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Empirical analysis of the anthropogenic pressure on the mangrove blue carbon-economic growth relationship*

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Abstract

This paper analyzes the determinants of economic growth in coastal economies with the purpose of highlighting the impact of human activity pressure on mangrove blue carbon (BC). We use a Bayesian Model Averaging-based estimation technique to fit alternative growth theories to 1960-2009 data on a BC sample of 23 coastal countries and a worldwide (WW) sample of 83 countries. In addition to having high mangrove blue carbon climate change mitigation potential, a representative country from the BC sample possesses features commonly associated with developing countries. Moreover, such a country's natural capital per capita has decreased by more than 50% during the half-century span of our data and its dependence on natural capital is almost twice as high as that of its WW counterpart. We find that the neoclassical theory, through income and investment in physical capital, demography, macroeconomic policy, and natural capital theories perform well in explaining growth in BC countries. In contrast, investment in physical capital and proxies for the macroeconomic policy and natural capital theories are found not to be good predictors of growth when using the WW sample of countries. These results put the finger on the critical problem of existing and potential anthropogenic pressure that coastal areas with BC are and can be subject to due to land conversion for agriculture, aquaculture, farming and other run-offs, marine resources exploitation, uncontrolled sewage, marine resources direct exploitation, and coastal constructions and public works related to natural capital exports. This admittedly grim picture of the coasts draws attention to at least two policy questions, namely, whether central governments ought to give local policy makers and communities incentives to promote nature-based solutions to climate change mitigation and the extent to which international financial institutions should provide financial support for such initiatives in developing countries.

Keywords: Economic growth, coastal countries, mangrove blue carbon, developing countries.
JEL classification codes: O10, O13, Q20, Q22.

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1. Introduction

In recent years, the so-called "Blue Economy" (BE), broadly referred to as the set of mankind activities utilizing the oceans to derive economic benefits, has come to be viewed as a development paradigm of its own encompassing economic, social, and environment benefits, in particular, for coastal countries. Associated with a myriad of expressions, including "Blue Growth," "Ocean Enterprise," and "Sustainable Ocean Economy" and considered as lucrative business or natural capital that sustain livelihood and stimulate innovation, BE emphasizes that marine-based economic development not only significantly contributes to improving human well-being and social equity, but also reduces environmental risk and ecological scarcity (Steven et al., 2019).

Among the different facets of BE, "Blue Carbon" (BC) is certainly one that has drawn much interest in both academic and policy making circles in recent years. Representing the organic carbon captured by coastal marine plants such as seagrass, mangroves, and tidal marshes, BC has come to be recognized as disproportionately contributing to global carbon sequestration. As such, and as an integral part of BE and development of coastal economies, by now, the role of BC in climate change mitigation and adaptation has reached international prominence.[1]

The oceans and their coasts represent the largest carbon sink on earth, removing approximately 2GtCO_2e year^{-1}, which represents about 25% of all human-activity-related yearly emissions of carbon dioxide and over half of all biological carbon captured yearly worldwide.[2] Moreover, as demonstrated in Duarte et al. (2005), once deforestation is accounted for, the net land carbon uptake is smaller, in relative terms, than that of the oceans and coasts and within the ocean and coastal carbon sinks, mangroves, seagrass meadows, tidal marshes and macroalgae, are known to support particularly intense carbon burial rates. As a consequence, BC has come to actually refer to the potential of coastal carbon sinks to mitigate climate change.[3]

It is only with the rising awareness of the international community about the climate change mitigation potential in coastal areas that BC has drawn attention beyond the biological conservation scientific community. In fact, the perception of BC as a global public good in climate change debates has lead to the production of academic and policy papers on the topic that has been multiplied by almost four between 2005 and 2012 (Duarte, 2008 and 2014). Yet, as pointed out in IUCN (2016), the awareness on the benefits of nature-based solutions to address climate change, in particular BC, is rather low at the local business as firms' managers tend to favor on-land mitigation options and expensive and hard adaptation measures.

While the carbon stocked under the soil of coastal areas is somewhat one order of magnitude lower than that of terrestrial forests, it can play an important role in the global carbon cycle since, in addition to being able to support intense burial rates, coastal ecosystems can keep the stored carbon for thousands of years in sediments. More specifically, mangroves, seagrass meadows, tidal marshes, and macroalgae contribute to almost 50% of the carbon burial in marine sediments while occupying only 0.2% of the ocean surface (Duarte, 2013; Fourqurean et al., 2012). Moreover, BC provides side-benefits such as coastal hazard

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[1] Introduced in Nellemann et al. (2009), the concept of BC is the coastal ecosystems analogous of Green Carbon, the later being related to terrestrial ecosystems such as forests. It emphasizes the significant contribution of coastal natural capital to organic carbon sequestration. Among others, see Boyd (2011), Macreadie et al. (2019), NOAA (2019), Steven et al. (2019, and Voyer et al. (2018) for an overview of BC as a critical sustainable development issue that urges for being considered in a multidisciplinary framework.

[2] Coastal areas constitute a larger carbon sink than rain forests (Duarte, 2014; Nellemann et al., 2009).

[3] Note that even though other marine ecosystems and species in the open ocean, more specifically, corals, kelp, plankton and marine fauna play a role in the carbon cycle, their storage capacity is temporary (Laffoley et al., 2014).

mitigation, shoreline stabilization and erosion control, safe harbors and sites for maritime industry, beach and fisheries production, pollution assimilation, water filtration, maintenance of water quality, and hydrological balances (Agardy, 2004; Herr et al., 2015). In particular, mangrove forests can provide alternative solutions to sea-dikes that can be both cost-effective and ecosystems preserving (Berrenstein, 2012).[4]

Despite these proven benefits, between 25% and 50% of the area covered by BC, in particular mangrove, has already been lost due to anthropogenic pressure in the last fifty years, and the bulk of these losses are related to forestry activities and aquaculture, including the construction of shrimp ponds and fish farms (Vaiela et al., 2009).[5] It seems then natural to examine countries having BC coastal ecosystems with the objective of highlighting the extent to which, *ceteris paribus*, these countries exert pressure on these ecosystems in the course of their economic development pathway. This is the goal that we pursue in this paper. More specifically, we seek to highlight the role of anthropogenic pressure on coastal BC-endowed countries' ecosystems in the context of analyzing the determinants of their economic growth. Our empirical strategy basically consists in performing an analysis of two datasets, one that emphasizes the presence of BC and another that doesn't, and attempt to infer from the comparison of the results some "marginal" effects of BC on economic growth.[6]

Drawing on significant existing knowledge on the fates of ecosystems' carbon upon its conversion, i.e., carbon that may be lost after habitat destruction, and relying on country-level geospatial information, we collected data for the 1960-2009 period on 23 countries that have high mangrove within their boundaries with the purpose of empirically analyzing the role of its BC potential for climate change mitigation in the economic growth of these (BC) countries. To further highlight this economic growth marginal "BC effect," next to this BC-country specific analysis, we conduct a somewhat "broader" investigation of economic growth determinants using available dataset for the same period on 83 worldwide (WW) countries. The objective is to compare the results obtained with both of these datasets and draw conclusions regarding determinants of growth in the two groups of countries with a special attention given to policy implications for the BC countries.

At this point, it is worthwhile making two remarks concerning our contribution to the literature. First, in terms of methodology, our approach, which basically rests on a comparison of economic growth regressions for the BC and WW countries, departs from a stream of the literature that has focused on the economics of mangrove forests. While this research question is certainly interesting in its own right, it is better explored by means of microeconomic tools of the type proposed by Barbier and Cox (2004) while, in contrast, in this paper we take a macroeconomic perspective.[7] Second, while we are well aware that the proxy we use for BC climate change mitigation potential, namely, coastal mangrove, represents by no means the totality of BC sequestered by natural resources, the importance of BC for climate change

[4] About 67% of the total adaptation costs for coastal protection come from sea dikes increasing to over 90% when maintenance costs are considered. For coasts only, total global adaptation costs, including beach nourishment, port upgrades, and capital and maintenance of river and sea dikes for a scenario of no additional sea-level rise range from 10.4 billion USD per year in the 2010s to an expected 9.5 billion USD in the 2040s (Nicholls et al., 2010).

[5] These benefits however come with some costs that BC imposes on some other ecosystem services. Parrotta et al. (2012) argue that it is thus necessary to integrate potential trade-offs among mitigation objectives, biodiversity and ecosystem services outcomes, and stakeholders' needs.

[6] In standard empirical analysis design terms, one can think of BC as the treatment the effect of which on growth we seek to estimate.

