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ADVANCES IN THE CDR ECONOMIC THEORY OF ENTREPRENEURSHIP AND GDP: FROM SURVEY OF ECONOMIC GROWTH MODELS TO UNIFIED THEORY

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Abstract

Growth models are surveyed, beginning with Malthus and ending with the capitalism, democracy, rule of law (CDR) model. Early models yielded changing parameters or did not explain all outcomes. The parsimonious CDR model is the first global time invariant cross-country model. It is the first to decouple exogenous entrepreneurial human capital of imagination and creativity from endogenous human and other capital stock. That is, the first to compute the value of ideas. These properties permit computation of the theoretical optimal growth rate, and demystification of the contemporary observed mature growth rate. It permits computation of the entrepreneurship elasticity of real gross domestic product (GDP). Based on the unitary elasticity, the theoretical optimal reinvestment in capital stock is validated by empirical gross fixed capital formation. The global macro-economic growth model is integrated with the micro-economic production function to form a unified economic growth theory. The final outcome is an economic growth model governed by scientific law and the placement of economic growth modeling on a sound scientific footing.

Keywords: CDR index; GDP; Capitalism; Democracy; Rule of Law; Entrepreneurship
JEL: E02, P16

1. INTRODUCTION

This paper examines the progress that have been accomplished in economic growth theories. For several centuries prior to the 20th, the registered historical aggregate GDP increased very slowly but steadily in most countries of the world. In the last century the average per capita GDP quadrupled to an average growth rate of 1.5% per year. We are interested to know the extent to which economic growth models explain and account for this phenomenon.

Classical economists like Smith (1776) considered capital formation from savings to be an important factor of economic growth. Ricardo (1817, 1821), another classical economist, stressed the important role played by technical progress. Sharipov (2015) summarized the principal theories of economic growth as follows:

Growth Concepts and Theories	Emerged
Mercantilism	15^{th} century
Physiocracy	2^{nd} half of 18^{th} century
Classical Theories	1776
Innovative Growth Theory of Schumpeter	1911
Keynesian Theories	1930s
Post-Keynesian (Neo-Keynesian) Theories	1950s
Neoclassical Theories and Exogenous Theory of Solow	1950s-1960s
Endogenous Growth Theory	1980s-1990s

Some modern theories have tried to explain causes occurring in the 19^{th} century that set the path for the rise in GDP during the next 100 years. The theories positively correlate population growth with economic growth and rising living standards. This was particularly the case in the United States of America (USA) and most Western European countries where standard of living has outpaced population growth. Japan, South Korea, Singapore, and Hong Kong experienced similar phenomena. In all cases institutional strength is the prevalent cause of economic success. This paper reviews the salient historical theories that have attempted to explain economic growth, including the most successful CDR model. CDR theory is a mathematical demonstration that intangible human capital ideas of imagination and creativity are converted to tangible wealth in the presence of the institutional catalysts of democracy and rule of law. While we recognize that democracy and rule of law are complex and contain many components and factors, the parsimony of the CDR model is possible because said components and factors are subsumed in democracy and rule of law. For the purpose of statistical analysis, it is not necessary to include all the already correlated elements in the model.

The remainder of the paper is organized as follows. Section 2 is an historical review of economic growth. Section 3 is a review of economic growth models. Section 4 is a review of the contributions from the CDR growth model, and extensions to identify its implications for immigration and to derive a parametric formula for the theoretical optimal growth rate. Section 5 contains conclusions and recommendations for future research.

2. HISTORICAL BACKGROUND OF ECONOMIC GROWTH

Prior to the industrial revolution, there was no sustained growth in per capita GDP. There were a few sporadic increases in living standards during the Roman Empire and in China during the Song dynasty. But there was no sustained economic growth.

Unified growth theory (Galor, 2011) has attempted to explain what 19^{th} century occurrence set some countries on a path of sustained growth. The theory suggests a fundamental change in the living standard and population growth relationship that allowed for sustained economic growth (see Figure 1). Before 1850 or thereabouts, increases in living standards appeared to lead to increases in population. Then, per the theory by Malthus (1798), population increase was followed by a fall in standard of living. However, at about 1850, England and their Western European neighbors and the USA, raised standard of living without population growth high enough to lower standard of living to previous levels. At the dawn of the 20^{th} century, standard of living rose more quickly than population. This is referred to as the demographic transition. This pattern contradicted the Malthusian population response.

That raised the following questions for which there are no obvious answers. Was technology changing more rapidly than population was capable of keeping up? Did technology lead to the family having fewer children? What can we learn about economic growth from economic history? Economic history might help identify the origins of technological and demographic changes. Unfortunately, there are only a few examples of sustainable growth and in each case there are so many factors that may have been involved. In the case of England for example, the factors may have been any, all, or none of the following: the industrial revolution, common law, the enlightenment, canals, colonies, finance, coal, steam engines, spinning jennies and in common parlance "pure dumb luck" (see also Senna, 2013).

Regardless of the reason, we are living in a unique period of sustained economic growth. The period is long enough to tell us some things that are generally true about sustained economic growth. Consider for example the relatively short period from 1870 to 2010. Here the data are more reliable. This history tells us that growth rates in the USA, England and Germany are similar. They are also persistent over time with an average annual per capita growth rate of approximately 1.8%. It is as if these countries had somethings in common. It is reasonable to say that through migratory patterns, Germany and England are the two largest ethnic populations in the USA. So, it is not surprising that these three countries share some common policy making mechanism and institutions. Diffusion of institutions from England and Germany to the rest of Western Europe is a possibility. But, not to Eastern European neighbors. There are no spillover effects from England to other countries. If there were, the spill would reach beyond just ten percent of the world. It would have spilled into Eastern Europe before spilling into Japan. Japan appears to have created its own industrial revolution. Whatever happened there appears to be similar to the more recent successes in Singapore, Hong Kong and South Korea. A likely explanation is once again institutions (North, 1991). There is no reason why institutions cannot develop separately and independently.

The growth rate of approximately 1.8% observed in the developed countries is becoming as clear as it is mysterious. For example, South Korea grew rapidly beginning in1950 but is now slowing to approximately 1.8%. At the same time that some countries experience rapid growth until they converge to 1.8%, some countries experience zero or negative growth. Learning the reason could alleviate poverty around the world.

Solow (1956) explained that economies gravitate towards a balanced growth path. That the marginal return on capital rises as the economy moves farther from the balanced growth path. Output rises rapidly when an economy is relatively poor compared to its balanced growth path, then converges back towards its balanced growth path. This process can take decades. An example is Germany after World War II. Solow explains that growth converges to a finite limit as capital is accumulated and the marginal return on capital falls. While this explanation is appealing, it is only apparent for countries that were developed and experienced a setback like war. It does not speak to the case of stubborn zero or negative growth in poor countries. Are their balanced growth paths zero or negative? Neither does Solow (1956) explain how developed countries got to be rich or where 1.8% comes from.

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Jones (1995a, 1995b) observed that the share of GDP going to research and development and the share of workers doing research and development have been increasing during the 20th century but the long-run growth rate remained constant. By all accounts, it appears that rate of growth is pinned down by the inherent speed of technological progress and technology progress is tied to population growth rate.

