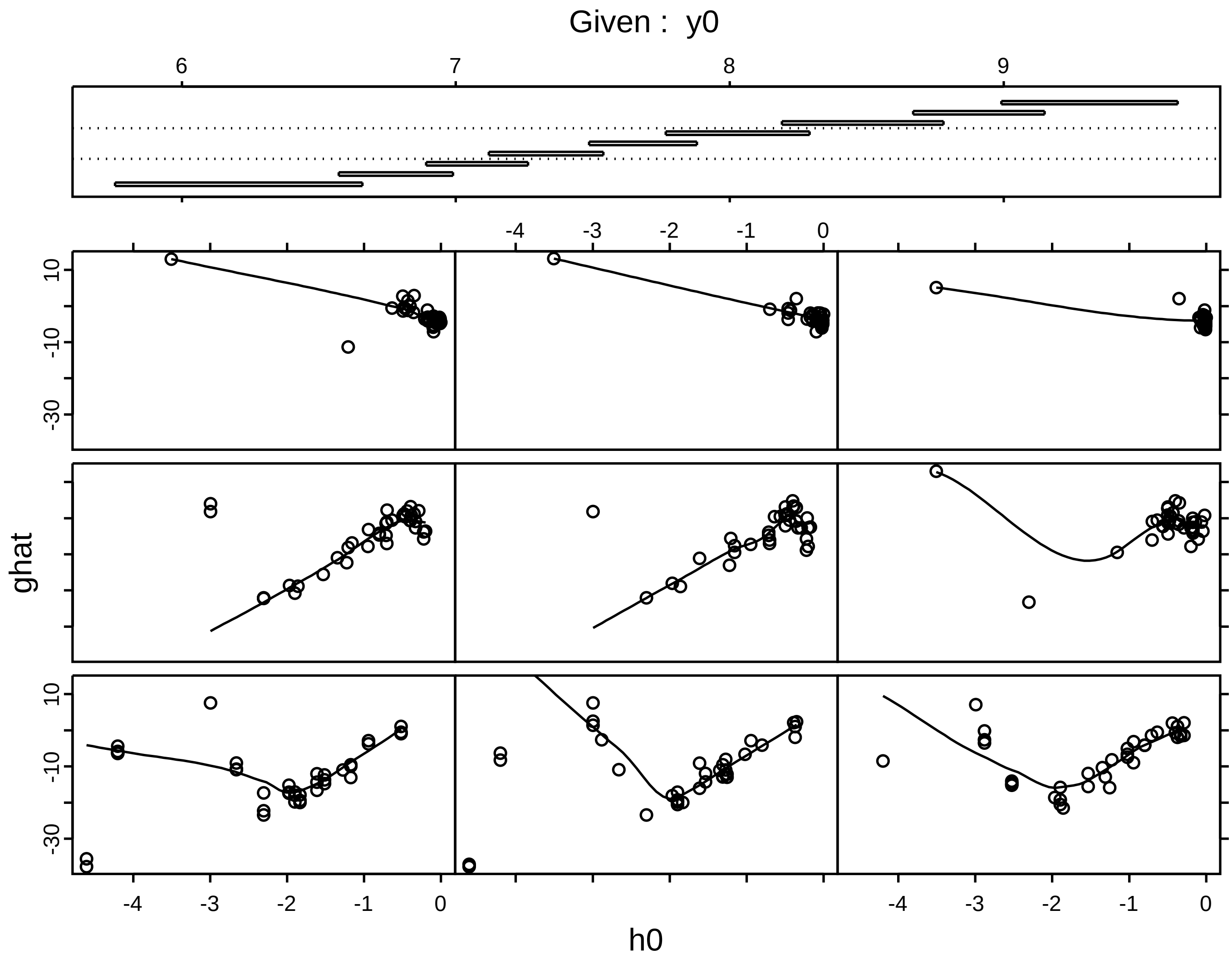


Figure 2g - predicted growth: ghat=gammahat1(h0)+gammahat4(h0)*y0

Figure 3a: intercept

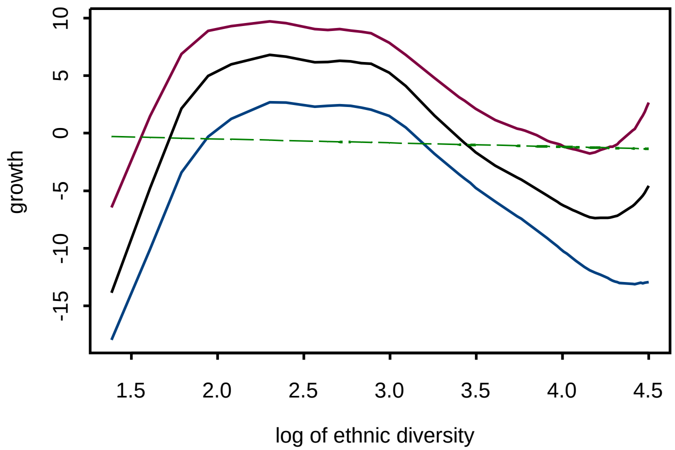