[7] We should add here that the literature concerned with the impact of natural capital on economic growth in coastal countries has typically focused on non-renewable natural resources.

mitigation as well as the relative weight of mangrove in BC warrants investigating its role in economic growth.[8,9]

The paper is organized as follows. The next section briefly reviews the standard theories within which economic growth is analyzed, discusses the extend to which these theories apply to BC countries, and describes the basic ingredients of the econometric methodology that we use to perform our analysis. The latter consists in specifying a set of regressions corresponding to 9 growth theories and using a model averaging approach to account for both model and growth determinants proxy specification uncertainty, more specifically, the Bayesian Moving Average (BMA) approach that has recently gained much popularity in economics.[10] Section 3 presents the data and discusses our empirical strategy. In section 4, we discuss and compare the BMA estimation results on the determinants of economic growth based on the samples of 23 BC countries and 83 WW countries. Section 5 gives some concluding remarks. The appendix provides a detailed description of the data and some complementary tables containing descriptive statistics and estimation results that are discussed in the main text.

2. Growth theories and their empirical relevance for mangrove blue carbon countries

A theoretical implication of the neoclassical growth theory as developed by Solow (1956) is that output per worker should converge worldwide as higher returns on capital in less developed countries will attract more capital leading to productivities that increase to the point of catching-up with more advanced economies. However, there is large empirical evidence that poorer countries have not maintained productivity growth at high levels, suggesting that there has been little worldwide unconditional convergence, and that most capital investment has gone to developed countries.

Under these circumstances, the concept of conditional convergence has thus been redefined to account for the fact that output per worker would not converge worldwide to a common level unless some other factors not incorporated in the standard framework coincide. As a result, to improve the explanatory power of the neoclassical-type growth models, in particular, to show how growth rates differ across time and countries, an impressively large number of new factors were introduced in empirical analytical frameworks to attempt to capture the part of growth that remained unexplained in the original neoclassical framework. This extension of the original framework has given birth to what is referred to as "new growth theories."

Durlauf et al. (2008a) identified 43 growth theories and 145 regressors as proxies for the determinants of growth in the empirical literature on economic growth. Overall, this literature has produced empirical evidence in favor of conditional convergence suggesting that poorer countries would growth at faster rates until they reach a steady state under the hypothesis of decreasing returns to scale. Besides this large set of theories, an additional difficulty in empirical analysis of economic growth is the possibility that a country might experience multiple economic growth regimes (Durlauf and Johnson, 1995). Under such circumstances,

[8] Indeed, non-mangroge natural resources, including salt marshes and sea grasses, have been shown by Pendleton et al. (2012), among others, to constitue large alternative BC stocks. For an interesting recent assessment of the relative environmental merits of mangrove forests and the way the protection of these vital habitats through BC financing mechanisms, see Zeng et al. (2021). See also Murray et al. (2011) on this point. Footnote 17 below discusses some data and scientific constraints faced by researchers interested in BC.

[9] An additional piece of motivation for conducting our analysis is that mangrove forests are also known to have some impact on growth through non-BC channels. See Getzner and Islam (2020) for a meta-analysis of economic value of mangroves and the references cited therein, e.g., Diaz et al. (2018), Kusumawardi et al. (2019), Micheletti et al. (2016), and Salem and Mercer (2012). From this broader perpective, our paper should be viewed as an attempt to perform an "all things equal" analysis of the mangrove (BC) growth effect.

[10] See Steel (2020) for a recent discussion of model averaging use in economics.

the data sample analyzed is typically split based on a cut-off point of the level of a relevant variable either relying on the results of a methodology or making an ad-hoc choice.[11]

Given the potentially large number of new growth theories, model uncertainty seems to be a fundamental problem when empirically analyzing the determinants of economic growth. From an econometric perspective, regression analyses have shown that a large number of variables are correlated with economic growth without necessarily implying a direction of causation. The lack of consensus on a structural form of growth model and subsequently on a reduced form to apply in empirical analyses has led some researchers to admit model uncertainty and let the data show which variables are correlated with economic growth (Capolupo, 2009). In order to evaluate the relevance of the so-called new growth theories, in particular, those that incorporate natural capital as a determinant of economic growth, Durlauf et al. (2005; 2008a) and Sala-i-Martin et al. (2004) have proposed the Bayesian Model Averaging (BMA) method that explicitly accounts for model uncertainty.[12]

Following Rodrik (2003) and Durlauf et al., (2008b), we classify growth theories into "proximate" and "fundamental" or "deep" theories. Proximate theories are those that are associated with the human and physical capital inputs and their productivity in the production of goods and services (Neoclassical theory, Demography), those that consider the determinants of growth that can be relatively rapidly influenced by macroeconomic policy measures (Macroeconomic policy), and those that emphasize countries' specific characteristics (Regional heterogeneity). As to the fundamental theories, they broadly reflect the fact that they emphasize natural capital (Natural capital), geographical (Geography), institutional (Institutions), and cultural (Religion, Fractionalization) determinants of growth. The latter theories pay special attention to variables that have a significant influence on a country's ability to accumulate production factors and invest in the accumulation of knowledge (Acemoglu et al., 2005). In contrast with those of growth used in proximate theories, determinants used in fundamental theories tend to depend on slow-moving parameters (Durlauf et al., 2008b). Table 1 below shows the classification of these theories and gives typical proxies that are used to capture the determinants of growth that are emphasized by each of these theories.

To what extent these proximate and fundamental theories of growth would be appropriate to account for the role of Blue Carbon that, as indicated in the introduction, is a key characteristic of coastal countries and as such deserves much attention from researchers interested in the determinants of growth? In his seminal work, Smith (1776) has already highlighted the relationship between the geographical location, international trade, and economic growth in coastal countries. More recently, economic historians have argued that the sea-based trade in the Mediterranean basin has significantly facilitated the fast growth in settlements in this region (Braudel, 1972; McNeill, 1974; Jones, 1981; Crosby, 1986). Also, the world regions that are easily accessible by the sea are typically more urbanized and have lower transport costs (Gallup et al., 1999) while countries with longer coastlines are likely to have more ports, a higher percentage of the population leaving close to the sea, and a larger share of economic activity associated with international trade (Bloom and Sachs, 1998; Masters and Sachs, 2001; Bloom et al., 2003).

Policy choices also depend upon geography. For instance, a coastal economy may have a higher elasticity of output with respect to trade taxes than a landlocked economy (Gallup et

[11] There are a number of studies that use a wide variety of statistical methods to identify multiple economic growth regimes (Durlauf et al., 2005). See Owen et al. (2007) and Konte (2013) for an overview of how the presence of multiple economic growth regimes has been addressed by dividing the sample according to different theories besides the neoclassical one, in particular, theories based on geographical, demographical, and institutional factors.

[12] Fernandez et al. (2001) argue about the the superiority of the BMA method over other techniques in selecting regressors to explain cross-country economic growth.

al., 1999) and coastal countries are generally prone to liberalize their economies earlier than landlocked countries. Moreover, there is evidence that natural capital exports in coastal countries, mainly non-renewable resources, often have a negative impact on economic growth (Sachs and Warner, 2001). Indeed, resource-scarce coastal countries in Africa have experienced an average growth rate of 4.1% between 1981 and 2006 whereas it was 2.3% in resource-rich coastal countries (Ndulu et al., 2007).[13]

Based on these streams of literature, theories that emphasize demography, macroeconomic policy, geography, natural capital, and institutions as determinants of economic growth appear to be appropriate when it comes to examining the economic development experiences of coastal countries, in particular, countries with BC, and this is the main hypothesis that we propose to test in this paper. Our empirical strategy is based on econometrically analyzing two datasets that cover the 1960-2009 period. The first dataset contains observations on a sample of 83 countries worldwide while the second focuses on 23 coastal countries with high annual mangrove mitigation potential. Our very purpose in running such an empirical experiment is to contribute to highlighting the determinants of economic growth while emphasizing BC and the potential anthropogenic pressure on these ecosystems as an important characterizing features of coastal countries.

As mentioned earlier, in order to account for uncertainty associated with the theories of growth and the latter's determinants' proxying within these theories, we run regressions and use the BMA methodology along the lines of Fernandez et al. (2011). Following Durlauf and Quah (1999), to avoid misleading information conveyed by annually varying economic growth rates on the long-term growth process, we average the data over 5 years and specify an augmented Solow neoclassical model that embeds a set of new growth theories as in Durlauf et al. (2005 and 2008a).[14] The generic form of our regressions is as follows:

$$\bar{g}_{i,t} = \gamma_0 \, log\left(g_{i,t-5}\right) + \gamma_1 \, log\left(s_{i,t}^{k}\right) + \gamma_2 \, log\left(s_{i,t}^{h}\right) + \gamma_3 \, log\left(\tau_{i,t} + \psi + \delta\right) + \beta' z_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \qquad (1)$$

where the subscripts $i = 1,2,\cdots,N$ and $t = 1,2,\cdots,T$ indicate the country and the year respectively, $\bar{g}_{i,t}$ is the average growth rate of real Gross Domestic Product (GDP) per capita over the periods $t, t+1, t+2, \cdots, t+5$, $g_{i,t-5}$ is the real GDP per capita at the beginning of the 5-year period, and $s_{i,t}^{k}$, $s_{i,r}^{h}$, and $log\left(n_{i,t} + \psi + \delta\right)$ are neoclassical growth theory measures of the net accumulation of factors, more specifically, $s_{i,t}^{k}$ is the saving rate of physical capital accumulation that captures or the investment in physical capital, $s_{i,t}^{h}$ is the saving rate of human capital accumulation or the investment in schooling, $\tau_{i,t}$ is the population growth rate, ψ is the augmenting technical progress parameter, and δ is the physical capital depreciation rate, $z_{i,t}$ is a vector of independent variables that allows us to extend the standard neoclassical theory by incorporating growth determinants' proxies

[13] The causes of the negative relationship between resource, in particular non-renewable, dependence and economic growth has been largely debated although no universally accepted theory of the so-called "resource curse" has emerged. Many potential explanations have been suggested including the crowding-out of manufacturing activities, the political capture of rents, unsustainable government policies, poor investment in human resources, economic shocks, low institutional quality, armed conflicts, lack of effective property rights and high transaction costs, and volatility of world resource prices. See Frankel (2012) and Torres et al. (2013) for recent surveys of the literature that addresses this important issue.

