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EMPIRICAL ANALYSIS OF AN AUGMENTED SCHUMPETERIAN ENDOGENOUS GROWTH MODEL

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This study conducts an empirical analysis of an augmented Schumpeterian endogenous growth theory using aggregate-level data from 1981 to 2017 for 31 OECD countries. Despite a considerable number of studies analysing endogenous growth, cross-country analyses utilising estimators robust to endogeneity-bias and controlling for the macroeconomic effect of institutions are still rare. In this paper, we employ a relatively consistent estimator to analyse an augmented neoclassical production function that links output per worker to capital accumulation, technological progress, and institutions. Our results from the extended system of generalised method of momentS estimation align with the mainstream consensus that capital accumulation and technological progress or innovation, in the form of R&D activities, determine the level of output per worker in the long run. But in addition, we find that effective institutions underlie the innovation effect. On average, the impact of R&D activities on output per worker is higher in countries with more effective institutions.

Keywords: Endogenous Growth Theory, Capital Accumulation, Generalised Method of Moments (GMM), Institutions, Neoclassical Production Function, OECD, Research & Development, Technical Progress
JEL Classification: O11, O30, O47, O57

1. INTRODUCTION

According to the neoclassical growth theory, the long-run rate of economic growth, as measured by the growth rate of output per worker, is induced by labor productivity, which is largely determined by the rate of technological progress (Solow, 1956 and 1957). In turn, the technological progress is contended to be exogenously determined by a scientific process that is separate from, and independent of, economic forces. This implies that, in the long run, economic growth does not depend on economic conditions. In particular, a country's long run growth is assumed unaffected by purposeful economic policy.

Contrarily, the endogenous growth theorists argued that long-run growth rate is influenced by 'endogenous' outcome of the conscious actions of economic agents. The endogenous analyses start from the observation that technological progress takes place through innovations, which can take the form of new products, processes and markets. This implies, unlike the neoclassical conclusion, that economic activities that stimulate innovations can affect a country's long run growth rate.

Since its emergence, different versions of the endogenous growth theory have been propounded. To begin with, the AK theory, which was the first version of endogenous growth theory, contend that the accumulation of capital includes the accumulation of both physical and human or intellectual capital, without making an explicit distinction between capital accumulation and technological progress. Furthermore, it asserts that the aggregated production function can exhibit a constant or even increasing marginal product of capital, because when firms accumulate more capital, some of that increased capital will be the intellectual capital that creates technological progress, which is expected to offset the tendency for the marginal product of capital to diminish (e.g, Frankel, 1962; Uzawa, 1965; Romer, 1986; Lucas, 1988).

The second wave of endogenous theory consists of the "innovation-based" growth theory, which belonged to two parallel models: "the product variety" model of Romer (1990) and "the Schumpeterian model" by Aghion and Howitt (1992, 1998) and Grossman and Helpman (1991). In the main, both of these models recognize that technological progress is distinct from physical and human capital. Accordingly, physical and human capital are noted to be accumulated through saving and schooling, while technological progress is seen to grow from purposeful activities that generate new ideas, methods and devices.

According to the product variety model, inventions, in the form of new, but not necessarily improved, varieties of products is the technological progress that causes productivity cum economic growth (Romer, 1990). The Schumpeterian theory, on the other hand, focuses on quality-improving innovations that render old products obsolete, through the process that Schumpeter (1942) called 'creative destruction'. The Schumpeterian paradigm relies on two main ideas. First is the idea that long-run growth relies on process innovation (due to the increase in the productivity of labor or capital), or product innovation (the introduction of new products), or organisational innovation (which is to make the combination of production factors more efficient). The second is the idea that innovations result from investments like research and development (R&D), firms' investments in skills, and the search for new markets that are motivated by the prospect of monopoly rents for successful innovators.

In all, according to the endogenous growth theories, the various economic activities that contribute to determining technological progress include increased investment in physical and human capital, investments in research and development, the extent of international openness, and several other determinants (e.g, Frankel, 1962; Uzawa, 1965; Romer, 1986, 1987, 1990; Lucas, 1988; Rebelo, 1991; Aghion and Howitt, 1992, 1998a, 1998b; Grossman and Helpman, 1991a, 1991b, 1994)[1].

Although considerable progress has been made in the theoretical modelling of technical change or technological progress, the same could not be said of the empirical counterpart. Particularly, fewer cross-country empirical studies utilising macro panel data have been carried out in support of most of the endogenous growth theories proposed. Furthermore, a majority of the few aggregate-level studies that have been conducted have often tended to produce conflicting results and conclusions. For example, while some studies (see Mohnen, 1990; Mohnen and Lepine, 1991; Coe and Helpman, 1995; Griliches, 1998; and Zachariadis, 2003) appear to show a statistically large significant relationship between technical progress (proxied either by R&D or patent stock or human capital proxies such as years of schooling or gross secondary school enrolment rates) and output growth (or productivity, in some cases), many have also produced contradictory results (e.g. Jones, 1995; Bilbao-Osorio and Rodrigues-Pose, 2004; Hall et al., 2009).

In all, the contrasting results in the empirical literature on endogenous growth have mostly been attributed to the difficulty inherent in the measurement of technological progress (Griliches, 1998; Hall et al., 2009). Without a doubt, a misspecified or inadequately measured technological progress means the likely omission of a relevant determinant in a model. And as observed by Blundell and Bond (2000), Blundell, Bond and Windmeijer (2000), the omission of a relevant variable in a model tend to lead to inconsistent output from traditional panel estimators.

This paper contributes to the existing knowledge in two-ways. First, we contribute to the growing empirical literature by utilising an estimator that has been shown to be robust, especially when endogeneity bias - caused by the omission of relevant variables or an error in the measurement of the variable or due to simultaneous causality between the dependent and independent variables - is likely to be present in the empirical model to analyse an augmented endogenous growth theory. Second, unlike previous studies, we also control for the potential effect of relative institutions. We posit that the inability of studies to account for the effect of relative institutional arrangement contributes to the inconsistencies of the empirical results on endogenous growth.

Furthermore, similar to North (1990), we also contend that the failure to account for the macroeconomic effect of institutional structures leads to inadequate analysis of the underlying determinants of the long-run performance of economies. So, not only does the omission of institutional variables lead to inconsistencies in empirical analysis but also to incomplete analysis of fundamental factors affecting economic growth in the long run.

To summarise, in this study, we utilise an estimator that is robust to endogeneity -bias to examine an augmented- Schumpeterian endogenous growth theory that builds on the original Schumpeterian endogenous growth model by Aghion and Howitt (1998a, b).

1 See Barro (1997) for a more detailed discussion of the seminal exogenous and endogenous growth theories.

We define our augmented-Schumpeterian model as an amalgamation of the AK, Schumpeterian, and institution-based growth theories that emphasizes the effect of capital (both physical and human) accumulation, R&D expenditure or, more broadly, innovation-inducing-activities, and institutional arrangements on output or economic growth. Our empirical analysis uses an extensive macro panel data of 31 OECD countries from 1981-2017.

The rest of the paper is structured as follows. Section two contains a critical review of some related empirical literature on empirical endogenous growth. Section three includes discussions on the macroeconomic role of institutions. Session four presents the data and methods used in this paper. Section five discusses the empirical results while section six provides the concluding remarks.

2. REVIEW OF SOME RELATED EMPIRICAL MODELS

The empirical framework mostly used in the endogenous growth study often follow the standard neoclassical production function (represented in Equation 1 below), where the dependent variable is a measure of output (Y) and the explanatory variable (X) is a vector of standard economic inputs such as labour, capital, intermediate inputs and so forth, and technological progress (A) is proxied by a variety of variables such as years of schooling or secondary school enrolment, R&D expenditure or patent counts, democracy or other institutional measures.

$$\log Y = c_t + \beta(\log X) + \phi(\log A) + \xi. \tag{1}$$

Equation (1), linear in the logarithms of the variables, have been used by Griliches (1980, 1986), Griliches and Mairesse (1983, 1984, 1990), Cuneo and Mairesse (1984), Mankiw et al. (1992), Barro (1995, 1999), Guellec and Potterie (2003), and Hall (2011), among a few others, to estimate the elasticity of output (or productivity) to factor inputs and some proxies of technological progress[2].

