Institutions, Innovation and Economic Growth in European Countries

d'Agostino, Giorgio and Scarlato, Margherita

Roma Tre University

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Giorgio d'Agostino[1], Margherita Scarlato[1,]

[a] *Department of Economics, Roma Tre University*

Abstract

This paper provides an empirical analysis of the linkages between the quality of government institutions and economic growth in the European context, highlighting innovation as the intermediate variable that drives this interplay. We use a standard non-scale R&D-based growth model as a theoretical framework and estimate the balanced growth path of per capita GDP for a sample of European countries and the transitional dynamic after a technological shock. Empirical analysis confirms the importance of technology as an instrument for increasing economic growth and suggests that inclusive institutions strongly affect this impact across the European countries. The magnitude of the effect is high: inclusive institutions redouble the effect of a technological shock on the growth rate of per capita GDP. This result suggests that innovation policies should carefully take into account the institutional setting of the contexts in which they are implemented in order to be effective.

JEL Classification: O30, O41, O43

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*Corresponding author: Margherita Scarlato, Department of Economics, Roma Tre University, Via Silvio D'Amico 77, 00145 Rome, Italy. Email: margherita.scarlato@uniroma3.it.

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1. Introduction

Neoclassical growth theory shows that innovation is a persistent source of economic growth (Romer, 1990; Aghion and Howitt, 1992; Grossman and Helpman, 1991) but it overlooks the role of institutions in molding technological and growth dynamics. Conversely, evolutionary theory considers innovation to be the driving force of economic change and stresses that institutional factors influence the way in which innovative efforts and external knowledge flows are translated in the economic growth process (Fagerberg and Srholec, 2008; Lundvall, 1992, Nelson, 2015).

More broadly, recent studies argue that differences in per capita income can be explained by various institutional features that may prevent a country from adopting the best technologies (Acemoglu et al., 2005; Casson et al., 2009; Tabellini, 2008). For example, institutional failure may emerge when technological advancement represents a threat to ruling groups and these groups consequently decide to block the adoption of innovations to preserve their political power (Acemoglu, 2006; Acemoglu and Robinson, 2000). According to Acemoglu (2012), civil and political rights are strictly intertwined with technological development and the various dynamics of economic growth. Similarly, other studies highlight the engagement of interest groups in rent-protecting activities which may constitute structural barriers to innovation and growth (Dias and McDermott, 2006; Dynopoulos and Syropoulos, 2007; Parente and Zhao, 2006; Van Long and Sorger, 2006). Lastly, Rodriguez-Pose and Di Cataldo (2014) show that the quality of government shapes the set of constraints and incentives in the private sector, affecting the capacity to transform public research and development policies into innovation. What emerges from these fields of research is that inclusive institutions, i.e. institutions that provide incentives and opportunities for a broad cross-section of society (Acemoglu, 2012), are favourable to both technological progress and economic growth.

This paper draws these different strands of literature together and investigates the link between the quality of government institutions and economic growth, highlighting innovation as the intermediate variable that drives this interplay. The key contribution of this paper is to establish an empirical framework in order to consistently estimate the impact of technological progress on per capita GDP growth rates by taking into account the fact that institutional factors influence the diffusion of innovations and, in turn, economic growth[1]. We follow Acemoglu et al. (2014) and consider the measures of government quality obtained from the World Bank Worldwide Governance Indicators (WGI) as proxies for inclusive political institutions. The sample that we use consists of 15 European Union (EU) countries for which we have sufficient data and the time length of the available data covers the period 1960-2010[2]. Our intention is to test if the quality of

[1]Investigating the origin of institutions is beyond the scope of this paper. For a discussion of this issue, see Dari-Mattiacci and Guerriero (2011), Guerriero (2014) and Carmignani (2006)

[2]The choice of this time span is conditioned by the availability of data provided by the World Bank regarding the institutional

government institutions in the European countries contributes to the innovative process, favouring economic growth. Providing further evidence on this issue is relevant to the current policy debate since innovation has been considered as one of the principal objectives of the EU under the general framework of the so-called Europe 2020 growth strategy (European Commission, 2010) and the regional policy framework (Farole et al., 2011).