[14] Even though averaging enables us to deal more adequately with business cycle effects, the sample size and the presence of heteroscedasticity and serial correlation impose constraints on the time horizon over which this averaging is performed. Indeed, the longer this averaging time span, the smaller the number of degrees of freedom, and hence the less accurate the estimates and the less explanatory power the regressors have (Durlauf et al. 2008b).

associated with some new growth theories, μ_i and ν_t are respectively country- and year-specific factors, γ_0, γ_1, γ_2, and γ_3 are unknown scalar parameters, β is an unknown vector parameter, and $\varepsilon_{i,t}$ is an error term.[15] The parameters γ_i, $i = 1,2,3$ satisfy:

$$\gamma_1 = e^{5\lambda}, \gamma_2 = \left(1 - e^{5\lambda}\right)\left(\frac{\alpha_k}{1-\alpha_k-\alpha_h}\right), \gamma_3 = \left(1 - e^{5\lambda}\right)\left(\frac{\alpha_h}{1-\alpha_k-\alpha_h}\right), \gamma_4 = -\left(1 - e^{5\lambda}\right)\left(\frac{\alpha_k+\alpha_h}{1-\alpha_k-\alpha_h}\right) \quad (2)$$

where $\lambda < 0$ is the rate of growth convergence and $\alpha_k, \alpha_h > 0$ are the elasticities of output with respect to, respectively, physical capital and human capital in a Cobb-Douglas production function assumed to exhibit decreasing returns to scale, i.e., $\alpha_k + \alpha_h < 1$.

We consider 8 new growth theories. The growth determinants associated these theories can be proxied by several variables incorporated in the vector of independent variables $z_{i,t}$. Table 1 below describes these theories and the proxies. Note that a proxy is used to represent an unobserved metric, that is, in our case, a factor that identifies a given growth theory. Hence, life expectancy and fertility rate for instance are very good candidate variables for proxying determinant variables in what is referred to as the Demography growth theory. When several proxies are used to represent a given growth theory, it is possible to disentangle the effects of each proxy. Thus, for instance, while examining whether or not the Religion theory is relevant to explain economic growth, it is possible to investigate the relative impact of each of the religions on economic growth.

Table 1. Growth theories, proxies for determinants of growth, and references

Proximate theories	Proxies and references
Neoclassical	Initial income, Population growth rates, Investment in physical capital, Investment in schooling (Solow, 1956)
Demography	Life expectancy, Fertility rate (Shastry and Weil, 2003; Weil, 2007)
Macroeconomic policy	Openness, Government expenditure, Inflation (Barro, 1997)
Regional heterogeneity	Latin America and Caribbean, Sub-Saharan Africa, East Asia and the Pacific, South-East Asia (Brock and Durlauf, 2001)
Fundamental theories	Proxies
Religion	Catholicism, Protestantism, Orthodox religion, Judaism, Islam, Buddhism, Hinduism, Eastern religion, Other religion (Barro and McCleary, 2003; Durlauf et al., 2012)
Natural capital	Natural capital, Natural capital per capita (Sachs and Warner, 1995; Gylfason, 2011)
Geography	Coastline, Landlocked (Sachs, 2003)
Fractionalization	Language, Ethnic group (Alesina et. al., 2003; Easterly and Levine, 1997)
Institutions	Liberal democracy, Public sector corruption, Legal formalism, Governance, Executive constraints (Djankov et al., 2002; 2003)

The regressions that we estimate include proxies for "Proximate" and "Fundamental" theories of growth. We will say that a given theory provides a satisfactory explanation for growth if the estimated coefficient of at least one variable that proxies this theory is statistically significant. By definition, proximate theory proxy variables can only have direct impacts on economic growth whereas fundamental theory proxy variables can have direct and/or indirect impacts. Hence, to uncover a direct impact on growth, a regression should include both proximate and fundamental theories' proxy variables referred to as, respectively,

[15] We make the typical assumption that the rate of technical progress and the physical capital depreciation rate add up to 5%, i.e., $\psi + \delta = 0.05$. See Mankiw et al. (1992).

"proximate variables" and "fundamental variables." If the parameter estimates of proximate variables or fundamental variables happen to be statistically significant, this would say that the corresponding theories are satisfactory to explain a direct effect on economic growth.

Now, to uncover indirect impacts of fundamental theories' proxy variables on economic growth, growth regressions should only include fundamental theories' proxy variables. When fundamental variables are significant while they were not when both proximate and fundamental variables are included, we conclude that the corresponding fundamental theories are satisfactory only to explain indirect effects on growth that passes through the proximate theories channel. Incidentally, we also examine correlations between proximate and fundamental variables for the purpose of obtaining some alternative evidence on the relationships between these two sets of theories.

Growth model and determinant proxy uncertainty is handled as follows. As indicated in the introduction, the BMA estimation approach that we use allows us to estimate regressions aimed at testing alternative theories of economic growth while explicitly accounting for the associated model uncertainty and the uncertainty related to the specification of proxy variables for each theory to be used as regressors (Brock and Durlauf 2001; Brock et al. 2003). Formally, let m designate an economic growth model in the model space M given available data D. Then, this model's posterior probability is given by

$$\mu(m|D) = \mu(D|m)\mu(m) \tag{3}$$

where $\mu(D|m)$ is the likelihood of the data given the model and $\mu(m)$ is the prior probability of the model m. In the empirical analysis, we set the prior probability that a particular theory is in the true model to 0.5 to reflect no discrimination and non-information across theories (Durlauf et al. 2008a). Given $\mu(m|D)$ expressed in equation (3), we then estimate the probability, P_{ξ}, that a given theory, ξ, is in the true model, as the aggregate posterior probability

$$P_{\xi} = \sum_{m \in \mathrm{M}} \mu(m|D, m \in A) \tag{4}$$

where A is the event that "At least one proxy variable associated with the theory ξ is in the true model," i.e., as far as empirical evidence is concerned, the parameter associated with this proxy variable is statistically significant.

3. Data and preliminary analysis

The data consists of one novel unbalanced panel dataset on 23 countries with high annual mangrove mitigation potential and another on 83 countries worldwide both for the period 1960-2009.[16] As our empirical analysis requires 5-year averaging, this 50-year timespan is split into ten 5-year periods. We should emphasize here that mangroves are the only coastal ecosystems for which it is possible to analyze the climate change mitigation potential and identify priority areas with some reasonable precision.[17] The annual mitigation potential for

[16] The data analyzed in this article will be shared on reasonable request to the corresponding author.

[17] Besides data availability constraints, there are still large sources of uncertainty in the rates of land use conversion and the fates of coastal vegetated ecosystem carbon upon conversion (Duarte, 2014, Pendleton et al., 2012). A key question about carbon is where it comes from and what happens to it when the ecosystem releases it. In the case of seagrass meadows, for instance, whether the carbon released from sediments when seagrass dies goes into the atmosphere, or remains somewhere else nearby, or simply contributes to increased ocean acidification are still open questions to the scientific community.

mangroves at current conversion rates is such that it would enable to offset 2.3 to 6.8% of the current fossil fuel emissions, over half of that projected for reducing rainforest deforestation (Nellemman et al., 2009). Much of the mangrove mitigation potential lies in a small group of countries. More specifically, about 80% of mangrove mitigation potential is concentrated in 25 countries whose annual mitigation potential is above 0.6 million tCO2e. Moreover, 55% of that potential resides in seven countries with at least two million tCO2e (Murray et al., 2011).