The alternative formulation, represented in Equation (2) below, replaces the levels with growth rates.

$$\Delta \log Y = \beta(\Delta \log X) + \phi(\Delta \log A) + \Delta\xi. \tag{2}$$

In this form, the rate of growth of output is related to the intensity (or the rate of change) of the explanatory variables. Several versions of the second equation have been estimated by Clark and Griliches (1984), Link (1981a, 1981b), Griliches (1986), Criscuolo and Haskel (2003) and Duguet (2006) using firm or line-of-business level data,

[2] Most of these studies follow the standard growth accounting approach of substituting Y with real GDP per capita.

and by Scherer (1982, 1984), Griliches and Lichtenberg (1984a, 1984b), Griliches (1994), Huergo and Jaumandreu (2004) and Rogers (2010) using industry or national aggregates.

In the main, most of these past studies have generally used cross-sectional data that does not allow for heterogeneity across countries - that is, the intercept is not allowed to be specific to individual countries - and the traditional Ordinary Least Square (OLS) estimator to estimate the unknown parameters. However, given that there is strong evidence of parameter heterogeneity that may arise from non-linearities in the production function across countries (see the remarks by Liu and Stengos, 1999; Kalaitzidakis et al., 2001, for instance), the cross-sectional estimates that do not allow for cross-sectional heterogeneity could thus be seen as both inconsistent and biased. Equivalently, the likely existence of measurement errors in the variables and the possibility of a simultaneous causation between output (or output growth) and some of the factor inputs also biases the consistency of the OLS estimators (e.g, Arellano and Bover 1995; Griliches 1995, 1998; Aghion and Howitt 1998a, 1998b; Wooldridge, 2001; Bond et al., 2010; Acemoglu et al., 2019)[3]. In essence, the results of these past studies need to be interpreted with caution since the traditional estimators do not address the inherent endogeneity bias that results from variable measurement errors or simultaneity bias.

To accommodate idiosyncratic individual effects, the error terms in Equations (1) and (2) have often been re-specified as a one-way error component model -Equation (3):

$$\xi_{i,t} = \mu_i + v_{i,t} \quad . \tag{3}$$

Here, μ_i is viewed as an individual fixed effect term that varies across entities (firms or countries) but not within entities over time, and $v_{i,t}$ is the usual white-noise error term. The fixed effect term μ_i captures those idiosyncratic individual effects that do not vary over time (that is, the time-invariant factors), which are often elided in cross-sectional data. In this case, a 'within-group' panel estimator, a fixed effect (FE) or random effect (RE) technique, can be used to consistently estimate the unknown parameters, if longitudinal data are available. Nevertheless, the FE and the RE approaches have also been shown to be biased, especially if there are measurement errors in the variables (Griliches and Hausman, 1986; Baltagi, 2013).

So, given that traditional technological progress proxies are prone to measurement errors due to the difficulty in accurately quantifying technical progress (e.g, Griliches,

[3] The main problem with quantifying technological progress, as Griliches pointed out, lies in the unavailability of a direct and relevant indicator that can adequately reflect the various complexities inherent in the process. The issue of timing and depreciation was also noted to contribute significantly to the measurement error. Similarly, future output and its profitability have been shown to depend on past R&D/investment, while present R&D/investment, in turn, also depends on both past income and the expectations about future income; thus, the simultaneity element.

1998), results, such as those obtained by Hall (1993), Hall and Mairesse (1995) and Harhoff (1998), that applied the within-group estimators also need to be interpreted with caution, because of the inherent bias of the within-group estimators when there are measurement errors in the variables.

In the context of a dynamic panel model, characterized by the presence of a lagged dependent variable among the regressors, Nickell (1981) showed that the within-group model would also be inconsistent and inefficient. The inconsistency with the one-way fixed effects model, particularly in a 'small T, large N' context, is seen to arise because the demeaning process which subtracts the mean value of the dependent and independent variables from their respective levels (see Equation (4) below) creates a correlation between the regressors and the idiosyncratic error term, which then renders the within-group estimator inconsistent.

$$Y_{i,t} - \bar{Y}_i = \gamma(Y_{i,t-1} - \bar{Y}_{i,-1}) + \beta(X_{i,t} - \bar{X}_i) + \phi(A_{i,t} - \bar{A}_i) + (v_{i,t} - \bar{v}_i). \quad (4)$$

Here, since $Y_{i,t}$ is a function of $v_{i,t}$, $Y_{i,t-1}$ is also a function of $v_{i,t}$. Therefore, $Y_{i,t-1}$, a right-hand regressor in (4), will be correlated with the error term, thus rendering the OLS estimator biased and inconsistent even if the $v_{i,t}$ are not serially correlated (e.g, Baltagi, 2013).

So, although the fixed effects estimator addresses the issue of cross-sectional heterogeneity, the demeaned autoregressive variable ($Y_{i,t-1} - \bar{Y}_{i,-1}$, where $\bar{Y}_{i,-1} = \sum_{t=2} Y_{i,t-1} / (T-1)$ is observed to still be correlated with $(v_{i,t} - \bar{v}_i)$ even if the $v_{i,t}$ are not serially correlated. This is because, as Baltagi (2013) explained, $Y_{i,t-1}$ will be correlated with $\bar{v}_i$ by construction: that is, the latter average contains ($v_{i,t-1}$ which is obviously correlated with $Y_{i,t-1}$. Therefore, because of the correlation between a regressor and the error term in a within-transformed dynamic model, the fixed effect estimator is said to be biased and inconsistent in a panel where N is large and T is fixed. The only exception is if $T \to \infty$. In this case, the within estimator of the unknown parameters for the dynamic error component model could be consistent.

Often, in order to get a robust estimation of coefficients and standard errors when some variables could contain measurement errors, and there exist a correlation between regressors and the idiosyncratic error term, in the context of a finite T dynamic panel data, the 'first-difference' transformation proposed by Anderson and Hsiao (1981), the 'long-difference' approach by Griliches and Hausman (1986), or the difference GMM by Arellano and Bond (1991) have been used to study endogenous economic growth (see Li, 2002; Madsen, 2002; Bond et. al., 2003; Chen and Yang, 2005; Duguet, 2006; Jafferson et al., 2006; Parisi et al., 2006; Bond et al., 2010; Mairesse and Robin, 2010; Acemoglu et al., 2014, 2019).

To begin with, the Anderson and Hsiao (1981) suggested first differencing the model to get rid of the individual effect and then using the second lag of the differenced dependent variable (from our example, that is $\Delta Y_{i,t-2} = Y_{i,t-2} - Y_{i,t-3}$) or simply the second lag of the dependent variable ($Y_{i,t-2}$) as an instrument for the autoregressive term

($\Delta Y_{i,t-1} = Y_{i,t-1} - Y_{i,t-2}$). According to these authors, the instruments are serially uncorrelated with the differenced error term ($\Delta v_{i,t} = v_{i,t} - v_{i,t-1}$), as long as the $v_{i,t}$ themselves are not serially correlated. However, as pointed out by Ahn and Schmidt (1993), this type of instrument variable estimation leads to consistent but not necessarily efficient estimates of the parameters in the model because it does not make use of all the available moment conditions and also does not take into account the differenced structure on the residual disturbances. Equally, Arellano (1989) finds that for simple dynamic error component models the estimate that uses differences (such as the second lag of the differenced dependent variable) rather than their levels as instruments, have a singularity point and very large variances over a significant range of parameter values. On the other hand, Arellano and Bond (1991) argue that additional instruments can be obtained in a dynamic panel data if one utilizes the orthogonality conditions that exist between lagged level values of the dependent variable and the disturbances. To this end, they recommended the use of instruments in levels for differenced variables.

The potential weakness with the Anderson-Hsiao and Arellano-Bond estimators was revealed by Arellano and Bover (1995) and Blundell and Bond (1998). It was shown that the lagged levels are poor instruments for first differenced variables, especially if the variables are close to a random walk. The Arellano and Bover (1995) and Blundell and Bond (1998) modification of the estimator include lagged levels as well as lagged differences in a system of equations that combines both level and differenced variables. This remodified approach is often referred to as a *system-GMM* (Blundell and Bond, 1998, 2000).