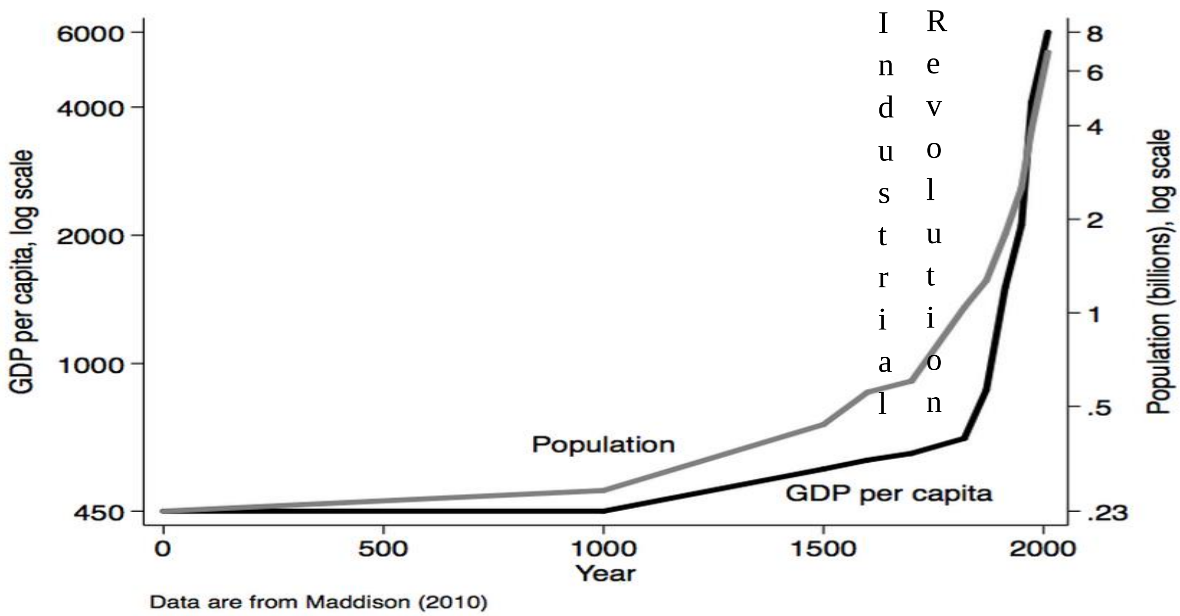

Figure 1. Global output per worker and population for 2010 years AD. For the first 1000 years both are nearly flat with no growth in per capita GDP. From 1000 to 1870, per capita GDP grew at about 0.2% annually. From 1870 to 1950, population and per capita GDP grew at about 1%. After 1950 they grew at about 1.6%.

3. CHRONONLOGICAL REVIEW OF ECONOMIC GROWTH MODELS

Models and theories of economic growth have evolved over time. From the classical to last century economists, economic growth has been attributed to different causes. Malthus (1798) was the first to propose a theory based on population explosion. He believed that inventions and higher living standards led to increases in the rate of population growth. And, population growth would lead to depletion of food and other resources. But, as growth economists go, Malthus is the dismal science advocate of neoclassical diminishing marginal property. He did not take into account that new and improved methods of farming would come to pass. It turns out that the reverse of Malthusian theory is true. Population has a positive impact on economic growth. See also Becker (1960).

Smith (1776) is associated with gain from specialization and cooperation that has indeed proved its value to growth ever since he suggested it. But it is not a complete growth model. Ricardo (1821) is associated with gain from trade. Along the way, he described labor as homogeneous. But economists went on to violate the homogeneity rule, suggesting that there exists unskilled labor with little or no growth and skilled labor, fructified with capital that is associated with higher growth.

Schumpeter (1911) initiated of the theory of economic growth. According to him, capital accumulation was not the main driving force of economic growth. He thought that economic development was due to entrepreneurial creativity and innovation. His theory is based on the assumption of private property, a competitive buyer and seller market, and efficient financial markets. Those conditions are absent in countries that lack a democratic system.

Harrod-Domar growth models (Harrod, 1939, 1948; Domar, 1946, 1957), based on Keynesian ideas of incomplete markets attempted to demonstrate the conditions for a dynamic stable full employment growth. Hahn (1987) said "Neo-classical growth theory is not a theory of history. In essence it is not even a theory of growth. Its aim is to supply an element in an eventual understanding of certain important elements in growth and to provide a way of organizing one's thoughts on these matters."

The theory presented by Lewis (1954) used the term economic development instead of growth. Lewis shared the overall vision of classical economists but did not always agree with their diagnosis and methods. His model implies enlargement of the differences between countries in the short run as a condition for equalization of income levels in the long run. Lewis's theory received theoretical support from Kuznets (1955) with the "Kuznets's Curve". The association between the dynamics of economic growth and the increasing share of urban population in the total population was the work of Kuznets.

Ramsey (1928) is also associated with modern growth theory. He attempted to find the optimal saving rate for production so as to maximize consumption. But he did not find a solution. Neither did Koopmans (1965) nor Cass (1965). Solow (1956, 1957) had better luck at solving the saving question with his neoclassical growth theory. He equated saving with population growth and postulated the capital accumulation function based on investment. Solow's adaptation of the Cobb-Douglas production is based on fixed capital. It does not include human capital ideas of imagination and creativity and must come up short when accounting for the totality of growth. The Solow growth model is stated in the aggregate, but there can be no such thing as an aggregate production function (Cohen and Harcourt, 2003, see Ridley and Ngnepieba, 2018 for a mathematical proof). There is no way around this fallacy of composition. Phelps (1961) revised it to the seemingly arbitrary golden rule rate for maximum consumption. This is a version of the marginal capital condition. Setting capital price to population rate creates some other complications. Introducing Samuelson's (1958) overlapping generations (OLG) arrangement into the neo-classical model is another possibility to solve the saving puzzle, but in the case of retirement such saving must be zero. Diamond's (1965) solution is also problematic. Romer (1986) and Benhabib and Farmer (1994) are associated with endogenous growth. They made consumption utility the specific objective of their models. Calculus was used to solve endogenous growth, but economists misapplied Pontryagin's principle (Pontryagin, et. al., 1962), arriving at inconsistent results from the golden rule (Choi, 2008). The assumption of increasing return to scale of Young's (1928) model, was confirmed by Adelman (1963). She recognized that the assumption of constant return to scale in many models raised problems. In her model, she separated natural resources from other forms of capital, similar to the way of land separation made by classical economists. She also suggested that the conceptual problems "which arise from the heterogeneity and incommensurability of the production factors may be reduced somewhat if we think of each input as a multi-component vector rather than as a single number".

Jorgenson (1963) is associated with fixed capital gain and maximum growth rate. But, rapid depreciation in fixed capital appears not to be properly factored in. This is somewhat of a setback to understanding growth. In any case fixed capital does not capture entrepreneurship that permits creation through disruption (Schumpeter, 1911, 1928, 1954). The Abramovitz (1986) model presents an explanation of differences in growth rates over the past two centuries, more illustrative than those of the early neo-classical models. Gomulka (1990) points out that technological changes have assumed the primary role because they initiate the original impulses to produce other changes that are qualitative, thereby questioning the usefulness of standard growth theory that is based on the assumption that those qualitative changes are cost free and exogenously given. Freeman (1995) makes a survey of the ideas on economic growth presented by different researchers and concludes that technical change and institutional change are the key variables to study in the explanation of economic growth. His paper makes the first tentative effort to develop a theoretical framework to explain the history of economic growth. Galor and Ashraf (2013) suggested that growth is related to genetics. That idea does not explain the difference in economic growth within genetic types such as Western Europe versus Eastern Europe; Japan versus China; Bermuda, Barbados and Trinidad and Tobago versus Haiti, Botswana versus Nigeria, etc. Even if certain limiting human characteristics or natural resources were obstacles in some nations, CDR is salutary to economic development in terms of making the best of what is possible. Choi (2016) reviewed the history of economic growth covering (i) Malthus and Population; (ii) Neoclassical economics; (iii) Endogenous growth; (iv) Real Business Cycles; (v) Savings and GDP. Over many years, various models have contributed to better understanding of economic growth. But, among these he could not find a consistent theory that successfully explains growth. In this paper we believe that it is because except for Schumpeter, these contributors do not appear to have known or understood where capital comes from. It just appears mysteriously in their discussions of growth models. They discuss build-up of capital, and production and distribution, but they do not identify the actual source of capital as human ideas of imagination and creativity (Ellis, 2018, Ridley, 2018b).