The choice of the eight growth theories that we consider in this paper besides the standard neoclassical one (see Table 1) and the associated variables that proxy the determinants of growth is in line with the work of Durlauf et al. (2008a). It is worth indicating that the natural capital variable used (see Table A.2 in the appendix) does not include characteristics of the marine environment. Indeed, it incorporates renewable (timber, non-timber forest resources, protected areas, cropland, and pastureland) and non-renewable (oil, natural gas, hard coal, soft coal, and minerals) resources. Table A.2 describes the variables used in our regressions, their content, and the sources while, for the purpose of performing a preliminary comparative analysis of the two datasets, Tables A.3 through A.6 exhibit some summary statistics on these variables.

Table A.4 allows us to compare the two datasets along the median statistic of the various variables while Table 2 below extract some information of interest. We see that compared to the WW countries, the BC countries are characterized by lower initial income and investment in education, higher fertility and natural capital in wealth, lower natural capital per capita, higher ethnolinguistic fractionalization, and less favorable political economy climate, in particular, higher public sector corruption.[18] Interestingly enough, these characteristics of the BC sample are features that are commonly associated with developing countries. Indeed, according to The World Bank classification, this BC sample contains 5% of high-income countries, compared to 36% in the WW sample, 39% of upper-middle income countries, compared to 32%, 39% of lower-middle income countries, compared to 32%, and 17% of low-income countries, compared to 9%. It seems thus interesting to compare the results obtained with the BC sample to the findings of the literature on the determinants of economic growth in developing countries. In particular, trade, natural capital, geography, fractionalization, demography, and the political environment, among other factors, are known to be particularly relevant determinants of growth in developing countries, most of which share features with coastal countries as documented in the literature.[19]

Prior to implementing the BMA econometric analysis, we performed a series of tests on our data.[20] More specifically, we found that the dependent variable is stationary in levels, that panel data estimation techniques are more suitable than standard pooled data ones, and that

[18] Table 2 also shows the median and standard deviation of some control variables, such as $latitude$, that the reader might find interesting to take a look at.

[19] See Bloom and Sachs (1998), Tavares and Wacziarg (2001), Durlauf et al. (2005), Ndulu et al. (2007), and Gylfason (2011) among others.

[20] Firstly, we did a Fisher unit-root test and found that the dependent variable is stationary in levels. Secondly, we checked whether or not data could be pooled by testing the random and fixed-effects panel data model against a pooled Ordinary Least Square (OLS) through the goodness-of-fit criterion. The panel data framework was preferred to pooled data suggesting that the parameters of the equation are time-variant over the ten periods of available data. Thirdly, we found evidence that there exists heteroskedasticity across panels through the Erlat Lagrange Multiplier (LM)-test as well as serial correlation through the Baltagi LM-test. OLS and fixed-effects methods adjust standard errors for intragroup correlation, which should therefore be robust to heteroskedasticity and serial correlation. The General Method of Moments (GMM) also allows us to control for heteroskedasticity and we test for the presence of serial correlation of order one and two. To apply Two-Stage Least Square (2SLS) for the economic growth regressions, we use Driscoll and Kraay (1998)'s approach that guarantees that the covariance matrix estimator is consistent, independently of the cross-sectional dimension, in contrast to the Parks (1967)-Kmenta (1986) and the Panel-Corrected Standard Errors (PCSE) approaches, which typically become inappropriate when the cross-sectional dimension of a panel gets large (Driscoll and Kraay, 1998).

there is evidence of heteroscedasticity and serial correlation, and treated the data accordingly. The correlation coefficients between fundamental and proximate variables shown in Tables A.5 and A.6 of the appendix for the BC and WW datasets convey some useful information on the existence of a direct explanatory power of fundamental variables that goes beyond an indirect influence through proximate variables in the economic growth regressions. We see from these tables that some fundamental variables, namely, those that proxy religion, natural capital, fractionalization, and institutions, may potentially exert an influence on economic growth through their impact on proximate variables except those that proxy macroeconomic policy, as shown by the significant pairwise correlations.[21]

Table 2. BC versus WW countries - Main differences in representative variables' median values

		BC countries		WW countries	
Theories & variables	Variable names	Median	Std Dev	Median	Std Dev
Neoclassical					
Initial income	inc	7.78	1.01	8.61	1.26
Schooling	sch	2.85	0.78	3.40	0.78
Demography					
Fertility rate	$fert$	1.64	0.38	1.32	0.52
Natural capital					
Natural capital in wealth	nat_w	0.30	0.20	0.17	0.32
Natural capital per capita	nat_pc	0.04	0.06	0.09	0.23
Fractionalization					
Ethnic group	eth	0.55	0.19	0.42	0.26
Institutions					
Liberal democracy	$demo$	0.27	0.20	0.38	0.29
Public sector corruption	$corr$	0.63	0.24	0.40	0.29
KKZ96	$kkz96$	-0.37	0.54	0.08	0.90
Executive constraints	exe	4.00	1.92	5.00	2.22
Others (controls)					
Latitude	lat	0.14	0.09	0.22	0.19
Minerals stock	min	-7.22	2.26	-6.25	2.96
System	sys	0.00	0.75	0.55	0.89

4. BMA estimation results

We now report on the results obtained by applying the BMA estimation methodology to the augmented Solow model and the eight new growth theories expressed in regressions for the average growth rate of GDP per capita corresponding to the ten 5-year periods from 1960 to 2009 given by equation (1), namely, 1960-64, 1965-69, 1970-74, 1975-79, 1980-84, 1985-89, 1990-94, 1995-99, 2000-04 and 2005-2009. Tables A.7 and A.8 present the results obtained respectively with the BC and the WW datasets. These tables give the BMA results for the case where both proximate and fundamental determinants are included in the model space (columns 2, 3, and 4) as well as the case where only fundamental growth determinants are included (columns 5, 6, and 7). Before discussing these results, it seems useful at this point to make a few remarks.

First, recall from our discussion of the BMA methodology in section 2 that whether a theory is satisfactory as a data generating process, i.e., is included in the true model, depends on its posterior probability, given by equation (4), that aggregates the probabilities that at least one proxy variable associated with the theory is a statistically significant predictor of the 5-

[21] We consider a correlation between two variables as significant if it is greater than or equal to 0.40 and we report it in bold in Tables A.5 and A.6.

year average growth rate of GDP per capita. Hence, we will pay a particular attention to the theories that have relatively high posterior inclusion probabilities. The standard practice (see Brock and Durlauf, 2001), which we follow, is to consider that a given growth theory is robust if the mean of its posterior is at least as large as twice its posterior standard deviation. The posterior inclusion probability of each theory is given in column 2 or 5 of Tables A.7 and A.8 and marked in bold when the theory is a relatively robust theory of growth, with robustness increasing as this probability gets closer to 1.

Second, as argued by Barlett et al. (2001), the ratio of the number of observations to that of the independent variables should not fall below 5. Thus, following Durlauf et al. (2005), we excluded from the BMA regressions the variables that have relatively weaker explanatory power in the set of variables presented in Table A.3 and A.4. For the BC sample analysis, this led us to exclude the religion variables that proxy Catholicism, Orthodox religion, Judaism, Hinduism, and Other religion whereas for the WW sample analysis the variables Catholicism, Orthodox religion, Judaism, and were excluded. We also checked for multicollinearity and this led us to further exclude some additional variables, namely, the variable of regional heterogeneity corresponding to East Asia and the Pacific and the institutions variables corresponding to liberal democracy, public sector corruption, legal formalism: Check (1), legal formalism: Check (2), and complexity.

Third, following Durlauf et al. (2008a), we checked for endogeneity and used as instruments for right-hand-side variables found to be endogenous earlier or initial values if available with the exception of inflation, religion shares, and natural capital and substituted their without model and proxy uncertainty Two-Stage Least Squares (2SLS) fitted values into the regressions. For inflation, we used as instruments the colonial dummy for Spain or Portugal colony, British, and French legal origins. For religion shares, we used the corresponding shares in 1900. As to natural capital, following van der Ploeg and Poelhekke (2010) we used a dummy for the existence of a presidential system and stock of minerals. It turns out that the 2SLS regression results are very similar to the BMA regression results with uncertainty.[22]

We now turn to the discussion of the BMA estimation results. Table 3 below presents the BMA posterior inclusion probabilities extracted from Tables A.7 and A.8 in the appendix. Recall that we are interested in evaluating the relative merit of each of the 8 new theories in explaining economic growth in the BC countries versus the WW countries. Given that our very objective is to highlight the role of blue carbon in economic growth, we first discuss the results that differ for BC and WW countries and then those that are similar.

Results different for BC and WW countries

From Table 3, we see that two new growth theories are robust for the BC countries but not for the WW countries, namely, the macroeconomic policy theory and the natural capital theory. Indeed, we see that the posterior probability of inclusion gets close to one (0.999) for the case where we include only the fundamental theories and the case where we include both the proximate and the fundamental theories. Regarding the macroeconomic policy theory, our finding is consistent with that of Gallup et al. (1999) who argue that macroeconomic policy is a relevant determinant of growth in coastal countries because of the important role played by international trade in these countries. As to the natural capital theory, the result provides further evidence of a relationship between natural resources and economic growth that has been established in the empirical literature. See, Ding and Field (2005), Cerny and Filer (2007), and Gylfason (2011), among others.