To conclude, the system-GMM has been shown to produce consistent estimates when there appears to be an endogeneity bias in the model (e.g Blundell and Bond, 2000; Blundell, Bond and Windmeijer, 2000; Baum et al., 2003; Roodman, 2009). And as far as we know, only a handful of studies (for example Levine et al., 2000; Bond et al., 2001; and Griffith et. al., 2006) have attempted to utilise the robust extended sys-GMM estimator to control the statistical bias that arises from the endogeneity of regressors, which are often due to variable measurement errors, simultaneous causality or the omission of relevant variables. This study contributes to the growing literature on endogenous growth by utilizing the robust extended system-GMM estimator to analyse an augmented-Schumpeterian growth model that, unlike previous related studies, also accounts for the effect of institutional structures.

3. THE MACROECONOMIC ROLE OF INSTITUTIONS

Although the Nobel Prize-winning economist, Douglas North, could be said to have brought to the fore the importance of institutions to economic development, the study of institutions and their effect on the economic processes could nevertheless be traced back to the works of scholars such as Thorstein Veblen (1857-1929) and John R. Commons (1862-1945).

Institutions, as broadly defined by North (1990, 1991), are the formal and informal constraints governing human behaviour. The informal constraints consist of sanctions, taboos, customs, traditions, and codes of conduct that evolve overtime, whereas the formal constraints include rules such as constitutions, the rule of law, and property rights. They are, as North puts it, generally *"humanly devised constraints that shape human interaction"* (North, 1990; p.4). Institutions can be further classified as socio-cultural, economic and political institutions, depending on the aspect of human interaction they structure.

Broadly, the ability of institutions to reduce the cost of economic transaction is remarked to underlie its strategic importance to the long-run performance of economies. To begin with, the costliness of information is observed to be the key to the cost of economic transactions (which consists of the costs associated with banking, insurance, finance, wholesale, and retail trade; or, in terms of occupations, with lawyers, accountants, security services, etc.). The costliness of information derives from the asymmetric nature of available information - a situation where both parties involved in an economic transaction have an unequal amount of information (that is, one party knows much more than the other)[4]. In turn, the costs of transactions determine the valuable attributes of economic exchanges, since they form part of production cost. And when the cost of transactions that go through the market are high, due to the expensiveness of obtaining relevant economic information or because of the cost of having imperfect information, they invariably affect the productiveness of the economy. For example, if the cost of seeking redress against someone who has broken the law (say because of default on loan repayment) are high, and also if the organisations that provide the physical structures to the law (such as courts) are ineffective (biased or corrupt), the effectiveness of the enforcement of the rules (in this regard the appropriate punishment) diminishes. Consequently, the ineffectiveness of the institutional structure fosters discontent and distrust among the citizens, thus inhibiting productive exchanges - such as future loan/credits grants - capable of stimulating economic growth.

In general, the essential part of the functioning of institutions is ascertaining violations of the community code of conduct and the severity of punishment. When it is not costly to ascertain violations of the rules of the game and to enforce appropriate punishment, the institutional arrangement is said to be effective. Subsequently, effective institutions create a sort of structure to human exchange by both incentivising productive human activities and disincentivising unproductive human activities. By spontaneously limiting the set of unproductive choices of individuals and organisations - such as nepotism, moral hazards, corruption, theft, and other nefarious activities - and providing

[4] For a background discussion on asymmetric information theory, see Akerlof, G. (1970), "The Market for Lemons: Quality Uncertainty and the Market Mechanism," *Quarterly Journal of Economics,* 84(1), 488-500; Spence, M. (1973), "Job Market Signalling," *Quarterly Journal of Economics,* 87(3), 355-374; Rothschild, M. and J. Stiglitz (1976), "Equilibrium in Competitive Insurance Markets: An Essay on the Economics of Imperfect Information," *Quarterly Journal of Economics,* 90(4), 626-649.

the framework within which productive human interaction or activities - such as collaborations, bank credits, etc - takes place, effective institutions systematically reduces the cost of economic transactions and redirect incentives that in turn direct individuals and organisations along productivity-increasing paths.

Despite its obvious implication for long term economic performance, it is only just recently that studies examining the macroeconomic role of institutional arrangements have started to emerge. The modern exponents of the primacy of institutions include Dani Rodrik of Harvard University and Daron Acemoglu, Simon Johnson and James Robinson of the Massachusetts Institute of Technology. These scholars, collectively, have written extensively on the importance of effective institutions for economic growth and development. For instance, the central message of the path-breaking book by Acemoglu and Robinson (2012), *Why Nations Fail*, is that without inclusive economic and political institutions nations will fail to achieve meaningful economic development. Likewise, Rodrik (2000, 2004, 2008), Rodrik and Subramanian (2008), and Williamson (2009), have also asserted that institutions are necessary, if not sufficient, conditions for rapid economic progress. Generally, there is a consensus among these development economists that those institutions that support markets (economic interactions and collaborations), such as those that enforce property rights and legally binding contracts, improve regulatory oversights, reduce conflicts, and constrain the political power of the elite *cum* corruption, are prerequisites for accelerating economic development.

In this paper, we argue that the omission of institutions is also central to the inconsistencies observed in the empirical literature on endogenous growth. This is chiefly because innovative activities face several uncertainties that only the presence of an effective institution can help to ameliorate. For example, following the exposition by Schumpeter (1934), the knowledge necessary for entrepreneurial decisions are mostly unknown and costly to acquire and there is also the issue of inaccurate information or analysis of the economy, such as whether the outcome of the entrepreneurial decision (be it a product or process) would be economically viable. These uncertainties, it is remarked, naturally make innovation to be shrouded in ambiguity. Furthermore, the objective uncertainty is said to be compounded by subjective reluctance of individuals to strike out into the unknown, often because of fear of the antagonism of non-innovators to innovators - in the form of legal and political obstacles and intellectual property theft and the likes. Both objective and subjective uncertainties, Schumpeter concluded, contribute to the inhibition of innovative activities in an economy. An institution that could reduce these uncertainties through, for example, guarding against the theft of intellectual property, we contend, incentivises innovation and discoveries. In turn, the outcome of the innovations and discoveries gives firms the competitive advantage, thereby contributing to the augmentation of the individuals' and the nation's wealth. In essence, effective institutions are critical in fulfilling the purpose of inducing individuals – by way of reducing objective uncertainties and the subjective reluctance that arises due to fear of loss of intellectual property right and its ensuing private gain - to innovate or embark on new discoveries that subsequently stimulates growth in the long-run. In essence, the inconsistencies in the empirical results could largely be due to the distinctiveness of institutional quality across countries.

In summary, although ideas and ideologies matter, it is the institutions that play the major role in determining just how much they matter. In essence, although ideas and ideologies shape the subjective mental constructs that individuals use to interpret the world around them and to make effective choices, by structuring the interaction of human beings in certain ways that ensures operational implementation of the ideas, institutions deliberately or accidentally affect the long run performance of the economy.

4. DATA AND METHODS

Annual data from 1981 to 2017 were collected for 31 OECD countries, providing a 37-year unbalanced[5] panel. The estimation in this paper uses both annual data and data for non-overlapping three-year periods[6]. The data for estimating the specified model - Equation (5) were retrieved from the Organisation for Economic Co-operation and Development (OECD) and the World Bank Governance Indicators statistics databases. The data set includes annual series of the Gross Domestic Product (GDP), total gross investment (gross fixed capital formation), the total employment figure, the gross expenditure on research and development and a proxy for institutions, in this case the rule of law estimates. All the variables are measured in constant international dollars, except the employment and rule of law figures[7].

For this study, we follow the traditional production function method of using economic output (the real gross domestic product per person employed (gdp_{pw}) in this case) as the dependent variable (e.g Barro et al., 2017, for instance). The gross fixed capital formation (GFCF) and the gross expenditure on R&D (GERD) were also divided by the employment figure to derive gross fixed capital per worker ($gfcf_{pw}$) and research and development expenditure per worker ($gerd_{pw}$), respectively. Table 1 below contains the descriptive statistics of the averaged dataset.

Our methodology builds on the Schumpeterian growth model developed by Aghion and Howitt (1998a, 1998b) and is similar to the Cobb-Douglas production function considered by Griliches and Mairesse (1998). The institutional element is supported by the theoretical works of Douglas North on institutional change and economic

[5] We have some missing variables for a number of countries that had no data for the gross expenditure on R&D ($gerd$) and investment for some periods.