The best (measured by mean square error) model to date for explaining what is responsible for economic growth is the Ridley (2016, 2017a, 2017b, 2017c, 2018a, 2019a, 2019b) and Ridley & Khan (2019) CDR model. It is the heterodox model that shows that the way capital is converted to GDP is the same all over the world. That is, it is governed by technology which is governed by the laws of natural science. And, the way to increase growth is to attract more capital. The source of capital is the ineffable human ideas of imagination and creativity. The way to attract capital is to implement guarantees of rule of law. That is, corruption must be reduced (Ridley and de Silva, 2019). Then democracy must be implemented such that capital can be deployed optimally. However, since the only source of wealth is the human mind, growth is ultimately tied to population growth rate. That is, each child brings its own wealth into the world (Simon, 1981). A child is not a liability, it is an asset. The CDR model is reviewed in greater detail in the following section on this contemporary growth model.

4. THE CONTEMPORARY CDR GROWTH MODEL

This paper extends the utility of the CDR model. In addition to a review of the contributions of the CDR model to understanding economic growth theory, it goes further to identify its implications for immigration; and to derive a parametric formula for the theoretical optimal growth rate.

The CDR growth model was created in the search for a model that accounts for the annual contribution to GDP. The objective was to create an index that can be used to calculate GDP for any year. To accomplish that the model was defined as CDR: $g=f(C,D,R)$, where all variables are standardized by linear transformation to ensure lower and upper bounds of 0 and 1. Then, GDP in any year can be estimated for any country by inverse transformation when the highest and lowest GDP are known for the year, hence the appellation "CDR index." The CDR index is based on published country market capitalization, ranking in democracy, and ranking in corruption (Goel, Mazhar and Nelson, 2016, Czap and Nur-tegin, 2012, see also Couttenier and Toubal, 2017, López, et. al., 2017, Ogun, 2018). The CDR variables are specific to this model and are defined as follows:

Definitions:

Entrepreneurship *is the process of starting a business, typically a start-up company offering an innovative product, process or service.*

Capitalist *is a person who deploys his or her personal capital so as to maximize his or her own benefit and includes all rational people.*

Real gross domestic product adjusted for purchasing power parity (G) *is the net product or value added that equates to standard of living.*

Capitalism (C) *is the mechanism for the collection and assembly of capital, measured by total market capitalization that reflects entrepreneurship capital and capital stock.*

Democracy (D) *is the private work force idea participation and periodic election of public representatives, and catalyst for the process of generating G from C.*

Rule of law (R) *is the reverse of corruption, the protection of shareholder and other property rights, and catalyst for the attraction of C.*

> ***Corruption*** *is the abuse of entrusted power for private gain and can be classified as grand, petty and political, depending on the amounts of money lost and the sector where it occurs.*
>
> ***Property (rights)*** *is a legal expression of an economically meaningful consensus by people about assets, how they should be held, used and exchanged.*

The value of creativity has been long recognized (Lotto, 2017). There are various tests for content knowledge, skill, aptitude and intelligence quotient. But there is no test for imagination and creativity. Still, we know it when we see it. CDR theory is the first ever to compute the contribution of *C*, *D*, *R* and their interaction to GDP. It is also the first to compute the entrepreneurial contributions of imagination and creativity. In the CDR model, *R* attracts *C* and *D* creates new pathways for the optimal deployment of *C* in the *C* to GDP conversion process. Surowiecki (2005) explains how the wisdom of crowds can yield a superior decision compared to that of any one member, even when that member is a superior individual.

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Ridley (2016) and Ridley, Davis and Korovyakovskaya (2017) were the first to identify the potential for GDP to be explained by CDR (see also Korovyakovskaya and Ridley (2017) on entrepreneurship). Ridley (2017a) gave a qualitative explanation of how the only source of wealth is the human idea of imagination and creativity. Just as Smith (1776) proposed that division of labor creates surplus capital, Ridley (2017b) explained how division of human capital creates surplus wealth. It is also a didactic account of the bauxite resources curse and how it cost Jamaica its currency (see also Auty, 1993, Frankel, 2012, Humphreys, 2005, Norman 2009, Peach and Starbuck, 2011, Sachs and Warner, 2001, Sala-i-Martin and Subramanian, 2003, Wadho, 2014, van der Ploeg, 2011).

Ridley (2017c) explored how Friedman's (1980, 2002) negative income tax proposal can be implemented to include work and supply side innovation from the bottom up. This is conditional on the understanding that the source of wealth comes from the mind regardless of one's position in the corporate hierarchy. No longer is it necessary to think of vanguards who take care of rearguards via taxation and social welfare payments. All people can contribute in one way or another in return for living or better wages. Ridley and Khan (2019) was a brief mathematical presentation of a model for decoupling exogenous capital from endogenous capital. That was the first time that such quantitative decoupling of capital was performed. It was also the first time that an estimated value was computed for ideas. This value of ideas was equated to entrepreneurship capital versus capital stock. There, entrepreneurship capital was found to contribute six times as much to GDP as capital stock. That is, $6/7^{th}$ or approximately 85% of GDP. This is quite surprising until one considers that capital stock is continuously depreciating or on its way to obsolescence. See also V101 Science (2013, 2106) and SPHSGeog (2015) for a visual depiction of the speed of global depreciation in the absence of human beings, maintenance and reinvestment.

Ridley (2019a) is an ordinary least squares (OLS) exposition on the genesis of wealth, the negligible importance of natural resources, geography, population characteristics, government spending, and the high importance of the human brain as the true natural resource (see Appendix A), and the play on the words of Adam Smith "an inquiry into the nature and causes of the wealth of states" where Laffer, et. al. (2014) compiled American data on the impact of state taxes on the economic growth and movement of people between states. Their data showed that states that tax and spend more exhibit less growth). This suggests that poor countries turn their focus from bemoaning their lack of natural resources and geography that they cannot change to raising their CDR index. The resource differences due to geography recognized by Diamond (1999) can be eliminated by trading. Bear in mind the massive growth and philanthropy from the digital high technology industries (IBM, Google, Facebook, Intel, Amazon, Microsoft, Apple, etc.) that are unrelated to natural resources (Garten, 2016, Gordon, 2016). Technology has created far more wealth than the world of forced labor where human capital is actually destroyed. Ridley (2019b) presented a consistent unbiased 2SLS CDR model for year 2014 data and 79 countries representing nearly all the people in the world for which data are available. It showed that the CDR model is global invariant (see Appendix B). It established the CDR hypothesis and presented an exposition on the information theory of entrepreneurship (see Appendix C). Ridley (2018a) expanded Ridley (2019a, 2019b) to create the entrepreneurship elasticity of gdp (see Appendix D). It also repeated the Ridley (2019b) year 2014 CDR model for years 1995 to 2016. It showed that the CDR model is the same for all years in 1995 to 2016 for which data are available. It thereby demonstrated that the CDR model is not only global invariant but is also time invariant. That is, global time invariant (see Appendix E).

The avant-garde CDR model is iconoclastic in the sense that it moves the source of wealth from the factory backwards to an earlier point in time when the human ideas of imagination and creativity occur. One of those ideas is indeed said factory itself. A production function can only relate physical units of inputs to physical units of outputs from a single machine. That is, there is no such thing as a macroeconomic production function when the inputs are different types of items, or outputs are different types of items, or outputs are made by different constructs. Furthermore, there is the fallacy of composition that we can simply jump from microeconomic conceptions to an understanding of production by society as a whole (Cohen and Harcourt, 2003, Ridley and Ngnepieba, 2018). The CDR model does not challenge the role of the factory as a unit of production. Nor does it challenge the role of the production function. Indeed, the CDR growth model is complementary to the production function and places economic growth theory on a sound scientific footing. See Appendix F for a unified theory for integrating the macro-economic CDR growth model into the micro-economic production function.