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[22] These results are available from the authors upon request.

Let’s emphasize here that in this paper we proxy both natural capital dependence and natural capital abundance, respectively, by natural capital in wealth and natural capital per capita. Usually, these two variables have not been found in the literature to have the same impact on economic growth. The evidence is that strong dependence on natural resource extraction is typically negatively correlated with economic growth while natural resource abundance in per capita terms is positively correlated with wealth (Gylfason, 2011). We do not find evidence that natural capital exports in coastal countries play a negative role in economic growth, although our analysis is mainly based on non-renewable resources. However, in addition to the results exhibited in Table A.7, we ran additional regressions with renewable and non-renewable resources taken into account as separate variables. These regressions did not convey any other additional information of interest that is worth adding to those already suggested by Table A.7.[23]

Another result that Table 3 highlights is that the religion and the fractionalization theories are robust to explain growth in the WW sample of countries, but not in the BC sample of countries. Indeed, using the latter data sample, the variables that proxy the religion theory turn out to have a weak explanatory power for growth and lead to a posterior probability of inclusion of 0.264, which is lower than the prior of 0.5 when accounting for proximate and fundamental theories. This conclusion contrasts with the finding of some studies such as Barro and McCleary (2003) that religion plays an important role in economic growth. The same is true for the fractionalization theory, as some previous studies such as Easterly and Levine (1997) and Alesina et al. (2003) have found that it is a satisfactory theory for explaining economic growth.

As to the neoclassical theory, investment in physical capital turns out to be a significant determinant of economic growth in countries with BC while it is not in the WW sample of countries (see Tables A.7 and A.8). This provides further evidence that investment in physical capital is positively and significantly correlated with economic growth in countries with BC, a result consistent with previous findings in the empirical literature. See, Barro (1991, 1996, and 1997), Barro and Lee (1994), Caselli et al. (1996), and Sachs and Warner (1995), among others.

Results similar for BC and WW countries

The demography, institutions, and neoclassical (through initial income) theories are found to have an (indirect or direct) impact on economic growth both in BC and WW countries (see Tables 3, A.7, and A.8).[24] More specifically, with regards to demography variables, we see from Table A.7 that fertility is significantly detrimental to economic growth, a result also found by Barro (1991, 1996, and 1997) and Barro and Lee (1994). Also, fertility might not directly (and negatively) impact growth, but indirectly if seen as a proxy for the (in)efficiency of social policies such as the absence of social security for the elders. The results showing that institutions play a role in economic growth is in line with the findings of Acemoglu et al. (2002).[25] In particular, as can be seen in Table 3, institutions really matter for economic growth when only fundamental growth theories are considered. This suggests that the impact of institutions on economic growth would be exerted indirectly through proximate theories’ proxies, a result found in our preliminary analysis discussed in section 3.

Table A.7 and A.8 show that results related to the neoclassical theory in BC countries

[23] The results of these additional regressions are available from the authors upon request.

[24] As to the regional heterogeneity and geography theories they appear not to be robust in explaining economic growth independently of the sample of countries (see Table 3).

[25] The role of institutions in economic development is emphasized by the "New institutional economics" school of thought to which the Nobel Laureates Coase (1998), North (1990 and 1995), and Williamson (2000) have significantly contributed.

coincide with those in the WW countries except for investment in physical capital. Overall, the findings are consistent with the conditional convergence literature as well as previous studies that have used BMA methods. We see from Table A.8 that there is robust evidence of conditional convergence as shown by a negative and significant coefficient associated with the initial income variable. This result has been found in many previous studies, including Barro (1991 and 1997), Easterly and Levine (1997), and Sachs and Warner (1995). The variables schooling and population growth are not significant independently of the sample of countries. These results are consistent with the findings of Durlauf et al. (2008a). Let us add that when we take out the demography theory from the model space, we find that population growth is negatively and significantly related to economic growth, a result consistent with the findings of Bloom and Sachs (1998), Kelley and Schmidt (1995), and Mankiw et al. (1992).[26]

Table 3. BMA posterior inclusion probabilities of new growth theories[+]

	Proximate and fundamental theories		Fundamental theories	
Theories	BC countries	WW countries	BC countries	WW countries
Demography	**0.980**	**1.000**		
Macroeconomic policy	**0.999**	0.028		
Regional heterogeneity	0.089	0.085		
Religion	0.264	**0.981**	0.524	**1.000**
Natural capital	**0.999**	0.250	**1.000**	0.227
Geography	0.086	0.056	0.089	0.035
Fractionalization	0.624	0.056	0.189	**0.964**
Institutions	0.366	**1.000**	**0.836**	**1.000**

[+] The posterior inclusion probability of a theory is market in bold to indicate that such a theory is relatively robust in explaining economic growth and robustness increases with this probability.

5. Conclusion

This article has attempted to enlighten human activity impact on blue carbon through the lens of economic growth. More specifically, we examine the determinants of economic growth in countries with mangrove blue carbon with the goal of evaluating the extent to which anthropogenic pressure on these coastal ecosystems affects growth. Our empirical strategy rests on using two 1960-2009 datasets, one on 23 mangrove-rich countries that possess features similar to those of typical developing countries and another on 83 worldwide countries, to estimate a set of growth theories. These theories include the standard neoclassical theory and eight other theories that emphasize demography, macroeconomic policy, regional heterogeneity, religion, natural capital, geography, language and ethnic fractionalization, and institutions as determinants of growth.

We find evidence that, through initial income and investment in physical capital, the neoclassical theory performs well in explaining growth in blue carbon countries. The same holds for the demography, the macroeconomic policy, and the natural capital theories. In contrast, the investment in physical capital variable, the proxies used for the macroeconomic policy theory and the natural capital theory turn out not to be significant predictors of growth when using the worldwide sample of countries. These results are consistent with the empirical evidence found in the literature on the determinants of economic growth in coastal countries, which, as mentioned, have characteristics that are often associated with developing countries. Moreover, our results on the role of natural capital measured in per capita terms are also consistent with the empirical literature on growth in developing countries that are typically characterized by low natural capital abundance in per capita terms and high economic dependence on natural capital as pointed out by Gylfason (2011).

[26] These results are available from the authors upon request.

Indeed, considering and comparing representative blue carbon and worldwide countries, during the half-century covered by our data, we found that a country with blue carbon has seen its natural capital per capita reduced by more than half and its economic dependence on natural capital is almost twice as high.[27] The results on natural capital put the finger on the critical problem of potential anthropogenic pressure that coastal areas with blue carbon can be subject to due to land conversion for agriculture or aquaculture, farming and other run-offs, and coastal construction and public works associated with natural capital exports. Moreover, typically higher fertility rates should accelerate urbanization, uncontrolled sewage, and marine resources direct exploitation as discussed in Estes et al. (2012). Given demographic pressure, blue carbon ecosystems have a high probability of being eroded for short-term gains, a practice that is still often preferred to ecosystem services management. See Larrère and Larrère (1997) and MEA (2005).

The findings of this paper suggest that society may gain from central governments giving local policy makers and communities incentives for promoting nature-based solutions to climate change and mitigation.[28] However, due to budgetary constraints faced by developing countries, international financial institutions should play a major role in providing financial support for such initiatives in these countries. Besides being both climate change mitigation and adaptation tools, these nature-based solutions could bring additional co-benefits for societal well being, thus being powerful investment instruments for sustainable urban planning in coastal areas.[29] Hence, compared to grey infrastructure solutions, these blue-green infrastructure solutions should be viewed as also having the potential to be socially rewarding.

This study clearly opens avenues for further research with the aim to improve our understanding of the stakes of the Blue Economy for society. One such routes is to further explore the role of characteristics of coastal countries other than that considered in this paper, i.e., mangrove blue carbon, in economic development. Besides our will to stretch our data beyond 2009 in order to account for the consequences of recent policy events in the sustainable development arena, increasing exposure to natural coastal hazard and declining marine biodiversity that result from human activity are phenomena that certainly deserve due attention and we intend to analyze them in the near future.

[27] This can be seen from Tables 2 and A.4.

[28] The need to promote such eco-system based approaches has been pointed out in the Naumann et al. (2011) report for the European Commision.

[29] An interesting discussion of this point is Kabisch et al. (2016).

Appendix

Data description, sources, and descriptive statistics
The data set constructed for this study contains observations for the period 1960-2009 on a sample of 23 countries endowed with high mangrove, referred to as BC countries, and another of 83 worldwide countries, referred to as WW countries, for which there is sufficient data on the growth determinants proxies of interest listed in Table 1 given in the main text of this paper. Tables A.1 below lists 25 countries with high annual mangrove climate change mitigation potential from which 2 have been withdrawn because not enough data on important variables could be collected on them.