[6] To mitigate the bias that often arise from persistent series, we averaged the observations over a non-overlapping multi-year period. This approach is consistent with the standard practice of using averaged series (see, for instance, Bond et al., 2001; Acemoglu et al., 2005; and Bond et al., 2010). The three-year average of each variable is computed as $([Y_T + Y_{T-1} + Y_{T-2}]\ /\ 3,\ [Y_{T-3} + Y_{T-4} + Y_{T-5}/3, \ldots [Y_{T-k+3} + Y_{T-k+2} + Y_{T-k+1}/3)$. Averaging the series yielded 12-period non-overlapping observations for each variable.

[7] See A1 in the Appendix for the long definition of these variables and their sources.

performance.

Table 1. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
GDP per person employed	356	60264.830	26588.090	16874.180	170013.900
GFCF per person employed	356	13669.730	6164.758	3034.982	53362.210
GERD per person employed	356	1299.319	825.361	81.879	3387.108
Rule of Law	403	1.272	0.634	-0.619	2.100

Source: Based on author's own calculation.

Table 2. Lag Length Selection Criteria

Lag	CD	J	J p-value	MBIC	MAIC	MQIC
1	1.00	91.230	0.180	-303.530*	-68.770*	-164.170*
2	1.00	79.220	0.100	-236.590	-48.780	-125.100
3	1.00	55.340	0.220	-181.520	-40.660	-97.900
4	1.00	41.950	0.110	-115.950	-22.050	-60.210

Source: Based on author's own calculation.
Note: *indicates the proposed optimal lag length by the models.

The instrumental variables used in the analysis are the lags of the predetermined variable (that is, the lags of the dependent variable) and those of the explanatory variables, which we assumed to be endogenous[8]. Also, the empirical method utilises year dummies to control for common time effects. For our preferred model with 3-year averaged series, only one period lags of the dependent and independent variables are used. The consistent moment and model selection criteria (MMSC) proposed by Andrews and Lu (2001) for GMM models was used to select the lag length. The MMSC is analogous to most of the commonly used maximum likelihood-based model selection criteria such as the Akaike Information Criteria (AIC) (Akaike 1969), the Bayesian

[8] We assume a priori that both capital per worker ($gfcf_{pw_{i,t}}$), gross expenditure on R&D per worker ($gerd_{pw_{i,t}}$), and the institutional proxy - *the rule of law estimate* - are potentially correlated with the country-specific effect (μ_i) and with the errors ($v_{i,t}$), as well as been imprecisely measured.

Information Criteria (BIC) (Akaike 1977; Schwarz 1978), and the Hannan-Quinn Information Criteria (HQIC). The MMSC models include the Moments of Bayesian Information Criteria (MBIC), the Moments of Akaike Information Criteria (MAIC) and the Moments of Hannan-Quin Information Criteria (MQIC) techniques[9]. The result of the moment and model selection criteria (presented in Table 2 below) suggest a first-order autoregressive model.

To analyse the long-run relationship between the technology proxy ($gerd_{pw}$), capital accumulation ($gfcf_{pw}$), the institutional proxy (*rule*), and output per worker (gdp_{pw}), we formulate the following autoregressive-distributed lag (ADL) model, similar to that used by Blundell and Bond (2000), Levine et al. (2000), Bond et al. (2001), and Bond and et al. (2010), except with regards the technology proxy used as well as the inclusion of an institutional proxy in our model. In general, we revisit the Cobb-Douglas production function first considered by Griliches and Mairesse (1998), albeit with the inclusion of an institutional proxy.

In sum, the following dynamic equation was considered:

$$\begin{aligned}\log(gdp_{pw_{i,t}}) = \gamma \log(gdp_{pw_{i,t-1}}) + \beta_0 \log(gfcf_{pw_{i,t}}) + \beta_1 \log(gfcf_{pw_{i,t-1}}) \\ + \varphi_0 \log(gerd_{pw_{i,t}}) + \varphi_1 \log(gerd_{pw_{i,t-1}}) \\ + \delta_1(rule_{i,t-1}) + \alpha_t + \mu_i + v_{i,t}, \qquad (5)\end{aligned}$$

where α_t represents time effects, μ_i denote the unobserved time-invariant country-specific effect and $v_{i,t}$ is the serially uncorrelated disturbance term. The subscripts i and t represent country and time period, respectively. The gross fixed capital formation per person employed and the gross expenditure on R&D per person employed are postulated to affect gross output per person employed both contemporaneously and with a lag. Rule of law, however, is assumed to affect output per person employed only with a lag; given that it takes time to instill confidence in the effectiveness of institutional structure or for institutional changes to affect the economy. The specification is later revised to include the institutional proxy as an interaction term with the technical change proxy. This latter specification we feel is more appropriate given that, as we have discussed earlier, institutions affect the economy indirectly through its impact on transaction costs and economic exchanges.

The difference-GMM initially proposed by Arellano and Bond (1991) involves first-differencing Equation (5) to eliminate the firm-specific effects and subsequently instrumenting with suitably lagged levels of the variables. The first-differenced equation can be expressed as follows:

[9] Abrigo and Love (2016) contain a brilliant summary of the Andrews and Lu (2001) moment and model selection criteria.

$$\begin{aligned}\log(gdp_{pw_{i,t}} - gdp_{pw_{i,t-1}}) = {} & \gamma[\log(gdp_{pw_{i,t-1}}) - \log(gdp_{pw_{i,t-2}})] \\ & + \beta_0[\log(gfcf_{pw_{i,t}}) - \log(gfcf_{pw_{i,t-1}})] \\ & + \beta_1[\log(gfcf_{pw_{i,t-1}}) - \log(gfcf_{pw_{i,t-2}})] \\ & + \varphi_0[\log(gerd_{pw_{i,t}}) - \log(gerd_{pw_{i,t-1}})] \\ & + \varphi_1[\log(gerd_{pw_{i,t-1}}) - \log(gerd_{pw_{i,t-2}})] \\ & + \delta_1(rule_{i,t-1} - rule_{i,t-2}) + (\alpha_t - \alpha_{t-1}) \\ & + (v_{i,t} - v_{i,t-1}). \qquad (6)\end{aligned}$$

The standard GMM assumption on the initial conditions (of orthogonality) imply $\mathrm{E}[X_{i,1}|v_{i,t}] = 0$ for $t = 2, \ldots, T$. This yields the following conditions:

$$\mathrm{E}[X_{i,t-s}|(v_{i,t} - v_{i,t-1})] = 0$$

for $s \geq 2$ when $v_{i,t} \sim$ MA(0), and $s \geq 3$ when $v_{i,t} \sim$ MA(1), (7)

where $X_{i,t}$ represents all the set of explanatory variables included in Equation (5), except the lagged logarithm of real GDP per worker.

Assumption (7) allows for the use of suitably lagged levels of the variables as instruments for Equation (6) (e.g, Arellano and Bond, 1991). The use of instruments is required to deal with the likely endogeneity of the explanatory variables in the first-differenced equation and also the problem that by construction the new error term, $(v_{i,t} - v_{i,t-1})$ is correlated with the lagged dependent variable $[\log(gdp_{pw_{i,t-1}}) - \log(gdp_{pw_{i,t-2}})]$.

As noted earlier, the difference-GMM estimator has been shown to have poor finite sample properties (bias and imprecision) when the lagged levels of the series are only weakly correlated with subsequent first differences, so that the instruments available for the first-differenced equations are weak (see Blundell and Bond, 1998, 2000). This issue is said to arise when the marginal processes for the explanatory variables could be highly persistent. This instrument weakness influences the asymptotic and small-sample performance of the difference estimator. Indeed, in a small sample Monte Carlo experiment, Arellano and Bover (1995) showed that the weakness of the level instruments can produce biased coefficients in a differenced equation.

To reduce the potential bias and imprecision associated with the usual difference estimator, we utilise the new estimator proposed by Arellano and Bover (1995) and Blundell and Bond (1998) and later reviewed and corroborated in Blundell and Bond (2000) and Blundell, Bond and Windmeijer (2000). The extended system GMM combines in a system the regression in differences (Equation 6) with the regression in levels (Equation 5). The instruments for the regression in differences are the same as above. The instruments for the regression in levels are the lagged differences of the corresponding variables. According to Blundell and Bond (1998, 2000), the joint stationarity of the dependent and independent processes is sufficient (but not necessary) for the validity of the additional moment restrictions for the equations in levels.