Ridley (2018b), Llaugel and Ridley (2018) and Ngnepieba, et. al. (2018) were the first to suggest a way for introducing economics students to CDR growth economics human ideas of imagination and creativity as the source of wealth. A student from a formerly oppressed community who is only told that wealth is created at a factory where goods are produced and subsequently distributed, exchanged and consumed might be inclined to see that as an activity of the rich and not see themselves in that picture. The student is asked to believe that the factory just exists somehow (Sowell, 2015 objects to this typical introduction). But a student who understands that the sole source of wealth is human ideas of imagination and creativity, may see him or herself as a potential entrepreneur. At a minimum, he or she will see him or herself as a partner in the entrepreneurial community. An entrepreneurial community is required for the success of entrepreneurs, communities and nations.

Discussion

Annual GDP is a one-year contribution to economic growth. The data analyzed in the CDR model are annual. The time from market capital acquisition to investment in the economy is approximately six months. It is encompassed inside one year. Therefore, there is no need to model multiple years to observe the impact from *C*. Still, the CDR model was re-estimated for several years to investigate this, and as it turned out established its time invariance. The $g=f(C, D, R)$ exits in four dimensions of which time is not one. In passing, we note that the CDR model can be used as a forecasting model. Global time invariance permits the estimation of *G* for any year in which country *C, D* and *R*, and the highest and lowest values of *G* amongst all countries are known for the forecast year. This can be the basis for the partial construction of a forecast for *G*. Forecasts for *C, D* and *R* must be made independently of *G* (Ridley, 2018c).

CDR theory is a mathematical demonstration of how the source of wealth is the ineffable human ideas of imagination and creativity and was the first to actually calculate the value of ideas. Low CDR countries are where ideas go to die. It is clear that low CDR countries must raise their CDR if they are to have any chance of economic growth. However, this is easier said than done when corrupt leadership is entrenched. At the time of this writing, South Korea is hosting the 2018 winter Olympics. Fifty years earlier South Korea experienced severe poverty. After the adoption of democracy, it is a country that poor countries can model themselves after. Meanwhile, right next door, North Korea continues to languish in poverty while nursing its position on corruption and anti-democracy. The cost of corruption is to corrode the fabric of society, undermine people's trust in political and economic systems, institutions and leaders and can cost people their freedom, health, money – and sometimes their lives. Transparency is a means for shedding light on shady deals, weak enforcement of rules and other illicit practices that undermine good governments, ethical businesses and society at large. Sir John James Cowperthwaite, a disciple of Adam Smith introduced to Hong Kong in experimental fashion, Smiths' principle of peace, easy taxes and tolerable administration of Justice. The rest as we say is history as Hong Kong like South Korea climb the economic growth ladder. The principle is embedded in the CDR model of capitalism, democracy and rule of law.

It is difficult to build reliable institutions of rule of law and democracy. The further behind a low CDR country is in the human capital stock component: science technology engineering and mathematics (STEM), the more it needs to catch up via education. But CDR theory shows that entrepreneurship human capital ideas of imagination and creativity contribute six times as much as all capital stock contributes to G. And, capital stock depreciates in about three generations (Taylor, 2018). So, long term growth is dependent on entrepreneurship capital. That is, a country needs both entrepreneurship capital and capital stock, and entrepreneurship requires democracy and rule of law. And, we now know that the optimal reinvestment of G in capital stock is about 21%. That is, STEM education is a necessary but not sufficient requirement for economic growth. On the other hand, CDR is necessary and sufficient.

Gilder (2103) believes that low entropy or low noise systems of predictable government, rule of law, property rights, etc., require great acts of heroism to enact. For example, sacrificial army and police, and inspired leadership are needed to permit the relatively high noise entrepreneurial inventions to pass into society. But, could it be that capitalism, democracy and rule of law are themselves also inventions. Therefore, just as known inventions can be taught through formal education, capitalism, democracy and rule of law can be learned through formal education, without the sacrifice of life and limb. Maybe it is a sacrifice only in the sense of being a labor of love?

The component of rule of law that is known as property rights is more difficult. Property rights are a legal expression of an economically meaningful consensus by people about assets, how they should be held, used and exchanged. Ninety percent of the countries of the world have no property rights for the common man (de Soto, 2000). Given modern satellite systems it should be that property can be surveyed rapidly. But, once surveyed the occupants and presumed owners of land must agree on the suggested boundaries before meaningful titles can be filed. Property is what Western Europeans and North Americans use as collateral to borrow money. Money in turn is invested in entrepreneurship. Mortgaging a home asset is a popular method used by entrepreneurs. Their mechanism for property rights was not a clean process and involved numerous fights, physical and legal. There was no and there is no manual for the acquisition of property rights that can be shared with undeveloped countries.

The natural effort of every individual to better his own condition...is so powerful, that it is alone, and without any assistance, not only capable of carrying on the society to wealth and prosperity, but of surmounting a hundred impertinent obstructions with which the folly of human laws too often encumbers its operations (Smith, 1776). This principle is embedded in the concept of democracy. For more on the potential of institutional economics for the purpose of raising *D* and *R* see Hamilton, 1919, North, 1991, Acemoglu, Johnson and Robinson, 2005 and Gilder, 2012, 2013, 2016. For future research on institutional design see Koltai and Muspratt, 2017, Acs, et. al, 2016, Feldman, 2014, van Praag and van Stel, 2013, van Hornel, et. al., 2017, Nurunnabi, 2017.

Implications for immigration

CDR is global time invariant. *C* is the sum of entrepreneurship capital(C_e), fixed capital stock(C_k), and trained knowledge stock(C_t). That is, $C=C_e+C_k+C_t$. Compared to other countries, American *C* is relatively very high. The reason is because American *R* is relatively very high. A poorly educated immigrant to America can bring their corporeal labor (*L*) plus their C_e and make contributions of measurable value. As that immigrant acquires C_t they can move up the skills and pay ladder to make larger contributions. Should that immigrant choose to avail themselves of educational opportunities, as they acquire C_t, they can make even greater contributions. A citizen from anywhere in the world will bring their human capital that is the same as that of an American born citizen of comparable education and training. The same immigrant that was unable to contribute in the old country, when allowed to function under American CDR, will add the same amount to GDP as their American born counterpart. Said GDP will not only add to the American economy, it will add to the economy of the world via America. A similar rise in world average GDP would increase if the CDR index of the old country were raised. An increase in CDR anywhere in the world raises the world's average GDP. There is no resulting contemporaneous reduction in GDP anywhere. Kane and Rutledge (2019) studied the effect of the immigration and economic performance from 1980-2015 in the USA. They concluded that although analysis by region and time reveals some differences in results, the overall correlation between immigration and performance variables is positive. Empirical finding by Altonji and Card (1991) indicate a modest degree of competition between immigrants and less-skilled natives.

Parametric derivation of the theoretical statistical expected endogenous contribution to g

The first estimate of the CDR model included not only *C*, *D* and *R* but also natural resources (*N*). The research began with the notion that *N* was very important. It turned out that *N* contributed only 6% to GDP making it much less important than ordinarily considered to be. Furthermore, a purpose of CDR is to determine national policy regarding what can be done to raise GDP, and *N* cannot occur by policy. Therefore, *N* can be dropped from the model without loss of generality. Still, the following parametric derivation of the theoretical optimal endogenous contribution of g includes *N* for purpose of accuracy in accounting.