Table A.1 Top 25 countries for annual mangrove climate change mitigation potential*

Country	Discounted annual mangrove mitigation potential (in million tones CO_2e year^{-1})
Indonesia	30,679,644
Mexico	8,137,233
Papua New Guinea	4,570,866
Malaysia	4,181,896
Vietnam	2,564,008
Colombia	2,261,764
Pakistan	2,026,638
United States	1,953,947
Guinea-Bissau**	1,832,201
Myanmar**	1,790,324
Philippines	1,762,242
Sierra Leone	1,716,291
Gabon	1,698,338
Honduras	1,631,183
Madagascar	1,539,227
Senegal	1,342,843
India	1,133,760
Venezuela	1,124,822
Panama	1,056,887
Tanzania	755,870
Ecuador	684,104
Nicaragua	681,651
Brazil	872,828
Cambodia	692,276
Thailand	603,800

* Data extracted from Murray et al. (2011).
** Country excluded from the analysis due to lack of sufficient data.

The sample of 23 blue carbon (BC) countries includes the following coastal ones:

- Brazil, Cambodia, Colombia, Ecuador, Gabon, Honduras, India, Indonesia, Madagascar, Malaysia, Mexico, Nicaragua, Pakistan, Panama, Papua New Guinea, Philippines, Senegal, Sierra Leone, Tanzania, Thailand, United States, Venezuela, Vietnam.

The sample of 83 worldwide (WW) countries contains:

- 20 countries from Latin America and the Caribbean region: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, Trinidad and Tobago, Uruguay, and Venezuela.
- 10 countries from Middle East and North Africa: Bahrain, Brunei, Egypt, Iran, Israel, Jordan, Kuwait, Saudi Arabia, Tunisia, and United Arab Emirates.
- 15 countries from Sub-Saharan Africa: Cameroun, Congo, Gabon, Ghana, Kenya, Malawi, Mauritius, Mozambique, Senegal, Sierra Leone, South Africa, Sudan, Uganda, Zambia, and Zimbabwe.
- 13 countries from East Asia and Pacific: Australia, China, Fiji, Indonesia, Japan, Malaysia, New Zealand, Papua New Guinea, Philippines, Republic of Korea, Singapore, Thailand, and Tonga.
- 5 countries from South Asia: Bangladesh, India, Maldives, Pakistan, and Sri Lanka.
- 2 countries from North America: Canada and United States and 18 countries from Europe and Central Asia: Austria, Belgium, Canada, Denmark, Finland, France, Greece, Hungary, Italy, Ireland, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, and United Kingdom.

As to the proxies for the determinants of growth, we collected data on variables regrouped below in ten categories, namely, Neoclassical, Demography, Macroeconomic policy, Regional heterogeneity, Religion, Natural capital, Geography, Fractionalization, Institutions, and Others (controls). The definition, the content of these variables, and the source(s) of raw data are given in Table A.2 below, while Tables A.3 through A.8 present some summary statistics and results that are discussed in the text.

Table A.2 Variables, contents, and sources

Theories & variables	Contents and sources
Neoclassical	
Growth of GDP per capita	Average growth rates of Gross National Product per capita (in 2005 USD) for the 10 five-year time segments 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, and 2005-2009. Source: Penn World Table 7.1.
Initial income	Natural logarithm of GDP per capita (in 2005 USD) in the beginning of each of the above 10 five-year time segments, i.e., in 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, and 2005. Instruments used to account for endogeneity of initial income its fifth lag, i.e., its values in 1955, 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, and 2000. Source: Idem.
Population growth rate	Natural logarithm of average population growth rates plus 0.05 for each of the above 10 five-year time segments. Instruments used for population growth rates for each of the above 10 five-period time segments are their average values over the time segments 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1995, and 2000-2004. Source: Idem.
Investment in physical capital	Natural logarithm of average ratios of investment in physical capital to GDP for each of the above 10 five-year time segments. Instruments used for investment are their average values over the time segments 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, and 2000-2004. Source: Idem.
Schooling	Natural logarithm of the ratio of male population enrolled in secondary school to total population in years 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, and 2005. Source: Barro and Lee (2014).
Demography	
Life Expectancy	Reciprocal of life expectancy at age 1 in years 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, and 2005. Source: The World Bank.
Fertility rate	The natural logarithm of the total fertility rate for each of the above 10 years. Source: Idem.
Macroeconomic policy	
Openness	Average ratio of exports plus imports to GDP for each of the above 10 five-year time segments. Instruments are average values over the time segments 1955-1959, 1960-1964, 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, and 2000-2004. Source: Pen World Table 7.1.
Government consumption	Average ratio of government consumption to GDP for each of the above 10 five-year time segments. Source: Idem.
Inflation	Consumer price inflation rate calculated as average for the 5 ten-year time segments 1960-1969, 1970-1979, 1980-1989, 1990-1999, and 2000-2009. Source: The World Bank.
Regional heterogeneity	
Latin America and Caribbean	Dummy variable. Source: The World Bank.
Sub-Saharan Africa	Idem.
South- & East- Asia	Idem.
Religion	
Catholicism	Catholicism share in 1970 expressed as a fraction of the population that expressed adherence to some religion. Instruments include the Catholicism share in 1900 expressed as a fraction of the population who expressed adherence to some religion. Source: Barrett et al. (2001).
Protestantism	Idem, but for Protestantism. Source: Idem.

Judaism	Idem, but for Judaism. Source: Idem.
Orthodox religion	Idem, but for Orthodox religion. Source: Idem.
Islam	Idem, but for Islam. Source: Idem.
Buddhism	Idem, but for Buddhism. Source: Idem.
Hinduism	Idem, but for Hinduism. Source: Idem.
Eastern religion	Idem, but for Eastern religion other than Buddhism and Hinduism. Source: Idem.
Other religion	Idem, but for some religion other than Catholisism, Protestantism, Judaism, Orthodox religion, Islam, Buddhism, Hinduism, and Eastern religion. Source: Idem.
Natural capital	
Natural capital in wealth	Time-invariant variable measuring the weight of natural capital in total wealth in 2000. Source: World Bank (2006).
Natural capital per capita	Time-invariant variable measuring natural capital per capita in 2000. The variable is scaled to take values between 0 and 1. Source: Idem.
Geography	
Coastline	Coastline length in km scaled to take values between 0 and 1. Source: UNEP (2015).
Landlocked	Binary variable equal to 1 if the country is landlocked and to 0 otherwise. Source: CIA (2009).
Fractionalization	
Language group	Time-invariant measure of linguistic fractionalization that reflects the probability that two randomly selected individuals from a population belong to different language groups. The measure takes values between 0 to 1. Source: Alesina et al. (2003).
Ethnic group	Idem, but with ethnic instead of language groups. The measure takes values between 0 and 1. Source: Idem.
Institutions	
Liberal democracy	Time variant-index that emphasizes the importance of protecting individual and minority rights against the tyranny of the state and the tyranny of the majority. This is achieved by constitutionally protected civil liberties, strong rule of law, an independent judiciary system, and effective checks and balances that, together, limit the exercise of executive power. To make this a measure of liberal democracy, the index also takes the level of electoral democracy into account. This variable is calculated as the average of the aggregate index for each of the time segments 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005, and 2005-2009. It values range from 0 to 1 with higher scores meaning a more liberal democracy. Source: The QOG Standard Dataset.
Public sector corruption	Time-variant index that measures the extent to which public sector employees grant favors in exchange for bribes, kickbacks, or other material inducements, and how often they steal, embezzle, or misappropriate public funds or other state resources for personal or family use. This variable is calculated in the same manner as the Liberal democracy variable and its values range from 0 to 1 with higher scores meaning more corruption. Source: Idem.
Legal formalism: Check (1)	Time-invariant index including professionals vs. laymen, written vs. oral elements, legal justification, statutory regulation of evidence, control of superior review, and engagement formalities indices, and the normalized number of independent procedural actions for the case of collection of a check. The values of this index range from 0 to 7 where higher values meaning a higher level of control or intervention in the judicial process. Source: Djankov et al. (2003).
Legal formalism: Check (2)	Time-invariant index of formality in the number of legal procedures for collecting on a bounced check. This index is rescaled to lie between 0 and 1 for 2003. Lower values mean less legal formality. Source: Doing Business-The World Bank.
Complexity	Time-invariant index of complexity in collecting a commercial debt valued at 50% of annual GDP per capita. This index is rescaled to lie between 0 and 1 for 2003. Lower scores imply less complexity. Source: Idem.