The stationarity property can be stated as follows:

$$\mathrm{E}[\log({gdp_{pw}}_{i,t+p})\,|\mu_i] = \mathrm{E}[\log({gdp_{pw}}_{i,t+q})\,|\mu_i] \text{ and } \mathrm{E}[X_{i,t+p}|\mu_i] = \mathrm{E}[X_{i,t+q}|\mu_i]. \quad (8)$$

Therefore, the additional moment conditions for the regression in levels are:

$$\mathrm{E}[\log({gdp_{pw}}_{i,t-s}) - \log({rgdp_{pw}}_{i,t-s-1})\,|(\mu_i + v_{i,t})] = 0 \text{ for } s = 1. \quad (9)$$

$$\mathrm{E}[X_{i,t-s} - X_{i,t-s-1}|(\mu_i + v_{i,t})] = 0 \text{ for } s = 1. \quad (10)$$

Overall, we use the moment conditions presented in Equations (7), (8) (9), and (10) and employ the extended sys-GMM procedure to generate consistent and efficient parameter estimates for equations (5) and (6). As noted earlier, we estimate these models using annual data and data for non-overlapping 3-year periods. We allow for richer dynamics in the empirical models based on the annual data. However, given that yearly data often contain series that are not close to their steady states throughout the study period - a virtue that biases the sys-GMM estimator - we instead utilised an averaged non-overlapping data to reduce the tendency of the series to deviate from their steady states and as such control the potential bias of the sys-GMM. Similarly, time dummies were also used to control for business cycle influences[10].

Lastly, consistency of the sys-GMM estimator is known to depend on the validity of the instruments. So, to prove the validity of our instruments, we consider two specification tests suggested by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998). The first is a Sargan-Hansen test of over-identifying restrictions, which tests the overall validity of the instruments by analysing the sample analogue of the moment conditions used in the estimation process. The second test examines the hypothesis that the error term $v_{i,t}$ is not serially correlated. By construction, the differenced error term is probably first-order serially correlated even if the original error term is not. The consistency of the sys-GMM however only depends on the error term being uncorrelated at the second-order. Furthermore, the GMM estimator is also known to be more efficient than the simple instrumental variable (IV) estimator if heteroskedasticity is present in a model with endogenous regressors (e.g

[10] The use of time-dummies is particularly important since, as noted by Roodman (2009), including them in the equation will make the assumption of no correlation across individuals in the idiosyncratic disturbances likely to hold.

Baum, 2006). So, to ascertain whether GMM is even appropriate we first test for the presence of heteroscedasticity in the model. We apply the heteroscedasticity test proposed by Pagan and Hall (1983) - e.g, the Breusch-Pagan/Godfrey/Cook-Weisberg and White/Koenker statistic - on the OLS regression of Equation (5). The results of our empirical analysis and the diagnostics are discussed in the next section.

5. RESULTS

Tables 4 and 5 report the results of our empirical analysis that were obtained from a range of estimators. Table 4 contains the results for the annual estimates while Table 5 report the results for the non-overlapping 3-year panel. For this study, we will focus on the result from the one-step system-gmm, for which inference based on the asymptotic variance matrix has been shown to be more reliable than for the (asymptotically) more efficient two-step estimator (e.g, Imbens, 1997). The first three columns of Table 4 and 5 report the results obtained using OLS, within-group and differenced-gmm estimators. The one-step system-GMM result and its two-step counterpart are reported in the last two columns respectively.

We take the impact multiplier of a change in $gfcf_{pw_{i,t}}$ to be β_0 and that of $gerd_{pw_{i,t}}$ to be φ_0. The effect after one period is derived from $\gamma\beta_0 + \beta_1$ and $\gamma\varphi_0 + \varphi_1$. The long-run (equilibrium) multipliers are $\beta_k = (\beta_0 + \beta_1)/(1-\gamma)$ and $\varphi_t = (\varphi_0 + \varphi_1)/(1-\gamma)$ and the adjustment speed is calculated as $(1-\gamma)\%$. We expect, in line with the observations by Bond (2002), the OLS estimator to produce an upward-biased estimate of the coefficient on the lagged dependent variable and the within-group estimator to produce a downward-biased estimate of this coefficient in the presence of group-specific effects. As a result, the true adjustment speed should lie above the OLS estimate and below the within-group estimates if there are evidence of group-specific effects.

We begin by first discussing the results of some preliminary tests. As mentioned earlier, GMM is said to be appropriate, compared to traditional IV estimators, only in the presence of heteroscedasticity. Applying the Breusch-Pagan/Cook-Weisberg heteroscedasticity test on the OLS regression of Equation (5) - both the annual and 3-yearly averaged series - we easily reject the null of constant variance for the regression residuals (see results in Table 3 below). This finding implies that the GMM estimator will be more efficient than the simple instrumental variable (IV) for our analysis.

Next, from the results of the annual estimates presented in Table 4 below we find that the estimate of the coefficient on the lagged dependent variable in the one-step system-GMM, as expected, lies below the OLS and above the within group estimates. Furthermore, performing a Wald coefficient restriction test on the OLS estimate of γ, we easily reject the hypothesis that $\gamma = 1$. Similarly, we reject the hypothesis that γ, from the within-group estimate is equal to zero. These results confirm the consistency of the bounds provided by the OLS and the within-group estimates.

Table 3. Breusch-Pagan / Cook-Weisberg Test for Heteroskedasticity

Annual Series Result		Averaged Series Result	
chi2(1)	22.860	chi2(1)	3.450
Prob > chi2	0.00	Prob > chi2	0.063

Source: Based on the author's own calculation

Notes: Variables fitted are the values of $\log(gdp_{pw})$. H_0: Constant variance

The tests of the validity of the instruments in the annual regression, as expected, produces several suspect statistic that imply the annual regression results need to be interpreted with caution. For example, the Hansen tests of instrument overidentification, including the diff-in-Hansen test of the additional instrument restriction in the system-GMM, produced p-values of 1.00. And as Roodman (2009) noted, a perfect Hansen statistic of 1.00 is a tell-tale sign of instrument proliferation and model misspecification: proliferation of instruments results in the overfitting of the endogenous variables as well as in the inability of the instruments to expunge the variables' endogenous components. These issues tend to weaken the power of the Hansen tests to detect the validity of the system-GMM instruments. So, given that the validity of the instruments is key for the reliability of the GMM estimator, the inconsistency of the instrument tests therefore means the results of the annual series regression should be disregarded.

Furthermore, given that the system-GMM require entities sampled to be close to their steady states throughout the study period (e.g Roodman, 2009), we suspect that by allowing for richer dynamics in the panel data through the use of longer time series that we could have possibly violated this assumption. This is because, as we have explained earlier, longer time series often include periods when individuals could be too far from their steady states. The perfect Hansen statistic of 1.00 certainly point to the possibility of a violation of the steady state assumption.

By averaging the variables, we hoped to produce individual samples that will not be too far from their steady states. This is important because, as mentioned before, the validity of the system-GMM depends on the assumption that changes in the instrumenting variables are uncorrelated with the fixed effects: that is, they require that throughout the study period, individuals sampled are not too far from their long-run means. We find, expectedly, that the Sargan and Hansen tests, including the diff-in-Hansen test, produced valid test statistic for the averaged panel. Despite the Sargan test rejecting the validity of the instruments used in both the one-step and two-step system-GMM, the consistency of the instruments is not undermined because there is evidence (e.g Blundell and Bond, 2000) of the increased power of the Sargan test to over-reject the instruments used in the system-GMM. The Difference-in-Hansen statistic that specifically tests the additional moment conditions used in the system-GMM equations accepts the validity of our instruments. Also, the null of no second-order serial correlation in the residuals is easily accepted for the one-step system-GMM.