Figure 3b:
coefficient of log population growth

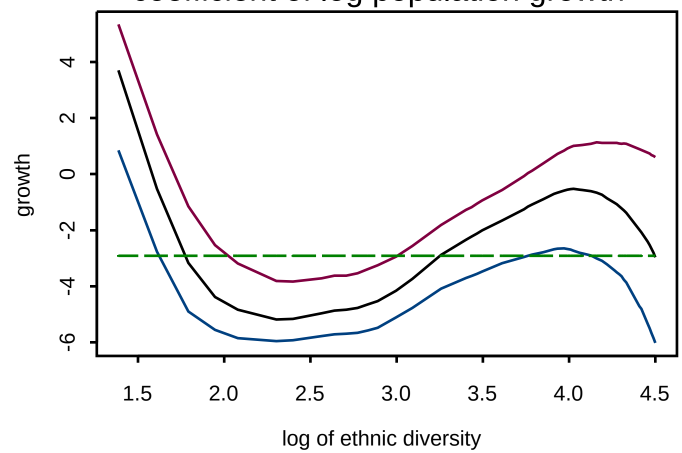


Figure 3c:
coefficient of log investments

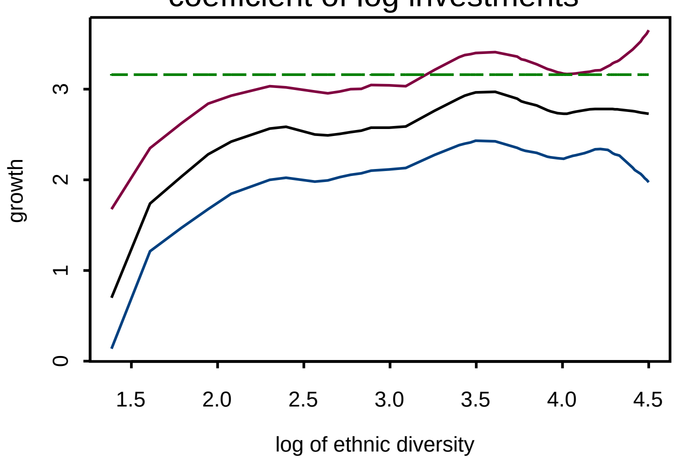


Figure 3d:
coefficient of log initial income

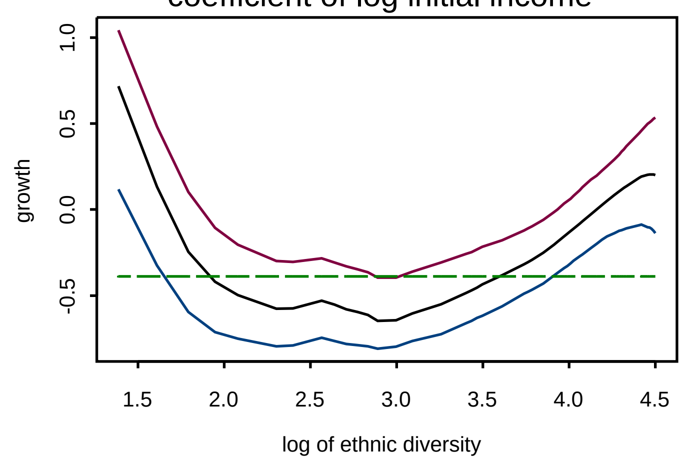
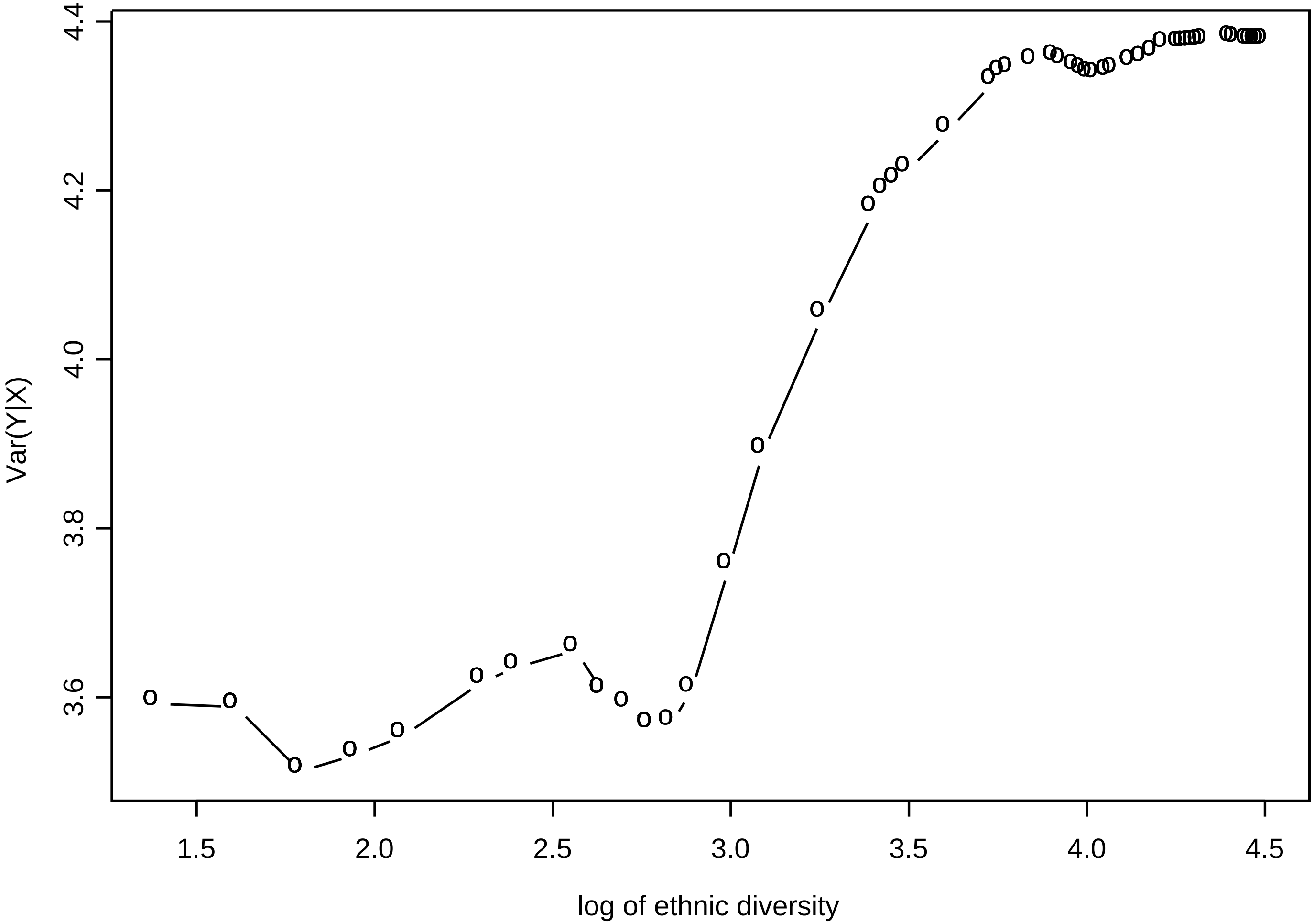