KKZ96	Time-invariant composite governance index calculated as the average of six indices that capture voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption in 1996. Its values range from -2 to 2 and higher values imply better governance. Source: Kaufmann et al. (2005).
Executive constraints	Time-varying index variable that measures the extent of institutionalized constraints on the decision making power of chief executives. This variable is calculated as the average for the time-segments 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005, and 2005-2009. Its values range from 0 to 7 and higher values mean greater institutionalized constraints on the power of chief executives. Source: Polity IV Project, 1946-2013.
Others (controls)	
Time dummy variables	Dummy variables for period segments 1960-1965, 1965-1970, 1970-1980, 1980-1985, 1985-1990, 1990-1995, 1995-2000, 2000-2005, and 2005-2009. Source: Authors.
Colonial (Spain or Portugal)	Binary dummy variable equal to 1 if a country was colonized by Spain or Portugal and 0 otherwise. Source: Barro and Lee (1994).
English legal origin	Binary dummy variable where a value of 1 indicates that a country was colonized by the UK and English legal code was transferred. Source: Easterly (2001).
French legal origin	Binary dummy variable where a value of 1 indicates that a country was colonized by France, Spain, Belgium, Portugal, or Germany and French legal code was transferred. Source: La Porta et al. (1999), Djankov et al. (2003).
Latitude	The absolute value of the latitude of a country's capital scaled to take values between 0 and 1. Source: Djankov et al. (2003).
Stock of minerals	Time-invariant variable equal to the logarithm of fuel and 35 other non fossil fuel stocks estimated for 1970 at market prices in USD per capita. Source: Moral-Benito (2012), Norman (2009), van der Ploeg and Poelhekke (2010).
System	Time-invariant variable that takes the value of 0 if the country has a presidential system, 1 if it has an assembly-elected president, and 2 if it has a parliamentary system. The mean value is between 1975 and 2010. Source: Beck et al. (2001).

Table A.3 Summary statistics for BC countries

Theories & variables	Variable names	Obs	Median	Mean	Std dev	Min	Max
Neoclassical							
Growth of GDP per capita	gdp	226	0.02	0.02	0.03	-0.10	0.12
Initial income	inc	225	7.78	7.87	1.01	5.94	10.65
Population growth rate	pop	230	-2.65	-2.68	0.10	-3.22	-2.46
Investment	inv	225	3.01	2.96	0.48	1.15	4.20
Schooling	sch	220	2.85	2.80	0.78	-0.23	4.11
Demography							
Life expectancy	$life$	230	0.01	0.01	0.00	0.01	0.04
Fertility rate	$fert$	230	1.64	1.52	0.38	0.43	2.01
Macroeconomic policy							
Openness	$open$	226	0.53	0.62	0.44	0.07	2.06
Government consumption	gov	228	0.08	0.10	0.07	0.02	0.41
Inflation	$infl$	182	0.07	0.24	1.31	0.00	16.67
Regional heterogeneity							
Latin America and the Caribbean	lac	230	0.00	0.34	0.47	0.00	1.00
Sub-Saharan Africa	ssa	230	0.00	0.21	0.41	0.00	1.00
South-East Asia	sea	230	0.00	0.08	0.28	0.00	1.00
Religion							
Buddhism	$buddhism$	230	0.00	0.10	0.26	0.00	0.92
Catholicism	$catholicism$	230	0.22	0.42	0.39	0.00	0.94
Eastern religion	$eastern$	230	0.00	0.02	0.07	0.00	0.25
Hinduism	$hinduism$	230	0.00	0.03	0.15	0.00	0.76
Judaism	$judaism$	230	0.00	0.00	0.00	0.00	0.03
Islam	$islam$	230	0.02	0.17	0.28	0.00	0.96
Orthodox religion	$orthodox$	230	0.00	0.00	0.00	0.00	0.02
Other religion	$other$	230	0.01	0.06	0.14	-0.16	0.49
Protestantism	$protestantism$	230	0.03	0.07	0.10	0.00	0.39
Natural capital							
Natural capital in wealth	nat_w	200	0.30	0.33	0.20	0.02	0.88
Natural capital per capita	nat_pc	200	0.04	0.06	0.06	0.00	0.26
Geography							
Coastline	$coast$	230	0.02	0.07	0.11	0.00	0.50
Fractionalization							
Language group	$lang$	230	0.35	0.41	0.31	0.01	0.89
Ethnic group	eth	230	0.55	0.54	0.19	0.18	0.87
Institutions							
Liberal democracy	$demo$	218	0.27	0.32	0.20	0.02	0.88
Public sector corruption	$corr$	218	0.63	0.58	0.24	0.02	0.97
Legal formalism: Check (1)	$check(1)$	160	0.47	0.50	0.17	0.22	0.83
Legal formalism: Check (2)	$check(2)$	170	3.90	4.04	1.08	2.34	6.00
Complexity	$comp$	220	0.62	0.60	0.14	0.29	0.82
KKZ96	$kkz96$	230	-0.37	-0.24	0.54	-1.16	1.61
Executive constraints	exe	220	4.00	4.17	1.92	0.75	7.00
Others (controls)							
Time dummy variables	$period$						
Colonial (Spain or Portugal)	$colo$	200	0.00	0.40	0.49	0.00	1.00
English legal origin	$engl$	230	0.00	0.34	0.47	0.00	1.00
French legal origin	fr	200	0.00	0.10	0.30	0.00	1.00
Latitude	lat	230	0.14	0.14	0.09	0.01	0.42
Stock of minerals	min	210	-7.22	-6.99	2.26	-11.59	-2.90
System	sys	230	0.00	0.58	0.75	0.00	2.00

Table A.4 Summary statistics: BC versus WW countries

Theories & variables	Variable names	BC countries Median	BC countries Std dev	WW countries Median	WW countries Std dev
Neoclassical					
Growth of GDP per capita	gdp	0.02	0.03	0.02	0.03
Initial income	inc	7.78	1.01	8.61	1.26
Population growth rate	pop	-2.65	0.10	-2.73	0.19
Investment	inv	3.01	0.48	3.11	0.52
Schooling	sch	2.85	0.78	3.40	0.78
Demography					
Life expectancy	$life$	0.01	0.00	0.01	0.08
Fertility rate	$fert$	1.64	0.38	1.32	0.52
Macroeconomic policy					
Openness	$open$	0.53	0.44	0.51	0.45
Government consumption	gov	0.08	0.07	0.08	0.06
Inflation	$infl$	0.07	1.31	0.06	1.36
Regional heterogeneity					
Latin America and the Caribbean	lac	0.00	0.47	0.00	0.42
Sub-Saharan Africa	ssa	0.00	0.41	0.00	0.38
South-East Asia	sea	0.00	0.28	0.00	0.23
Religion					
Buddhism	$buddhism$	0.00	0.26	0.00	0.14
Catholicism	$catholicism$	0.22	0.39	0.17	0.37
Eastern religion	$eastern$	0.00	0.07	0.00	0.07
Hinduism	$hinduism$	0.00	0.15	0.00	0.11
Judaism	$judaism$	0.00	0.00	0.00	0.09
Islam	$islam$	0.02	0.28	0.01	0.34
Orthodox religion	$orthodox$	0.00	0.00	0.00	0.10
Other religion	$other$	0.01	0.14	0.00	0.13
Protestantism	$protestantism$	0.03	0.10	0.04	0.24
Natural capital					
Natural capital in wealth	nat_w	0.30	0.20	0.17	0.32
Natural capital per capita	nat_pc	0.04	0.06	0.09	0.23
Geography					
Coastline	$coast$	0.02	0.11	0.01	0.19
Fractionalization					
Language group	$lang$	0.35	0.31	0.33	0.29
Ethnic group	eth	0.55	0.19	0.42	0.26
Institutions					
Liberal democracy	$demo$	0.27	0.20	0.38	0.29
Public sector corruption	$corr$	0.63	0.24	0.40	0.29
Legal formalism: Check (1)	$check(1)$	3.90	1.08	3.39	1.10
Legal formalism: Check (2)	$check(2)$	0.47	0.17	0.38	0.18
Complexity	$comp$	0.62	0.14	0.53	0.15
KKZ96	$kkz96$	-0.37	0.54	0.08	0.90
Executive constraints	exe	4.00	1.92	5.00	2.22
Others (controls)					
Time dummy variables	$period$				
Colonial (Spain or Portugal)	$colo$	0.00	0.49	0.00	0.39
English legal origin	$engl$	0.00	0.47	0.00	0.49
French legal origin	fr	0.00	0.30	0.00	0.28
Latitude	lat	0.14	0.09	0.22	0.19
Mineral stocks	min	-7.22	2.26	-6.25	2.96
System	sys	0.00	0.75	0.55	0.89

Table A.5 Correlations between proximate and fundamental theories' proxy variables: BC countries[+]