Table 4. Regression Results from the Annual Panel [(a),(b)]

Variables	OLS	Within-Group	One-step diff-GMM	One-step sys-GMM	Two-step sys-GMM
$\log(gdp_{pw_{i,t-1}})$	0.958***	0.935***	0.892***	0.958***	0.968**
	(0.007)	(0.014)	(0.024)	(0.008)	(0.353)
$\log(gfcf_{pw_{i,t}})$	0.209***	0.225***	0.194***	0.209***	0.092
	(0.039)	(0.021)	(0.023)	(0.022)	(0.310)
$\log(gfcf_{pw_{i,t-1}})$	-0.186***	-0.194***	-0.166***	-0.186***	-0.286
	(0.036)	(0.017)	(0.019)	(0.020)	(0.174)
$\log(gerd_{pw_{i,t}})$	0.014	0.027	0.019	0.014	0.079
	(0.021)	(0.018)	(0.021)	(0.021)	(0.241)
$\log(gerd_{pw_{i,t}})$	-0.016	-0.012	-0.004	-0.016	-0.012
	(0.020)	(0.014)	(0.020)	(0.021)	(0.192)
$rule_{i,t-1}$	0.005**	0.005***	0.003	0.005	0.028
	(0.002)	(0.002)	(0.004)	(0.003)	(0.029)
Constant	0.270***	0.332***		0.00	1.714
	(0.066)	(0.049)		(0.00)	(3.702)
m(1) [(c)]	1.120	-	-2.680	-2.630	-1.540
	[0.265]	-	[0.007]	[0.009]	[0.124]
m(2) [(c)]	1.060	-	0.020	-0.010	0.520
	[0.290]	-	[0.986]	[0.993]	[0.602]
Sargan [(d)]	-	-	0.093	0.036	0.036
Hansen [(e)]	-	-	1.00	1.00	1.00
Diff-in-Hansen [(f)]	-	-	-	1.00	1.00
Observations	643	643	612	643	643
R-squared	0.996	0.990	-	-	-
Number of id	31	31	31	31	31
Number of instruments	-	-	612	643	643
Wald test ($\gamma = 1$ and $\gamma = 0$)	0.00	0.00	-	-	-

Notes: (a) *** p<0.01, ** p<0.05, * p<0.1. (b) Robust standard errors in parentheses. (c) m(1) and m(2) are the Arellano-Bond test for first-order and second-order serial correlation. The p-values for the null of no serial correlation are reported in square brackets. (d.) Sargan tests the validity of instrument overidentification. This test is not robust, but not weakened by many instruments. Only the p-values for the null hypothesis of valid instrument are reported. (e) Hansen also tests the validity of instrument overidentification. This test is robust, but weakened by many instruments. Only the p-values for the null hypothesis of valid instrument are reported. (f) Diff-in-Hansen tests the additional instruments used by the sys-GMM estimator. Only the p-values for the null hypothesis of valid instrument is reported.

Table 5. Regression Results from the non-Overlapping 3-year Panel [(a),(b)]

Variables	OLS	Within-Group	One-step diff-GMM	One-step sys-GMM	Two-step sys-GMM
$\log(gdp_{pw_{i,t-1}})$	0.906***	0.844***	0.920***	0.892***	0.871***
	(0.015)	(0.015)	(0.091)	(0.055)	(0.050)
$\log(gfcf_{pw_{i,t}})$	0.210***	0.171***	0.099	0.176***	0.161**
	(0.031)	(0.026)	(0.062)	(0.037)	(0.059)
$\log(gfcf_{pw_{i,t-1}})$	-0.157***	-0.078**	-0.090	-0.124***	-0.100*
	(0.030)	(0.028)	(0.053)	(0.044)	(0.049)
$\log(gerd_{pw_{i,t}})$	0.080***	0.097***	0.113**	0.052	0.068**
	(0.024)	(0.025)	(0.049)	(0.036)	(0.027)
$\log(gerd_{pw_{i,t}})$	-0.079***	-0.076***	-0.116**	-0.086*	-0.089***
	(0.024)	(0.020)	(0.049)	(0.044)	(0.027)
$rule_{i,t-1}$	0.007	0.003	0.032	0.041**	0.031***
	(0.005)	(0.017)	(0.037)	(0.017)	(0.010)
Constant	0.610***	0.766***	-	-	-
	(0.118)	(0.051)	-	-	-
m(1) [(c)]	4.380	-	-2.560	-2.840	-2.770
	[0.00]	-	[0.011]	[0.005]	[0.006]
m(2) [(c)]	2.430	-	0.220	-0.100	0.00
	[0.015]	-	[0.825]	[0.921]	[0.997]
Sargan [(d)]	-	-	0.00	0.00	0.00
Hansen [(e)]	-	-	0.800	0.765	0.765
Diff-in-Hansen [(f)]	-	-	-	0.571	0.571
Observations	325	325	294	325	325
R-squared	0.994	0.993	-	-	-
Number of id	31	31	31	31	31
Number of instruments	-	-	45	49	49
Wald test ($\gamma = 1$ and $\gamma = 0$)	0.00	0.00	-	-	-

Notes: (a) *** p<0.01, ** p<0.05, * p<0.1. (b) Robust standard errors in parentheses. (c) m(1) and m(2) are the Arellano-Bond test for first-order and second-order serial correlation. The p-values for the null of no serial correlation are reported in square brackets. (d.) Sargan tests the validity of instrument overidentification. This test is not robust, but not weakened by many instruments. Only the p-values for the null hypothesis of valid instrument are reported. (e) Hansen also tests the validity of instrument overidentification. This test is robust, but weakened by many instruments. Only the p-values for the null hypothesis of valid instrument are reported. (f) Diff-in-Hansen tests the additional instruments used by the sys-GMM estimator. Only the p-values for the null hypothesis of valid instrument is reported.

Furthermore, performing a Wald coefficient restriction test on the OLS estimate of γ, we easily reject the hypothesis that $\gamma = 1$. Similarly, we reject the hypothesis that γ, from the within-group estimate is equal to zero. These results confirm likewise the consistency of the bounds provided by the OLS and the within-group estimates of the averaged series.

Overall, the one-step system-GMM parameter estimates for the non-overlapping 3-year average model appear to be reasonable, although the estimated coefficient of $\log(gerd_{pw_{i,t}})$ is statistically insignificant. The estimated coefficient on the lagged dependent variable is higher than the within-group estimate and lower than the OLS estimate. The result point to an adjustment speed of 11%. Furthermore, the result indicate that capital accumulation has a significant positive effect on the steady-state level of output per worker (of around 0.48), even after controlling for unobserved country-specific effects and allowing for the likely endogeneity of investment. We also find that the level of effectiveness of institutions does have a significant impact on the level of output produced by a worker. Our analysis, however, show that nominal gross expenditure on R&D does not have a contemporaneous positive effect on gross domestic output per worker, but a significant negative effect in the long term. Such result is hard to interpret. Fortunately, due to the lack of theoretical support for a direct relationship between institutional quality and output growth and the possibility of multicollinearity bias in the model when the institutional variable is simultaneously included with the R&D variable, we decided to reparametrize our methodology to include the institution proxy as an indirect control variable in the model.

We experimented by including the institution proxy - *the rule of law* - first as an exogenous instrument only (Model 1). We also re-estimated the model with the institutional proxy as an interaction term with the R&D variable (Model 2) as well as a dummy regressor in the main equation (Model 3). To derive an institutional dummy, we classified all *rule of law* observations less than the panel median value as 0 and above as 1. We also examined the effect of the institutional dummy as an interaction term with the R&D variable (Model 4). Lastly, we analysed a model with the institutional dummy as an exogenous instrument only (Model 5). The models with the interaction terms (Models 2 and 4) allows us to measure the effect of R&D on output given the level of institutional quality. The results of these analyses are presented in the table below.