The empirical analysis is built on the basis of the theoretical framework provided by a standard R&D-based growth model in which constant returns to scale in private inputs are offset by duplication of discoveries and creative destruction effects (fishing out effects) that guarantee decreasing returns to scale across the economic system (Eicher et al., 2000; Eicher, 2001; Jones, 1995; Jones and Williams, 2000; Peretto and Smulders, 2002; Steger, 2005a, 2005b).

Following d'Agostino and Scarlato (2015), we propose a novel interpretation of the standard model by suggesting that institutional factors affecting the interaction process between firms and social context influence the degree of diffusion of the technological knowledge that has already been accumulated. Thus, the positive spillovers generated by inclusive institutions that promote the adoption of new ideas or blueprints may partially offset the negative externalities caused by the fishing out hypothesis. Consequently, inclusive institutions have a positive impact on technological progress and economic growth.

To incorporate these assumptions in the empirical analysis, we propose a two-step strategy for estimating the effect of a permanent technological shock (i.e. an increase in the stock of knowledge) on economic growth, controlling for the quality of institutions. First, we estimate the balanced growth path for the 15 European countries, which is jointly function of private investment and technology[3] and, secondly, we estimate the transitional dynamics of a technological shock. We use the mean intercept and slope of the balanced growth path to estimate the short-run linkages between inclusive institution, technology and economic growth. Our methodology corrects for omitting variable bias, allowing us to omit several control variables that may distort the estimation results in the short-run analysis.

Empirical results confirm the central importance of technological advance for economic growth in Europe, and a positive relationship between inclusive institutions and innovation emerges. Elasticity measures show that enhancing the quality of government institutions may generate strong incentives for knowledge diffusion and the adoption of innovation, thus promoting economic growth. The magnitude of the effect is high: inclusive institutions redouble the effect of a technological shock on the per capita GDP growth rate. In

quality of the EU countries.

[3]**S**ince the theoretical framework is an endogenous growth model, in line with Bond et al. (2010) we account for the long-run contribution of private investment to generate sustained growth. We further extend this analysis and introduce technology as a driver of long-run economic growth.

addition, this effect is positive and significant for different institutional variables and particularly strong when considering the variables that measures political stability and government effectiveness.

The remainder of the paper is organised as follows. In Section 2, we present the estimation strategy. In Section 3, we present the data and variables and in Section 4, we discuss the empirical results. In the final section, we conclude the paper by summarising the main findings and highlighting the relevant policy implications.

2. Estimation strategy

A number of studies analyse the link between institutions, the productivity of economy-wide inputs and the diffusion of knowledge (Ahlerup et al., 2009; Akomak and ter Weel, 2009; Dias and Tebaldi, 2012; Tebaldi and Elmslie, 2008, 2013). In line with the existing literature, we assume that inclusive institutions promote cooperation between firms and researchers, strengthen the flow of knowledge from educated to non-educated workers and speed up the dissemination of ideas. The overall effect is to generate positive spillovers that promote the adoption of new ideas and technologies.

Following our companion paper (d'Agostino and Scarlato, 2015), we embody these assumptions in a standard non-scale R&D-based growth model (Eicher et al., 2000; Eicher, 2001; Jones, 1995; Peretto and Smulders, 2002; Steger, 2005a, 2005b) that takes in account the positive spillovers related to the quality of institutions. A formal representation of the model is presented in Appendix A, whereas for an extensive discussion of the main hypotheses of the model we refer to our companion paper (d'Agostino and Scarlato 2015).

The model considers a closed economy consisting of three sectors that produce, respectively, a single homogeneous final good (FO sector), different varieties of intermediate capital goods (CG sector) and blueprints (R&D sector). Unlike previous contributions to this field (Eicher et al., 2000; Eicher, 2001; Jones, 1995; Peretto and Smulders, 2002, Steger 2005a, 2005b), we assume that the interaction process between firms and institutional and social factors determines the degree of diffusion of knowledge and the adoption of new ideas or blueprints. As a consequence, the background institutional context influences technological progress and economic growth.