Fundamental theories' proxies	Proximate theories' proxies										
	pop	inv	sch	$life$	$fert$	$open$	gov_c	$infl$	lac	ssa	sea
Religion											
$buddhism$	-0.37	**0.41**	-0.14	-0.06	-0.18	0.17	-0.10	-0.05	-0.25	-0.09	-0.12
$catholisism$	0.04	0.02	0.13	-0.32	-0.00	-0.01	-0.10	0.12	**0.86**	-0.26	-0.42
$hinduism$	0.00	-0.00	-0.04	0.31	0.05	-0.21	0.23	-0.05	-0.26	-0.09	**0.71**
$judaism$	-0.35	-0.09	0.38	-0.30	**-0.44**	-0.24	0.09	-0.03	-0.19	-0.09	-0.13
$islam$	**0.40**	-0.32	-0.26	**0.42**	0.37	0.09	0.05	-0.07	**-0.51**	**0.55**	0.33
$orthodox$	-0.37	-0.08	0.36	-0.27	**-0.42**	-0.32	0.06	-0.04	-0.16	-0.12	-0.05
$protestantism$	-0.35	-0.08	**0.41**	-0.34	**-0.46**	-0.16	0.18	0.01	-0.18	-0.18	-0.16
Natural capital											
nat_pc	-0.20	0.31	0.17	-0.34	-0.26	-0.10	-0.12	0.07	**0.51**	-0.28	-0.36
Fractionalization											
$lang$	0.27	-0.05	-0.17	0.41	0.27	0.20	0.14	-0.16	**-0.83**	0.20	**0.42**
Institutions											
$demo$	-0.27	-0.19	0.37	-0.27	**-0.54**	-0.25	0.09	0.13	-0.00	0.06	0.06
$corr$	0.09	0.20	**-0.47**	0.27	0.29	0.18	-0.11	0.04	0.03	0.17	-0.14
$check(1)$	0.39	-0.16	-0.13	0.07	0.34	0.22	0.18	-0.11	**0.53**	0.19	-0.04
$check(2)$	0.37	-0.18	-0.18	0.08	0.35	0.25	0.17	-0.09	**0.51**	0.19	-0.19
$comp$	**0.40**	-0.18	-0.24	0.15	0.33	0.33	0.20	-0.09	0.31	0.31	-0.30
$kkz96$	-0.35	0.15	**0.44**	**-0.41**	**-0.50**	0.08	0.01	-0.04	-0.25	-0.19	-0.32
exe	-0.23	-0.07	**0.43**	-0.26	**-0.46**	-0.18	-0.04	0.02	-0.01	-0.16	0.22

[+] Values of correlation greater than or equal to 0.40 are considered as significant and indicated in bold. The complete correlation matrix is available from the authors upon request.

Table A.6 Correlations between proximate and fundamental theories' proxy variables: WW countries[+]

Fundamental theories' proxies	Proximate theories' proxies										
	pop	inv	sch	$life$	$fert$	$open$	gov_c	$infl$	lac	ssa	sea
Religion											
$catholicism$	-0.16	-0.07	-0.00	0.05	-0.07	-0.09	-0.23	0.13	**0.54**	-0.22	-0.22
$hinduism$	0.06	0.00	-0.06	-0.00	0.11	-0.09	0.14	-0.02	-0.10	-0.06	**0.70**
$islam$	**0.44**	-0.11	-0.24	-0.01	0.35	0.21	0.03	-0.03	-0.23	0.07	0.17
$other$	**0.41**	-0.14	-0.28	-0.01	**0.42**	0.03	0.12	-0.01	-0.10	**0.73**	-0.00
Natural capital											
nat_w	**0.53**	-0.18	-0.34	-0.02	**0.59**	-0.03	0.17	0.06	0.13	**0.48**	0.19
nat_pc	0.27	-0.23	-0.26	-0.01	**0.50**	0.01	0.38	0.03	0.06	**0.40**	0.09
Fractionalization											
$lang$	**0.43**	-0.15	-0.20	-0.02	**0.41**	0.11	0.10	-0.03	-0.32	**0.57**	0.27
eth	**0.60**	-0.23	-0.30	-0.04	**0.61**	0.13	0.06	0.11	0.26	**0.50**	0.09
Institutions											
$demo$	**-0.60**	0.08	**0.50**	0.04	**-0.72**	-0.11	-0.08	-0.03	-0.22	-0.28	-0.08
$corr$	**0.55**	-0.20	-0.42	-0.02	**0.65**	0.12	0.08	0.08	0.28	0.32	0.02
$check(1)$	0.11	-0.09	-0.22	-0.08	0.21	0.07	-0.01	0.13	**0.50**	-0.16	0.08
$check(2)$	0.11	-0.09	-0.23	-0.08	0.22	0.08	-0.02	0.13	**0.50**	-0.17	0.02
$kkz96$	**-0.63**	0.24	**0.45**	0.03	**-0.73**	-0.06	-0.14	-0.11	-0.36	-0.38	-0.27
exe	**-0.48**	0.04	**0.47**	0.00	**-0.57**	-0.09	-0.09	-0.00	-0.11	-0.24	0.04

[+] Values of correlation greater than or equal to 0.40 are considered as significant and indicated in bold. The complete correlation matrix is available from the authors upon request.

Table A.7 BMA estimation results for average growth rate of GDP per capita regression: BC countries[+]

Theories & variables	Proximate and fundamental theories: Posterior inclusion probability	Posterior mean	Posterior standard deviation	Fundamental theories: Posterior inclusion probability	Posterior mean	Posterior standard deviation
Neoclassical						
inc		-0.072*	0.024		-0.057	0.033
pop		0.353	0.263			
inv		0.071*	0.034			
sch		-0.002	0.031			
Demography	**0.980**					
$life$		-4.365	7.676			
$fert$		-0.215*	0.071			
Macroeconomic policy	**0.999**					
$open$		0.001	0.008			
gov_c		-0.015	0.086			
$infl$		-0.012*	0.006			
Regional heterogeneity	0.089					
lac		-0.000	0.007			
ssa		-0.003	0.026			
sea		0.002	0.015			
Religion	0.264			0.524		
$buddhism$		0.001	0.012		0.029	0.059
$eastern$		0.105	0.211		0.232	0.277
$islam$		-0.064	0.131		-0.059	0.093
$protestantism$		0.007	0.051		-0.000	0.060
Natural capital	**0.999**			**1.000**		
nat_w		-0.085	0.089		-0.028	0.075
nat_pc		0.097	0.326		0.422	0.376
Geography	0.086			0.089		
$coast$		-0.004	0.032		-0.005	0.038
Fractionalization	0.624			0.189		
$lang$		0.002	0.016		0.001	0.013
eth		0.132	0.140		0.027	0.074
Institutions	0.366			**0.836**		
$kkz96$		0.008	0.026		0.085	0.050
exe		-0.003	0.006		-0.001	0.004
Others (controls)						
$period$		Yes			Yes	
Obs		208			208	

[+] A "*" indicates statistical significance of the coefficient associated with the corresponding proxy variable. The posterior inclusion probability of a theory, given in column 2 or 5, is market in bold to indicate that such a theory is relatively robust in explaining economic growth and robustness increases with this probability.

Table A.8 BMA estimation results for average growth rates of GDP per capita regression: WW countries⁺

Theories & variables	Proximate and fundamental theories: Posterior inclusion probability	Posterior mean	Posterior standard deviation	Fundamental theories: Posterior inclusion probability	Posterior mean	Posterior standard deviation
Neoclassical						
inc		-0.051*	0.008		-0.014*	0.006
pop		-0.016	0.050			
inv		0.018	0.012			
sch		-0.012	0.010			
Demography	**1.000**					
$life$		-0.006	0.024			
$fert$		-0.159*	0.025			
Macroeconomic policy	0.028					
$open$		-0.000	0.001			
gov_c		-0.000	0.013			
$infl$		-0.001	0.000			
Regional heterogeneity	0.085					
lac		0.000	0.001			
ssa		-0.002	0.010			
sea		0.000	0.002			
Religion	**0.981**			**1.000**		
$eastern$		0.288*	0.076		0.433*	0.062
$hinduism$		0.001	0.012		0.017	0.039
$islam$		0.000	0.004		-0.001	0.007
$protestantism$		-0.003	0.012		-0.003	0.012
$other$		0.001	0.013		0.000	0.011
Natural capital	0.250			0.227		
nat_w		-0.006	0.018		-0.012	0.026
nat_pc		0.000	0.000		0.000	0.000
Geography	0.056			0.035		
$coast$		-0.000	0.004		0.000	0.005
$land$		-0.001	0.006		-0.000	0.003
Fractionalization	0.056			**0.964**		
$lang$		-0.001	0.006		-0.002	0.010
eth		-0.000	0.004		-0.089*	0.031
Institutions	**1.000**			**1.000**		
$kkz96$		-0.000	0.002		0.000	0.003
exe		-0.006*	0.003		0.000	0.003
Others (controls)						
$period$		Yes			Yes	
Obs		640			640	

⁺ A "*" indicates statistical significance of the coefficient associated with the corresponding proxy variable. The posterior inclusion probability of a theory, given in column 2 or 5, is market in bold to indicate that such a theory is relatively robust in explaining economic growth and robustness increases with this probability.

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