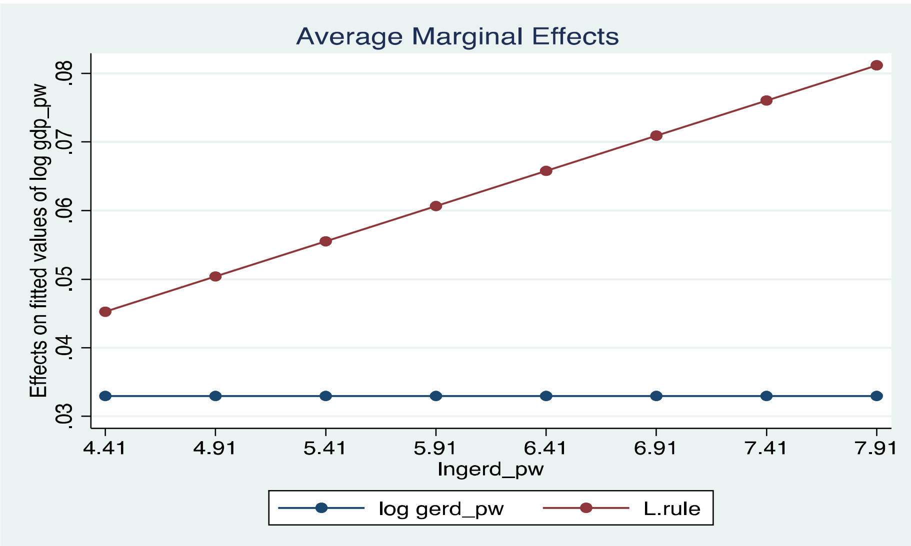
The results in the table above indicate that the models with institutional proxies ($rule$ and the $dummy$ counterpart) as exogenous instrumental variables (that is Models 1 and 5 respectively) had some improvement in the R&D coefficients; both now have a significant positive long-run effect. For Model 1, the contemporaneous impact of $\log(gerd)$ on output per worker is 0.10 while the long run impact is around one half of the immediate impact (0.053). When the institutional proxy is converted into a dummy and used as an instrument in the model, the contemporaneous impact of the R&D variable on output remained relatively the same (at 0.108). However, the long-run equivalent is relatively higher, at 0.097.

Table 6. Reparametrized Models [(a),(b)]

Variables	One-step sys-GMM Models [(g)]				
	1	2	3	4	5
$\log(gdp_{pw_{i,t-1}})$	0.868***	0.733***	0.810***	0.819***	0.857***
	(0.031)	(0.102)	(0.079)	(0.080)	(0.037)
$\log(gfcf_{pw_{i,t}})$	0.205***	0.156*	0.153***	0.157***	0.207***
	(0.041)	(0.083)	(0.054)	(0.052)	(0.045)
$\log(gfcf_{pw_{i,t-1}})$	-0.120***	-0.101*	-0.093	-0.095*	-0.122**
	(0.042)	(0.058)	(0.055)	(0.054)	(0.045)
$\log(gerd_{pw_{i,t}})$	0.100***	0.122*	0.141***	0.136***	0.108***
	(0.030)	(0.061)	(0.050)	(0.049)	(0.030)
$\log(gerd_{pw_{i,t}})$	-0.093***	-0.103*	-0.144***	-0.139***	-0.094***
	(0.029)	(0.055)	(0.042)	(0.039)	(0.028)
$g(gerd_{pw_{i,t}})\ \#rule_{i,t-1}$		0.010**			
		(0.005)			
$Dummy$			0.069**		
			(0.031)		
$Dummy_0\# \log(gerd_{pw_{i,t}})$				0.00	
				(0.00)	
$Dummy_1\# \log(gerd_{pw_{i,t}})$				0.008**	
				(0.004)	
m(1) [(c)]	-2.900	-2.230	-2.720	-2.710	-2.860
	[0.004]	[0.026]	[0.007]	[0.007]	[0.004]
m(2) [(c)]	-0.200	-0.020	0.090	0.050	-0.230
	[0.838]	[0.986]	[0.926]	[0.957]	[0.822]
Sargan [(d)]	0.00	0.00	0.00	0.00	0.00
Hansen [(e)]	0.896	0.865	0.983	0.973	0.904
Diff-in-Hansen [(f)]	0.797	0.120	0.634	0.687	0.809
Observations	325	325	325	325	325
Number of id	31	31	31	31	31
Number of instruments	49	48	48	48	49

Notes: (a) *** p<0.01, ** p<0.05, * p<0.1. (b) Robust standard errors in parentheses. (c) m(1) and m(2) are the Arellano-Bond test for first-order and second-order serial correlation. The p-values for the null of no serial correlation are reported in square brackets. (d.) Sargan tests the validity of instrument overidentification. This test is not robust, but not weakened by many instruments. Only the p-values for the null hypothesis of valid instrument are reported. (e) Hansen also tests the validity of instrument overidentification. This test is robust, but weakened by many instruments. Only the p-values for the null hypothesis of valid instrument are reported. (f) Diff-in-Hansen tests the additional instruments used by the sys-GMM estimator. Only the p-values for the null hypothesis of valid instrument is reported. (g) Model 1 included rule as an exogenous instrument only; Model 2 included lagged rule as an interaction term with the R&D variable; Model 3 included rule transformed as a dummy. With rule observations less than the median classified as 0 and above as 1; Model 4 included the rule dummy as an interaction term instead; Model 5 included the rule dummy as an exogenous instrument only.

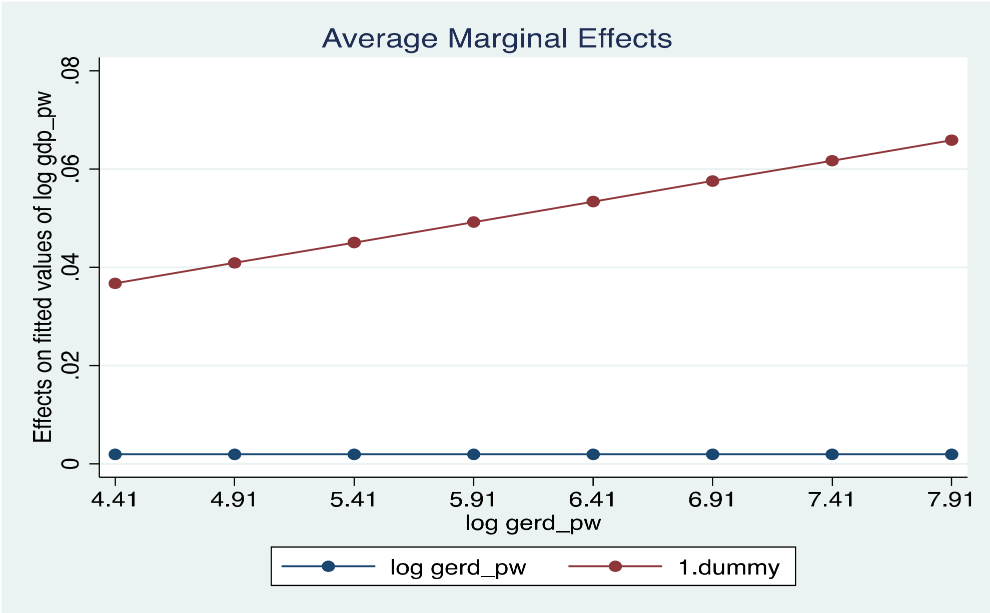
The interaction models (2 and 4) allowed us to measure the marginal impact that derives from having effective institutions. We experimented by interacting the R&D variable with both the continuous institutional variable ($rule$) and the factor $dummy$ counterpart. The use of dummy allows us to perform some specific analyses that are not possible with continuous variables. To begin with, in the case of Model 2, we see that for every unit change in the R&D variable, output, on average, will synchronously increase by 0.122. However, the increase is larger for countries with better institutional arrangement. Such will see a synchronous increase of around 0.132. In Model 4 with the dummy variable, the contemporaneous impact increases by around 6%, from 0.136 to 0.144 for countries with superior institutional arrangement. When we included the institutional dummy as an independent regressor in the model (Model 3), we observed that having a more effective institution increases the contemporaneous impact of R&D expenditure on output from 0.141 to 0.210. The key point here is that, in all cases, increasing R&D expenditure leads to significant marginal increases in output per worker when there exists effective institutional arrangement.