In accordance with Steger (2005b), the growth rate of the stock of knowledge (or technology) in the economy is linked to the level of accumulated technological knowledge and the stocks of private capital (K) and labour (L) employed in the R&D sector. This function can be expressed as follows:

$$\dot{A} = J = A^{\eta_A} \left[(1 - \theta) L \right]^{\eta_L} \left[(1 - \phi) K \right]^{\eta_K} , \tag{1}$$

where η_A, η_L and η_K describe the productivity parameters of the stock of knowledge (A), private capital (K) and labour (L), respectively. These parameters are given the sum of the firm level productivity, described by the apex P, and the external effects across the entire system (described by the apex e). Formally, $\eta_L = \eta_L^P + \eta_L^e$, $\eta_K = \eta_K^P + \eta_K^e$, $\eta_A = \eta_A^{SO} + (1 - \eta_K)$, with η_A^{so}, $\eta_K^P\ \eta_L^P > 0$ and $\eta_K^e\ \eta_L^e < 0$ and where η_A^{SO} is the degree of diffusion of the existing knowledge already accumulated in the R&D sector (Steger, 2005a; Jones, 1995).

This model formulation allows for negative externalities associated with private resources (η_k^e, $\eta_L^e < 0$), which are consistent with constant returns to scale in private inputs ($\eta_K^p + \eta_L^p = 1$), but decreasing returns to scale for the economic system as a whole. Within this formulation, increasing values of η_k^e and η_L^e reduce the overall productivity of the share of private capital ($1 - \phi$) and labour $(1 - \theta)$ and, given that $\eta_A = \eta_A^{SO} + (1 - \eta_K)$, these externalities also constrain the spread of existing knowledge.

The model formalises the productivity of technology η_A as the sum of two opposite effects: a negative effect depending on the inverse of the productivity of private capital $1 - \eta_K$ and a positive one depending on the spillover effect η_A^{SO}. These two opposite effects identify, respectively, the negative externality linked to the fishing out assumption and the positive externality due to the quality of government institutions that improve the diffusion of the existing stock of knowledge.

In the theoretical model, the negative externalities due to the fishing out assumption constrain the accumulation of new technology and impede the rise of increasing returns to scale. As a consequence, the model belongs to the AK family and the estimation strategy must account for recent contributions summarised in Bond et al. (2010). The simplest way to represent an AK model is as follows:

$$\gamma_{it}^c = \alpha_1 \gamma_{t-1}^c + \beta \Delta x_{it} + \zeta x_{it-1} + e_t + f_i + \Delta \epsilon_{it} \tag{2}$$

where γ_{it}^c is the growth rate of the per capita private consumption (which is proxied by the growth rate of per capita GDP) and x_{it} is a vector that account for the country-specific steady-state growth rate (see Appendix A equations **??** and **??**). The first difference expression of this model formulation is obtained by assuming that the level formulation of Equation (**??**) contains a non-stationary process c_{it} that in the first difference is equal to $\Delta c_{it} = \theta_0 + \theta_1 x_{it-1} + u_{it}$. Moreover, unlike the model of Bond et al. (2010), private capital and consumption along the balanced growth path grow at a constant rate determined by the steady state conditions of private capital (β_K), whereas the long-run growth rate of technology along the balanced growth path is determined by the steady state conditions of technology (β_A). Vector x_{it} and its lagged value x_{it-1} account for both of these conditions such that $x_{i,t}, x_{i,t-1} = [K, A]$.

Furthermore, in line with steady-state conditions (Equations **??** and **??** in Appendix A), the inclusion of x_{it-1} takes into account the fact that past values of private capital and technology predict a more rapid long-run growth rate and that the positive and significant parameters ζ associated with x_{it-1} allow for the presence of endogenous growth (Bond et al., 2010). In addition, e_t is the time fixed effect and ϵ_{it} is the error term. Because (**??**) is expressed in the first difference, the country-specific fixed effects cancel out. If we consider the steady-state in which $x_{it} = x_i$ and suppose that output per worker grows at country-specific rate g_i, we obtain:

$$g_i = \frac{e_t}{1-\alpha} + \left(\frac{\zeta}{1-\alpha}\right) x_i, \tag{3}$$

where the formulation accounts for the hypothesis of heterogeneous steady-state growth rates that increase with the share of private capital in total output and the level of technology. When the parameter vector is $\zeta > 0$, this hypothesis is validated.