From appendix A and appendix B, the CDR statistical model for GDP is

$$g = \beta_0 + \beta_C C + \beta_D D + \beta_R R + \beta_{CDR} C \cdot D \cdot R + \beta_N N + \varepsilon$$

where all variables are standardized by linear transformation to ensure upper and lower bounds on $0 \leq g, C, D, R, CDR, N \leq 1$. Democracy and corruption are rank ordered, where the highest = 1 and the lowest = the number of countries. Note that N can be dropped for policy making, leaving just CDR.

The estimated OLS model is

$$\hat{g}_i = \mathbf{1.53}C_i + 0.14D_i + 0.23R_i - 1.21C_i \cdot D_i \cdot R_i + 0.38N_i.$$

Using latitude measured in L_i units as the instrument for purging endogenous capital from C_i (latitude is correlated with C_i and uncorrelated with ε_i and obviously exogenous since GDP cannot influence latitude),

$$\hat{C}_i = 0.04 - 0.07L_i - 0.16D_i + 0.22R_i + 1.11C_i \cdot D_i \cdot R_i - 0.02N_i.$$

The estimated 2nd stage least squares model for estimating g from exogenous new idea human capital entrepreneurship ($\hat{C}_i$) is

$$\hat{g}_i = \mathbf{1.30}\hat{C}_i + 0.12D_i + 0.28R_i - 0.98\hat{C}_i \cdot D_i \cdot R_i + 0.39N_i.$$

The CDR model is designed to get at what a country can do to raise its g, not an accurate computation of average world g. C does not include non-publicly traded private market capital. Those data are not available and will never be available. Still, let us see what CDR predicts for annual g. All the variables in the CDR model are based on per unit values. Therefore, the regression coefficients are the contribution to $\hat{g}_i$ per unit. So, the purely endogenous contribution to g is the expected value of the contribution from the endogenous capital ($C_i - \hat{C}_i$) plus the unbiased 2SLS contributions from $D_i, R_i, \hat{C}_i \cdot D_i \cdot R_i, N_i$ converted to endogenous g via the dot product with the unbiased regression coefficients.

That is, expected endogenous contribution to g = $(1/2)(\hat{\beta}_0 + (\hat{\beta}_C - \hat{\beta}_{\hat{C}}) + \hat{\beta}_D + \hat{\beta}_R + \hat{\beta}_{\hat{C}DR} + \hat{\beta}_N)$, where (1/2) is the mean of the range [0,1]. When calculated from the original regression coefficients prior to rounding, $\hat{\beta}_C = \mathbf{1.534346}$ and $\hat{g}_i = -0.00051 + \mathbf{1.295617}\hat{C}_i + 0.116963D_i + 0.275395R_i - 0.98133\hat{C}_i \cdot D_i \cdot R_i + 0.388146N_i$.

Expected endogenous contribution to g = (1/2)(-0.00051 +(**1.534346-1.295617**)+0.116963+0.275395-0.98133+0.388146) per unit
=0.018698 per unit
≃ 1.8%.

We mention in passing an interesting observation that this equates to $\frac{1}{4}e^2$, where e is the Napier's constant (Euler's number) and base for the natural logarithm. While some countries might grow faster than 1.8% others will grow slower than 1.8%. As it turns out this theoretical 1.8% is numerically equal to what economists have observed empirically as the steady state rate to which countries converge as they develop. The developed country per capita g dominance of the world might explain the world proximity to 1.8%. The standard deviation of $\hat{g}_i$, $\sigma_{\hat{g}_i}$=0.208513 per unit. The standard deviation of the mean of g, $\sigma_{\bar{g}_i}$=0.208513/$\sqrt{79}$=0.02346≃ 2.3%. We know from the plots of the residuals $\hat{\varepsilon}_i$ versus $\hat{g}_i$ from the regression, their histogram and a chi square goodness of fit test that they are approximately random and normally distributed

(Appendix A, Figure 2, Figure 3a and 3b). Therefore, the 95% confidence interval (CI) for the estimate of mean contribution to g,

$$CI = 1.8+/-(z\sigma_{\bar{g}_i})\% = 1.8+/-(1.96x2.3)\% = \{-2.7\%, 6.3\%\}.$$

As best we can tell this derivation of annual endogenous contribution to g explains the previously observed but unexplained 1.8% and brings that mystery to an end. This statistical account is not a scientific explanation per say. But one might speculate that the contribution to g is matched to the contribution from human population. That is, each child brings its own wealth into the world. A child is an asset not a liability. Furthermore, the child's discoveries that are exogenous entrepreneurial capital can add to the endogenous contribution of 1.8%.

The foregoing endogenous analysis clears up one of the many mysteries of economics. Price is an item of information that tells consumers how much to purchase and tells suppliers how much to produce (Friedman and Friedman, 1980). It promotes the efficient use of society's resources. Any attempt to interfere with free market prices distorts said information. It is easy to confuse this price with the observed sticker price that appears on products. Rising sticker prices create the illusion that immediate purchases save money. This is bolstered by the impression of rising value reflected in higher prices. Falling sticker prices create the illusion that delayed purchases save money, even though value is being foregone. That is, even though the purchaser must postpone access to the utility of the product. But the true price of a product is the price per unit of value due to the power of its features. Quite often these features are technological. But their source is always human ideas of imagination and creativity. For example, a motor car today that is associated with the common man contains features that previously were only found in the best cars. Although the car sticker price has risen, the price per feature has fallen. Another example is the personal computer that contains features that were once the sole domain of past supercomputers. The example of the computer is special since its sticker price has fallen while the features have risen! This phenomenon began with the industrial revolution and has continued ever since. That is, effective price deflation has been occurring ever since the industrial revolution. Each unit of deflation is the result of a human idea of imagination and creativity. Such entrepreneurship capital has routinely increased the size of the economy beyond the endogenous contribution.

5. CONCLUSIONS

The history of economic growth models was reviewed beginning with Malthus (1798) and ending with the CDR model. We started with Malthus because his model was so rudimentary and limiting, least promising, with no resemblance to reality. It could easily be eliminated from further consideration as explanatory growth model. Smith's (1776) division of labor was contemporaneous with Malthus (1798). But, while not a model per say, it was expansive and a good explanation of the success of what were to become rich nations. The documented contributions from each model were then considered, including their shortcomings, leading finally to the astonishingly good statistical properties of the parsimonious CDR model. The CDR model gives us the basis for a unified theory for integrating the macro-economic CDR growth model into the micro-economic Cobb-Douglas production function. That is, a homeomorphic mapping from intangible aggregate macro-economic space into tangible micro-economic production spaces.

This paper went further to calculate mean annual growth rate from the coefficients of the CDR model. That calculation estimated a 95% confidence interval that included the observed 1.8% for developed countries that was heretofore unexplained. This serves as one empirical validation of the CDR model. Another was the previous computation of CDR theoretical optimal reinvestment in capital stock (Ridley, 2019b) that is validated by observed empirical gross fixed capital formation of approximately 21%. Another was the previous validation and the global time invariant property of the CDR model (Ridley, 2019b). These validations of the CDR model place economic growth theory on a sound scientific footing by way of the CDR law.

We have seen from the global time invariant CDR model that the way in which capital is converted to gross domestic product adjusted for purchasing power parity is a universal constant. The only explanation that we offer is that after adjusting for country factors of productivity, said capital is converted in accordance with the physical and chemical laws of the natural sciences. But the CDR model also includes the catalysts democracy and rule of law. Without these catalysts, the capital attraction and conversion processes are so slow as to be negligible. Low CDR countries are where ideas go to die. With these catalysts the capital attraction and conversion to GDP processes occur at a superior rate. Like capital, the coefficients of democracy, rule of law and interaction variables are global time invariant. The only explanation that we offer is that economic catalysis by democracy and rule of law function the same way across the world. We do not know the basic science that is involved. A suggestion for future research is that which is aimed at discovering this basic science. Suffice it to say that it is likely a natural psychological science that connects people, irrespective of location and culture. While it may be the case that increased economic freedom has resulted in some improvement in the economies of poor countries, they do remain impecunious. The reason is that their efforts to improve democracy and rule of law are perfunctory at best.