Source: Author's own calculation

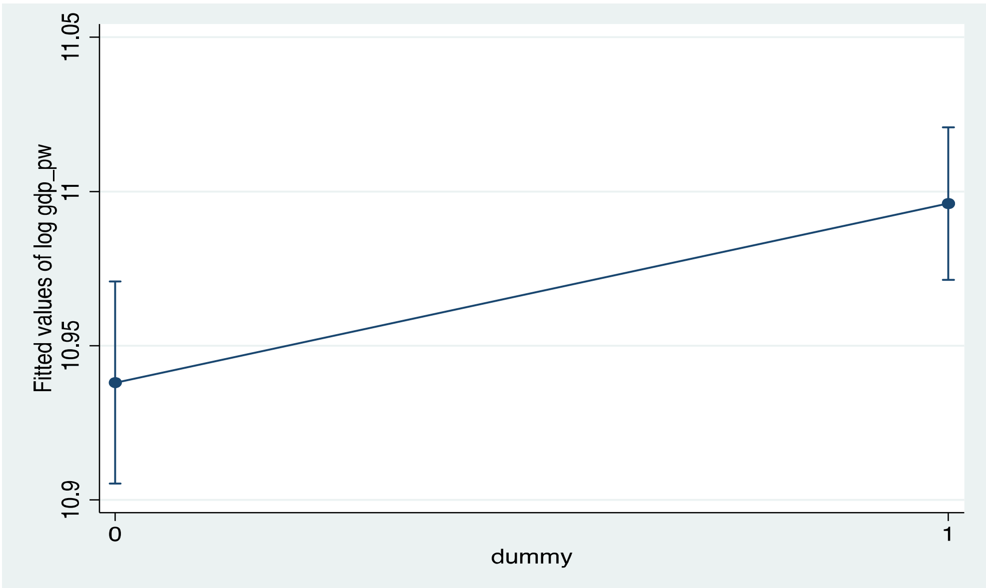
Figure 1. Marginal Effect from $rule$ Interaction

Our results underscore the strategic relevance of institutional quality. From Figures 1 and 2, it is obvious that the average marginal effect of R&D expenditure on output growth is significantly higher in countries with higher institutional quality than in countries with lower institutional quality. In fact, we see that the predicted intercepts are significantly different for the two broad categories (Figures 3).



Source: Author's own calculation

Figure 2. Marginal Effect from *dummy* Interaction



Source: Author's own calculation

Figure 3. Predictive Margins from *dummy* Interaction

Overall, according to our results, the major source of output growth is increased productivity deriving from improvements in the quality of human and physical capital and human interaction that are the product of purposeful investment in the productive assets of the economy, on research and development and, more importantly, the level of institutional effectiveness. The productive assets, such as land, plant, machinery, and equipment, good road, railway, seaport, and airport networks, as well as adequate school, office, hospital, private residential/commercial buildings, and IT infrastructures are fundamental for growth. However, in the presence of effective institutions, R&D investments complement, through their applied outcomes, the improvements in the quality of both human and physical capital, which in turn drives productivity *cum* output growth. From a micro-perspective, effective institutions incentivise the pursuit of discoveries and allow for their implementation. In turn, the application of the new knowledge led to process, product and organisational innovations that increases the possibility of monopoly rents that subsequently incentivises firms to increase investment in complementary physical and human capital as well as in further R&D, which in turn leads to increased productivity and output as well as an increase income. This endless cycle of accumulation, with the reinforcing *growth-loop*, is what we contend that determines the performance of the economy in the long-run.

6. CONCLUDING REMARKS

The main purpose of this study is to provide a consistent empirical analysis of an endogenous growth process. We built upon the Schumpeterian endogenous growth theory originally proposed by Aghion and Howitt (1998a, 1998b) by considering the effect of institutional arrangement on the growth process. We started by showing that despite the tremendous progress that has been made in the theoretical modelling of endogenous growth, little progress has been achieved with regards the provision of consistent empirical support. The inconsistencies of past empirical studies, we highlighted, emanate from the vulnerability of traditional estimators that do not address the potential problems posed by the endogeneity bias arising from variable measurement errors as well as the omission of a relevant institution proxy. Using a panel data consisting of 31 OECD countries from 1981 to 2017, we proceeded to provide a robust empirical estimate for an augmented-Schumpeterian endogenous growth theory.

Based on the empirical results, we observed that there is indeed an infinite-sample bias, due to instrument proliferation, when the system-GMM estimator is used to analyse variables that are not close to their steady states. However, using a 3-year averaged panel that addresses the infinite-sample problem, we find, from the consistent one-step system-GMM estimation, that capital accumulation and purposive R&D expenditure does certainly affect output in the long term, especially when the latter is done in a hospitable environment that promotes cooperative and innovative solutions to complex human exchanges.

A few policy implications that can be drawn from our results are as follows: (i) Given the significant role capital accumulation plays in determining the level of output per worker in the long-run, constraints, such as inadequate human and physical capital - in the form of poor education, healthcare system, road and other distribution networks, electricity and other infrastructural amenities - are more likely to undermine economic growth in the long term. As such, the government needs to implement policies that tackles these deficiencies if they are keen on stimulating long-run economic growth. (ii) Given that institutions affect the performance of an economy by their effect on incentives and the cost of exchange and production, their ought to be a collective effort in ensuring the evolution of effective institutions that create a hospitable environment for cooperative and innovative solutions to complex human exchange. (iii) Policies to boost R&D, such as subsidies to business R&D and government involvement in R&D activities that are risky and expensive for businesses to undertake, are equally vital for the growth of income per capita in the long run.

Lastly, although we have attempted to account in our analysis the macroeconomic impact of institutions, there is still a lot to be done in this regard because the manner in which the institutional quality proxy we utilised in our analysis is measured leaves a lot of questions unanswered. For starters, the institutional quality proxy utilised in this study is based on the outcome of the surveys of foreign and domestic investors, in which the respondents subjectively rate the quality of institutional arrangement in their resident country. So, the proxy reflects investors' personal opinions, rather than any formal aspects of the relevant institutional setting. The problem with this is that we cannot explicitly pinpoint, although we can broadly show that institutions matter, the specific rules, legislation, or institutional design - whether formal or informal - that is actually responsible for the institutional outcome been measured. Therefore, a major task for growth economists going forward is to develop a consistent framework that can enable the objective measurement of the formal and informal aspects of institutions.

APPENDIX

A1. Variables Definition and Sources

1. Variable: GDP

- Indicator name: GDP (constant 2010 US$)
- Long definition: GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for

depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2010 U.S. dollars. Dollar figures for GDP are converted from domestic currencies using 2010 official exchange rates. For a few countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions, an alternative conversion factor is used.

- Source: OECD National Accounts data files.

2. *Variable: Gfcf*

- Indicator name: Gross fixed capital formation (constant 2010 US$)
- Long definition: Gross capital formation (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. Fixed assets include land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchase; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Inventories are stocks of goods held by firms to meet temporary or unexpected fluctuations in production or sales, and "work in progress." This is according to the 1993 SNA; net acquisitions of valuables are also considered capital formation. Data are in constant 2010 U.S. dollars.
- Source: OECD National Accounts data files.

3. *Variable: Employment*

- Indicator name: Employment Figure
- Long definition: Employed people are those aged 15 or over who report that they have worked in gainful employment for at least one hour in the previous week or who had a job but were absent from work during the reference week. The working age population refers to people aged 15 to 64. This indicator is seasonally adjusted and it is measured in terms of thousand persons aged 15 and over.
- Source: OECD statistical database.

4. *Variable: Gerd*

- Indicator name: Gross expenditure on R&D (constant 2005 US$)
- Long definition: Gross domestic expenditure on R&D (GERD) is total intramural expenditure on R&D performed in the national territory during a specific reference period.
- Source: OECD statistical database.

5. *Variable: Rule*

- Indicator name: Rule of Law: Estimate

- Long definition: Rule of Law captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.

- Source: Detailed documentation of the World Governance Indicators (WGI), interactive tools for exploring the data, and full access to the underlying source data are available at www.govindicators.org. The WGI are produced by Daniel Kaufmann (Natural Resource Governance Institute and Brookings Institution) and Aart Kraay (World Bank Development Research Group). Citation: Kaufmann, D., A. Kraay and M. Mastruzzi (2010). "The Worldwide Governance Indicators: Methodology and Analytical Issues," World Bank Policy Research Working Paper No. 5430.

A2. List of Countries

S/N	Country	ID	S/N	Country	ID	S/N	Country	ID
1	Mexico	MEX	11	Czech Republic	CZE	21	Norway	NOR
2	Turkey	TUR	12	Italy	ITA	22	Korea Republic	KOR
3	Poland	POL	13	Slovenia	SVN	23	Austria	AUT
4	Slovak Republic	SVK	14	Ireland	IRL	24	Denmark	DNK
5	Greece	GRC	15	United Kingdom	GBR	25	Germany	DEU
6	Hungary	HUN	16	Canada	CAN	26	Japan	JPN
7	Estonia	EST	17	Australia	AUS	27	Finland	FIN
8	Portugal	PRT	18	Belgium	BEL	28	Israel	ISR
9	Spain	ESP	19	France	FRA	29	United States	USA
10	New Zealand	NZL	20	Netherlands	NLD	30	Switzerland	CHE
						31	Sweden	SWE

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