The inclusion of the steady-state path in Equation (**??**) allows us to identify the estimated parameters without omitted variable bias. Bond et al. (2010) estimate a simple formulation of Equation (**??**) by using instrumental variables to reduce the presence of serial correlation between the lagged values of the dependent variable and error terms. We adopt a similar approach by using an instrumental variables (IV) estimator with an instrument matrix dated $t-2$ and earlier to allow for the expected MA(1) error structure in these first-differenced model specification. More specifically, we use lagged observations from $t-2$ to $t-6$ on the per capita GDP growth rate on the private capital and technology growth rates, and on the lagged values of the last two variables by level and lagged observations dated $t-2$ and $t-3$ on a set of additional instruments (trade and government spending as a share of GDP). Following this outline, Equation (**??**) is estimated with a ADL(p,q) model, specified as:

$$\gamma^c_{it} = \alpha_1\gamma^c_{t-1} + ... + \alpha_p\gamma^c_{t-p} + \beta_1\Delta x_{it} + ... + \beta_q\Delta x_{it-q} + \zeta_1 x_{it-1} + ... + \zeta_q x_{it-q} + d_t + q_i + \delta_{it}, \tag{4}$$

where d_t is the time-specific idiosyncratic term, δ_{it} is the error term, and x_{it} is again a vector defined as $x_{it} = [K, A]$.

The parameters estimated by Equation (**??**) are used to obtain the long-run elasticity measures of private capital and technology with respect to the per capita GDP growth rate (called the long-run elasticity level effect), which are given by $\bar{g}^L_i = \frac{\zeta_1+....+\zeta_p}{1-\alpha_1-...-\alpha_p}\frac{\bar{x}_i}{\bar{\gamma}^c_i}$, where $\bar{x}_i$ is an interquartile mean vector that includes investment in private capital and technology and $\bar{\gamma}^c_i$ is an interquartile mean vector of the per capita GDP growth rate for each country i.

These elasticity measures describe the initial steady-state level for each country. In addition to this gauge of elasticity, we also calculate long-run elasticity measures that accounts for the slope of the balanced growth path (called the long-run elasticity growth effect). Like the previous measures, these elasticity are defined as $\bar{g}_i^G = \frac{\beta_1 + \ldots + \beta_p}{1 - \alpha_1 - \ldots - \alpha_p} \frac{\gamma_{\bar{x}_i}}{\bar{\gamma}_i^c}$, where $\gamma_{\bar{x}_i}$ is the interquantile mean value of $x_{it} = [K, A]$ in first-difference form.

To complete the empirical framework, we analyse how the institutional variables disseminate their effects. We estimate two auxiliary regressions that account for the direct influence of the institutional variables on technology and the indirect effects of institutions on the per capita GDP growth passing through a technological shock. We specify the following auxiliary regressions:

$$\gamma_{it}^a = a_{11}\gamma_{t-1}^a + d_{12}\Delta z_{it} + d_{13}d\_\bar{g}_i^a + \Delta\phi_{it} \tag{5}$$

$$\gamma_{it}^c = a_{21}\gamma_{t-1}^a + d_{22}\Delta z_{it} + d_{23}d\_\bar{g}_i^k + \Delta\psi_{it}. \tag{6}$$

where γ_{it}^a and γ_{it}^c describe the growth rates of technology and per capita private consumption (proxied by the per capita GDP) and z_{it} is a vector of institutional variables (see Section **??**). All of these equations include error terms ($\Delta\mu_{it}$, $\Delta\phi_{it}$ and $\Delta\psi_{it}$). Equations (5) and (6) are estimated with one lag for each variables, using an IV approach. In line with Roodman (2009), we constrain the instruments matrix to increase the consistency of the GMM estimators when the sample size is characterised by a short-time span.

To estimate short-run relationships efficiently, we control for the specific steady-state path of each country. As a consequence, in each specification we take into account the long-run elasticities estimated using Equation (**??**). To accomplish this task, we include in each equation a set of specific time trends ($d\_\bar{g}_{it}$) with initial values equal to $\bar{g}_i^L$ and growing according to $\bar{g}_i^G$. For example, if the long-run elasticity growth effect for a given country is equal to 1.2 and its long-run elasticity level effect is 1.3, then the specific country trend is obtained by multiplying the value of the long-run elasticity level effect by 1.2, for each year.

Furthermore, to consider that consumption grows at a constant rate equal to β_K along the balanced growth path and that the long-run technology growth rate is β_A, we include country-specific time trends linked to technology ($d\_\bar{g}_i^a$) in the first regression and country-specific time trends linked to private capital ($d\_\bar{g}_i^k$) in the second one.