The time for recriminations regarding prior mercantilism, colonialism and imperialism has passed. Even if rich countries benefited from such activities, they would have been even better off earlier than now had they pursued higher CDR instead. Future research should be on how poor countries can raise their CDR rather than debate questions about geography and natural resources that cannot be changed. Surely, the effect on distance by modern sea and air transportation if not its annihilation altogether by the internet for purpose of communication, should have mitigated geography. This is as far as science can take us (Ball, 2012). But it hasn't for the poor. How can we raise the estates of the least among us? While this is beyond the scope of this paper, it was determined that the GDP of Singapore is astonishingly high. It is also the case that Singapore implemented a bonus pay system for government leaders and workers that is tied to economic performance. Future research can investigate whether or not there is a relationship between their bonus pay system and their CDR index, and ultimately their GDP.

APPENDICES

For convenience, the following appendices are reconstructed here from prior CDR publications.

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Appendix A: The Global Invariant CDR model

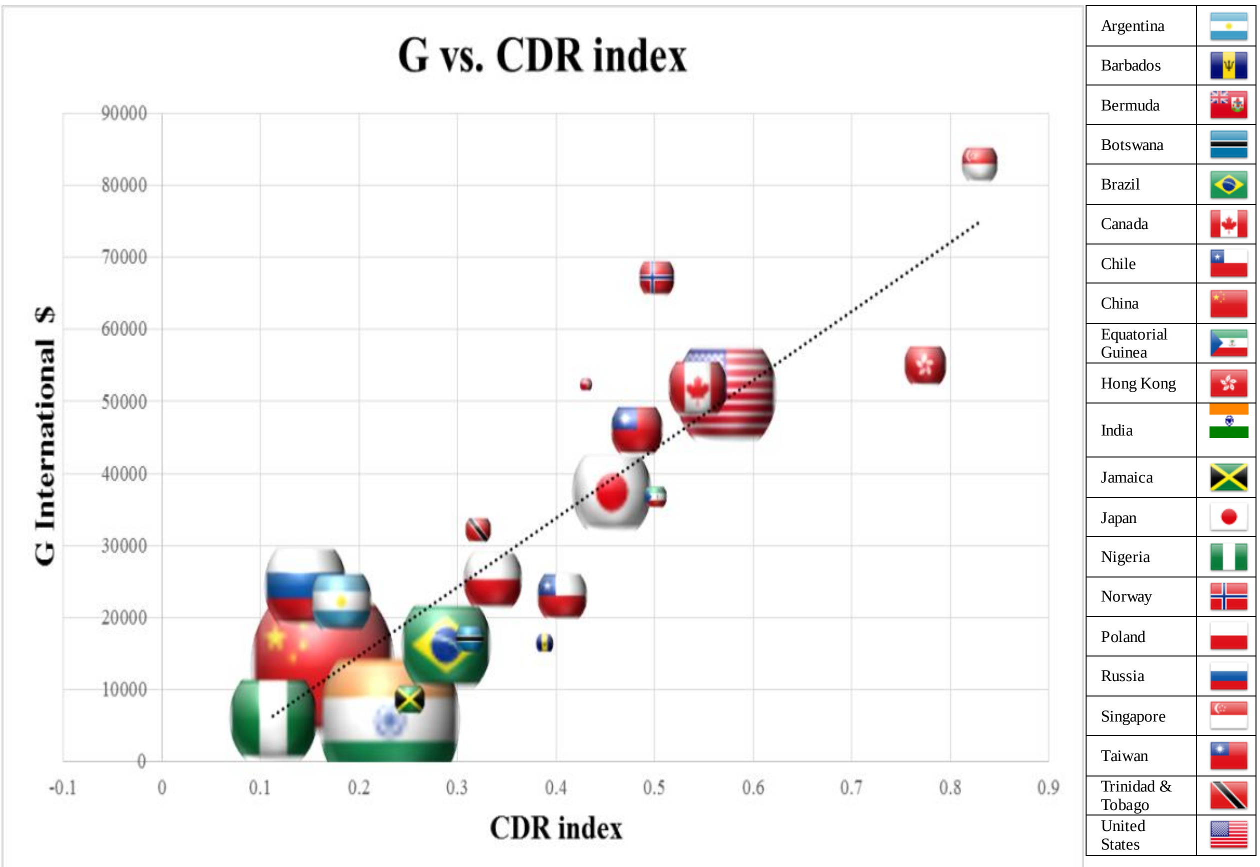

Figure 2. Vexillological chart of year 2014 G vs CDR Index for 79 countries (line). Bubble size (21 countries) is the square root of population. This model was re-estimated for years 1995 to 2016 with similar results. For additional comments on the countries listed see Ridley (2017a, 2017b).

Standardized g model

The ordinary least squares *g* model is specified as follows:

$$g = \beta_0 + \beta_C C + \beta_D D + \beta_R R + \beta_{CDR} C \cdot D \cdot R + \beta_N N + \varepsilon$$

where, the intercept β_0 and the coefficients β_C,β_D, β_R, β_{CDR},β_N are all dimensionless, ε is a random, normally distributed error with a mean of zero and constant standard deviation, and where all model variables are standardized as follows:

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g	$= \frac{G - \text{lowest } G}{\text{highest } G - \text{lowest } G}$
G	= per capita real gross domestic product per capita (PPP) *(Change in per capita wealth=G less consumption, depreciation and obsolescence)*
C(Capitalism)	$= \frac{\text{per capita capitalization} - \text{lowest per capita capitalization}}{\text{highest per capita capitalization} - \text{lowest per capita capitalization}}$
D(Democracy)	$= \frac{\text{lowest democracy rank} - \text{democracy rank}}{\text{lowest democracy rank} - \text{highest democracy rank}}$
R(Rule of law)	$= \frac{\text{lowest corruption rank} - \text{corruption rank}}{\text{lowest corruption rank} - \text{highest corruption rank}}$
N(Natural resources)	$= \frac{\text{per capita total natural resource rents} - \text{lowest per capita total natural resource rents}}{\text{highest per capita total natural resource rents} - \text{lowest per capita total natural resource rents}}$

These transformations standardize the variables and ensures upper and lower bounds on $0 \leq g, C, D, R, CDR, N \leq 1$.
Democracy and corruption are rank ordered, where the highest = 1 and the lowest = the number of countries. *G* is measured in $/capita/year. (click here for data)

$\hat{g}$= 1.53C + 0.14D + 0.23R - 1.21C·D·R + 0.38N

t= (6.60) (1.69) (2.60) (4.40) (5.59) F ratio = 81.

Partial correlations (contributions to R^2_{adj}*):*

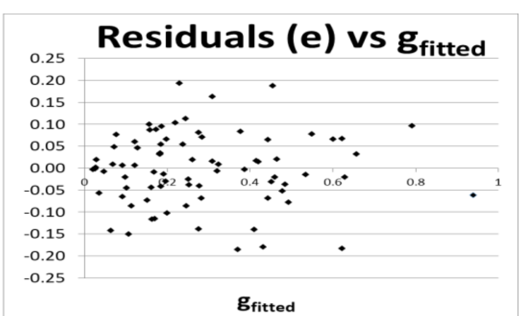
59% 5% 10% 3% 6% R^2_{adj} = 83%.

where ^ denotes estimated or fitted value and *G* can be estimated from

$\hat{G} = \hat{g}$ (highest *G*-lowest *G*) + lowest *G*.

*H*ighest *G*=83,066. Lowest *G*=1,112.

The CDRindex = 1.53C + 0.14D + 0.23R - 1.21C·D·R comprises positive C, D and R effects and a negative component due to friction from democracy that reduces G from what it might otherwise be if there were perfect agreement amongst decision contributors. The contribution from N is negligible and can be dropped from the model since it is not a decision variable that is under the control of government.