Figure 3e:
Conditional Variance



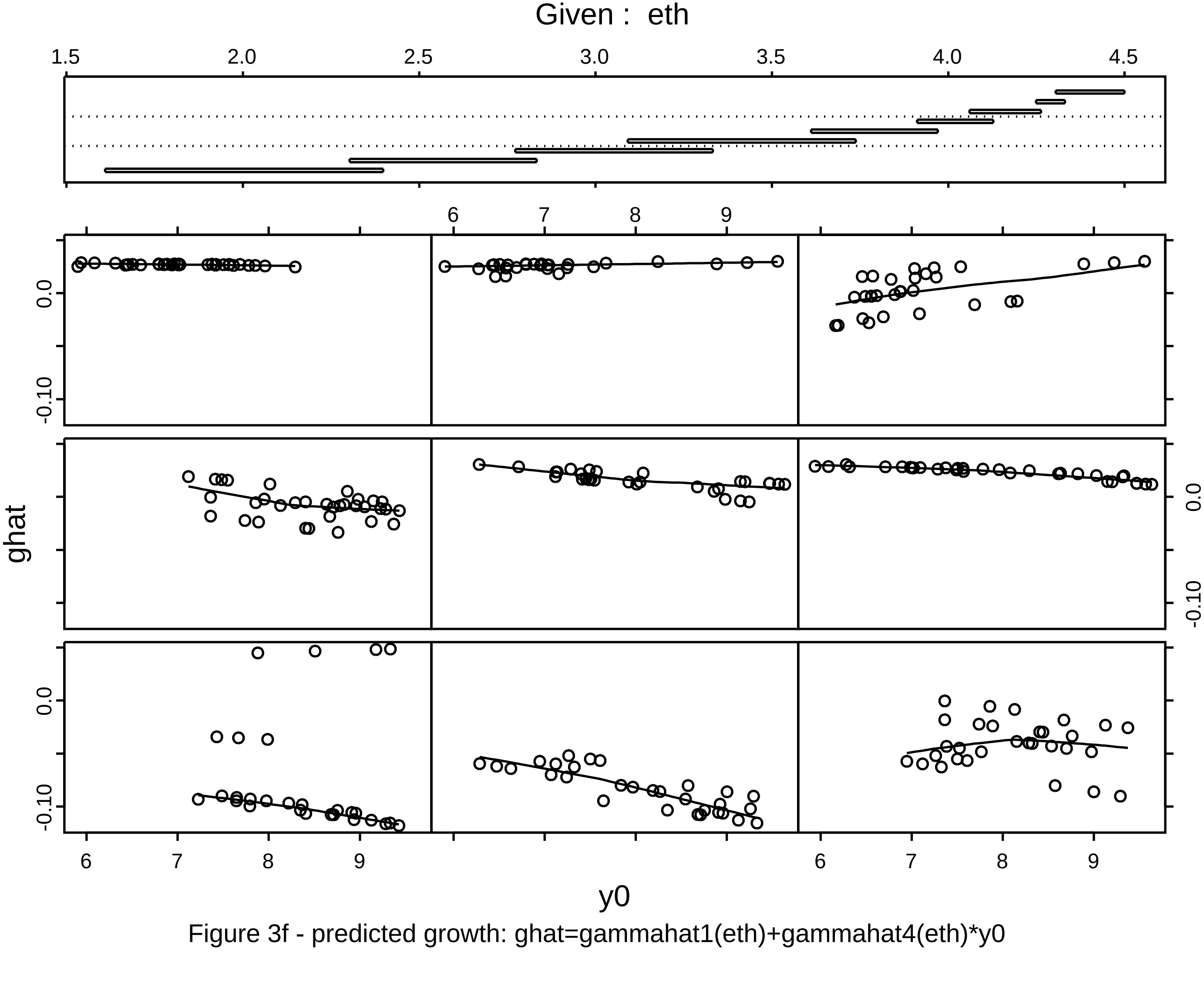


Figure 3f - predicted growth: ghat=gammahat1(eth)+gammahat4(eth)*y0

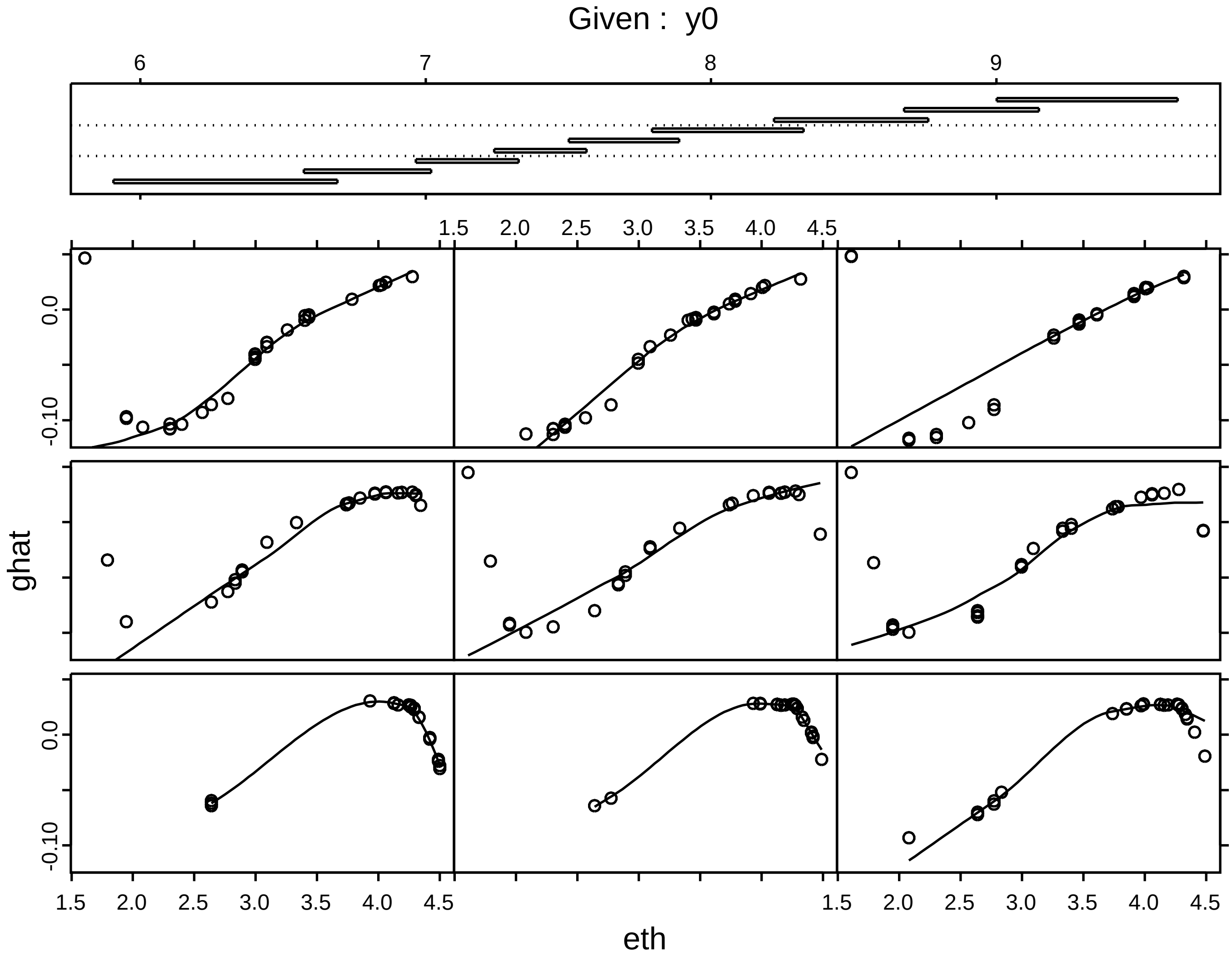


Figure 3g - predicted growth: ghat=gammahat1(eth)+gammahat4(eth)*y0

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