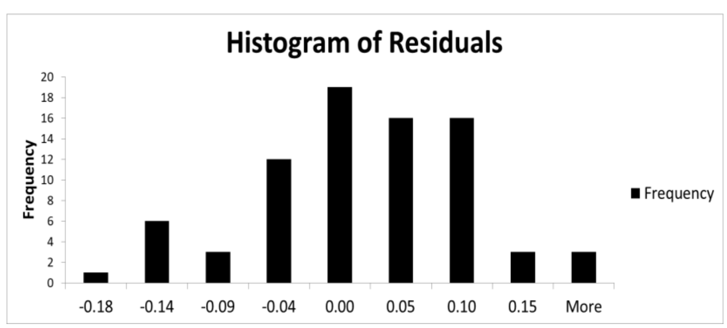


Figure 3a. Plot of residual vs. fitted values of *g*. Figure 3b. Histogram of residuals

Remark1: Przeworski and Limongi (1993) reviewed 18 studies on various data samples ranging from 1949 to 1992 on the question of democracy and economic growth (see Adelman and

Morris, 1967, Dick, 1974, Huntington and Dominguez, 1975, Weede, 1983, Kormendi and Meguire, 1985, Kohli, 1986, Landau, 1986, Sloan and Tedin, 1987, Marsh, 1988, Pourgerami, 1988, Scully, 1988, 1992, Barro, 1989, Grier and Tullock, 1989, Remmer, 1990, Pourgerami, 1991, Helliwell, 1992). The findings were split equally between yes and no, and no findings at all (see Barro (1996), Przeworski and Limongi (1997) for more on democracy). Therefore, the conclusion of the review was that the answer was as yet unknown. Here, we uncover and clear up the reason for the confusion by presenting a statistical cross-country regression model that includes both a positive democracy term and a negative interaction term that contains democracy. The signs are easily explained as a positive democracy effect and negative friction between capitalism, democracy, and rule of law, where all three make significant contributions to explaining G. Since D and R are exogenous catalysts, beyond the comprehensive interaction of interest: C·D·R, other than minor spurious statistical effects, possible subsidiary interaction effects C·D, C·R and D·R are meaningless and irrelevant.

Remark2: The direction of causation is obviously from *D and R* to *G*. Furthermore, *D* and *R* reflect economic freedom, and Gwartney, Holcombe and Lawson (2004, 2006) used Granger (1969) testing to show the direction of causation to be from and economic freedom of the world (EFW) to GDP. *R* is the exogenous catalyst of governance that recognizes property rights and discourages corruption (Goel, Mazhar and Nelson, 2016, Czap and Nur-tegin, 2012). The reverse of corruption was chosen to represent *R*. It is a ranking of countries. *R* encompasses property rights, an important feature for economic growth (McCloud and Kumbhakar, 2012).

Remark3: Economic freedom advocated by Friedman and Friedman, 1980, Friedman, 2002, Gwartney, Holcombe and Lawson, 1999, Gwartney and Lawson 2003, Heritage Foundation, 1995-2016, Sowell, 2015, Rand, 1961, reduced government, and increased empowerment of people, are consistent with the CDR model. Economic freedom appears to be working in favor of GDP (Gwartney, Lawson and Hall, 2015).

Appendix B: New human capital versus old capital stock from prior human capital

The OLS model is

$$g_i = \beta_0 + \beta_c C_i + \beta_d D_i + \beta_r R_i + \beta_{cdr} C_i \cdot D_i \cdot R_i + \beta_n N_i + \varepsilon_i,$$

$$\hat{g}_i = \mathbf{1.53}C_i + 0.14D_i + 0.23R_i - 1.21C_i \cdot D_i \cdot R_i + 0.38N_i.$$

$|t|$ = (6.6) (1.69) (2.60) (4.40) (5.59) R^2_{adj}=0.83

Endogeneity due to capital stock within C may bias the estimates of the $\beta's$. To guard against that, a consistent 2SLS estimate of β_C can be obtained. Consider latitude (absolute distance from the equator (L_i)) as an instrumental variable (IV) for C to purge it of endogenous capital stock (see also La Porta,1999). We assume that this IV is uncorrelated with the errors in the OLS model. It turns out that L_i is statistically significant (*t*=3.77). The significant estimated 1st stage least squares regression that includes L_i is

$$\hat{C}_i = 0.04 - 0.07L_i - 0.16D_i + 0.22R_i + 1.11C_i \cdot D_i \cdot R_i - 0.02N_i.$$

$|t|$ = (3.20) (3.77) (4.64) (6.43) (27.11) (0.61) R^2_{adj}=0.94

The estimated 2nd stage least squares regression for estimating g from exogenous $\hat{C}_i$ is

$$\hat{g}_i = \mathbf{1.30}\hat{C}_i + 0.12D_i + 0.28R_i - 0.98\hat{C}_i \cdot D_i \cdot R_i + 0.39N_i.$$

$|t| =$ (2.66) (0.88) (1.95) (1.88) (4.45) R^2_{adj}=0.74

Appendix C: Entrepreneurship: information theory of economics

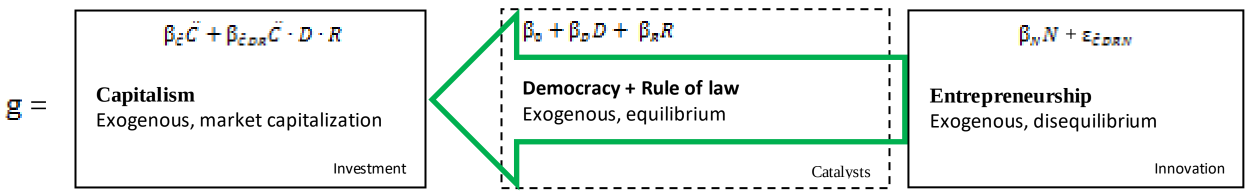


Figure 4. Conversion of exogenous innovation $\hat{C}$ to g through a DR channel.

Capital is typically converted via a production process into products and services. R is necessary to attract $\hat{C}$ and D is necessary to create additional pathways that deploy $\hat{C}$ effectively. New ideas appear to us as quanta of information that must be detected and acted on (Gilder, 2013, Romer, 1990, Lucas, 1988). But, a low D, low R high noise environment blocks exogenous innovative $\hat{C}$. A high D, high R low noise environment is required for the detection of human entrepreneurial ideas. Sometimes it is the people who no one imagines anything of, that do the things that no one can imagine (Moore, 2014). Heterogeneous exogenous catalysts D and R are government variables that provide positive social equilibrium effects. Heterogeneous variables do not change their form. Exogenous variables are external to the process, do not get used up, and at the end of process are ready for reuse as before. Catalysts do not take part in the process (Berzelius, 1835). The process by which exogenous innovative $\hat{C}$ is converted to products is depicted in Figure 4. The variable g is the standardized version of G used to estimate the CDR model.

Appendix D: Entrepreneurship capital elasticity of g

Consider the scenario where a fraction f_i of $\hat{g}_i$ is reinvested in capital stock, such that

$$\hat{g}_i = 1.3(\hat{C}_i + f_i\hat{g}_i) + 0.12D_i + 0.28R_i - 0.98(\hat{C}_i + f_i\hat{g}_i) \cdot D_i \cdot R_i.$$

Then,

$$(1 - 1.3f_i + 0.98f_i \cdot D_i \cdot R_i)\hat{g}_i = 1.3\hat{C}_i + 0.12D_i + 0.28R_i - 0.98\hat{C}_i \cdot D_i \cdot R_i,$$

$$\hat{g}_i = (1.3\hat{C}_i + 0.12D_i + 0.28R_i - 0.98\hat{C}_i \cdot D_i \cdot R_i)/(1 - 1.3f_i + 0.98f_i \cdot D_i \cdot R_i)$$

and the marginal return on entrepreneurial capital ($\hat{C}_i$) is

$$\partial E[\hat{g}_i]/\partial\hat{C}_i = (1.3 - 0.98D_i \cdot R_i)/(1 - 1.3f_i + 0.98f_i \cdot D_i \cdot R_i).$$

The entrepreneurial capital ($\hat{C}$) elasticity of g is defined from the percentage change in g in response to a 1% change in $\hat{C}$, ceteris paribus. This point elasticity can be investigated directly from the marginal return on $\hat{C}$. That is, from

$$(\hat{C}_i/\hat{g}_i)\partial E[\hat{g}_i]/\partial \hat{C}_i = \frac{\hat{C}_i(1.3+0.98D_iR_i)(1-1.3f_i-0.98f_iD_iR_i)}{(1-1.3f_i-0.98f_iD_iR_i)(1.3\hat{C}_i+0.12D_i+0.28R_i+0.98\hat{C}_iD_iR_i)}.$$

From figure 5, in general, as *D* and *R* increase, the elasticity of g falls. When there is no reinvestment (*f*=0), g is always inelastic. As the reinvestment fraction increases to *f*=0.1 and 0.2, the elasticity increases. If a unitary elasticity of 1.0 can be obtained for some combination of these variables, such that g is maximum, then the policy suggested is to reinvest about 10% when *D* and *R* are between 0 and 0.5. As *D* and *R* increase from 0.5 to 0.9, increase the fraction of reinvestment in like manner to about 20%. As *D* and *R* increase from 0.9 to 1.0, the fraction of reinvestment should be increased to about 25%. Assuming uniform distribution across countries, the average is about 10%+(25-10)%x0.5=17.5%. Adding 3.5% for depreciation and obsolescence brings this number up to 21%. This is consistent with the World Bank report of 21% for year 2014 worldwide average gross fixed capital formation (GFCF). GFCF does not include book value recovery of depreciation for tax purposes, but it does include actual replacements. Neither one of these includes capital stock investment in training to develop knowledge and skills. Therefore, we proffer that the theoretical g=*f*(*C*,*D*,*R*) function is validated by the empirical GFCF.

Figure 5. Entrepreneurship elasticity of g

Appendix E: The Global Time Invariant CDR model

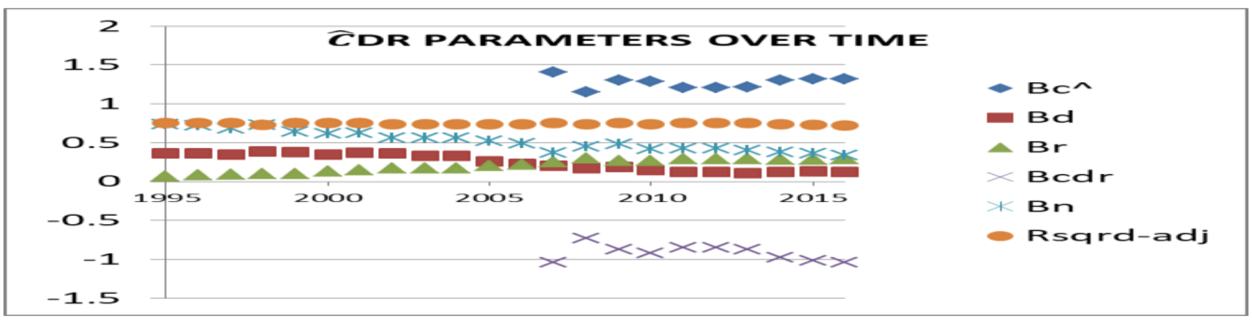


Figure 6. CDR model 2SLS parameters for different years

The year 2014 CDR model was re-estimated using samples from 2016 to 2016, 2015 to 2016, 2014 to 2016, 2013 to 2016, and so on. The Bd, Br and Bn parameter estimates from the ĈDR models are approximately constant for 22 years (see Figure 6 where the available spreadsheet characters are the closest to the regression model coefficients). They converge in the forward direction of time. The Bc and Bcdr estimates are approximately constant for the most recent 9 years. Prior to 2008, capitalization data were not available for all countries. So capitalization was held constant. Therefore, Bc and Bcdr increase in absolute value as G was decreasing, going back in time and capitalization was held constant. Constancy and convergence of the parameter estimates demonstrates model stability and consistency. It demonstrates that endogenous capital stock was purged from total capital to leave only exogenous entrepreneurship human capital. So, if the C̃DR model contains only exogenous regressors, the 2SLS parameter estimates must be best linear unbiased (blue) estimators. So, the 2SLS parameters estimates are unbiased. The CDR data came from a real-life uncontrolled experiment, but the 2SLS process yields a global time invariant C̃DR scientific law. Even if there is some bias, the model yields useful stable estimates. Some two hundred and forty years after Smith (1776) announced an inquiry into the nature and causes of the wealth of nations, the cause is found to be capitalism, democracy and rule of law, and the C̃DR model places economics on a sound scientific footing.

Appendix F: Integrating the CDR macro-economic model with the micro-economic production function

In general, consider *m* countries, *i=1, 2, 3, m,* where country *i* contains n_i production units. The *i*th country G estimate is $\widehat{G}_i=\widehat{g}_i$(highest G-lowest G) + lowest G, where in equilibrium, $\widehat{g}_i = f(C_i, D_i, R_i) = \widehat{\beta}_C C_i + \widehat{\beta}_D D_i + \widehat{\beta}_R R_i + \widehat{\beta}_{CDR} C_i \cdot D_i \cdot R_i$. There is no such thing as an aggregate production function (Cohen and Harcourt, 2003, Ridley and Ngnepieba, 2018). Production of $\widehat{G}_i$ is obtained from the sum of n_i micro-economic production units. Consider a deterministic Cobb-Douglas function $v_{ij} = f(f_{ij}\widehat{G}_i, L_{ij})$ applied to the *j*th unit of production in the *i*th country, where existing capital stock K_{ij} is replaced by capital obtained by the investment of the fraction f_{ij} of $\widehat{G}_i$, L_{ij} is the matching quantity of physical labor in person-hours per annum, and v_{ij} is the annual value of production. Assume that the wages paid to labor is W_{ij}. All labor is identical in nature and functionality. This operating definition of homogenous labor is consistent with the original theory of comparative advantage (Ricardo, 1817). Any human differences due to knowledge, experience and skills are transferred into production capacity of capital stock. Assuming constant returns to scale, then $v_{ij}=A_{ij}(f_{ij}\widehat{G}_i)^{\alpha_{ij}} W_{ij}^{1-\alpha_{ij}}$, where A_{ij} is the total factor productivity and α_{ij} and 1-α_{ij} are output elasticities of capital and labor respectively. The total monetary value of production for country *i* is given by

$$\sum_{j=1}^{n_i} v_{ij} = \sum_{j=1}^{n_i} A_{ij}(f_{ij}\widehat{G}_i)^{\alpha_{ij}} W_{ij}^{1-\alpha_{ij}}.$$

The global monetary value of production of all *m* countries is therefore

$$\sum_{i=1}^{m}\sum_{j=1}^{n_i} A_{ij}(f_{ij}\widehat{G}_i)^{\alpha_{ij}} W_{ij}^{1-\alpha_{ij}}.$$

Or, substituting for $\widehat{G}_i$,

$$\sum_{i=1}^{m}\sum_{j=1}^{n_i} A_{ij}\{f_{ij}[f(C_i, D_i, R_i)(\text{highest G} - \text{lowest G}) + \text{lowest G}]\}^{\alpha_{ij}} W_{ij}^{1-\alpha_{ij}}.$$

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