We use the parameters estimated from Equation (**??**) and (**??**) to obtain two sets of elasticity measures that show the effect of the institutional variables on the technology growth rate and on the per capita GDP growth rate after a shock on technology (i.e. an exogenous increase in the stock of knowledge).

The first set of elasticity measures is given by:

$$e_{\gamma^a} = d_{12}\frac{\bar{z}}{\bar{\gamma}^a}, \tag{7}$$

where $\bar{z}$ is the interquantile mean value of each institutional variable. These elasticity measures account for the direct impact of the institutional variables on the technology growth rate when a shock on technology occurs.

The second set of elasticity measures accounts for the net impact of a technological shock on the per capita GDP growth rate when we control for the positive spillovers linked to the quality of government institutions:

$$e_{\gamma^c} = d_{21}\frac{\bar{\gamma}^a}{\bar{\gamma}^c} + d_{22}\frac{\bar{\gamma}^a}{\bar{\gamma}^c}. \tag{8}$$

where the first part of (**??**) represents the direct impact of the technological shock on per capita GDP growth rate, whereas the second part represents the effect of the institutional variables which amplifies the total impact of the shock.

3. Data and variables

The empirical analysis is based on two different periods for a set of 15 European countries. The set of countries examined, along with the descriptive statistics for each variable, is reported in Appendix B. Data covering the 1960-2010 period are used to estimate the steady-state level of the economy for each country (**??**), whereas those covering the 1996-2010 period are used to estimate Equations (**??**) and (**??**) and identify the positive spillovers linked to institutional factors. The choice of the time span is conditioned by the availability of the measures of the institutional quality provided by the World Bank.

We use different data sources to identify the main economic variables. The first is the Penn World Table dataset edited annually by the University of Pennsylvania. This dataset contains information on per capita GDP growth rates at constant prices in a chained series (and the corresponding per capita growth rates) and on private capital. From this source, we extract the per capita GDP growth rate and the ratio of investment in physical capital to GDP used to measure the growth rate of private capital and the share of private capital in GDP x_{it} in Equation (**??**). To account for technology growth rate γ_{it}^a and the technology level a_{t-1}, we collect data from the AMECO database which is redacted yearly by the Statistical Office of the European Commission. From this database, we extrapolate the annual contribution of technology to total factor productivity at constant 2000 prices[4].

As far as institutions are concerned, several indicators are available from the literature (e.g. Flachaire et al., 2014). Our analysis focuses on political and economic institutions which are crucial for assessing the quality of government in line with the definition of inclusive institutions provided by Acemoglu (2006, 2012)

[4]Since our model explicitly accounts for blueprint prices (see Equation **??**), we prefer to use the annual contribution of technology to total factor productivity to measure technology instead of other variables such as ICT patents.

and Acemoglu et al. (2005, 2016). In more detail, we consider six variables reflecting the characteristics of the political system (voice and accountability, and political stability and the absence of violence) and the quality of governance (government effectiveness, control of corruption, rule of law and regulation quality). While these variables do not cover all the relevant institutional dimensions, they include some of the most important aspects of the institutional context affecting innovative activities.

These variables are extracted from the Worldwide Governance Indicators (WGIs) provided by the World Bank (Kaufmann et al., 2010). The WGIs dataset brings together and summarise information from 30 data sources that report the views and experiences of citizens, entrepreneurs, and experts in the public, private and non-governmental organisation (NGO) sectors around the world on the quality of various aspects of governance. They draw on four distinct data sources: surveys of households and firms (comprising the Afro-barometer survey, Gallup World Poll and Global Competitiveness Report Survey), commercial business information providers (comprising the Economist Intelligence Unit, Global Insight and Political Risk Services), NGOs (made up of data sources including Global Integrity, Freedom House and Reporters Without Borders) and public sector organisations (composed of data sources including the Country Policy and Institutional Assessment of the World Bank and regional development banks, the European Bank for Reconstruction and Development Transition Report and the French Ministry of Finance Institutional Profiles Database). All these variables range from -2.5 to 2.5 where 2.5 describes the best performance.

We briefly describe the variables we have chosen. The voice and accountability variable captures perceptions of the extent to which a country's citizens are able to participate in selecting their government and perceptions of freedom of expression, association and the press. The political stability and absence of violence variable measures perceptions of the likelihood that the government will be destabilised or overthrown via unconstitutional or violent means, including politically motivated violence and terrorism. This variable accounts for government instability and the presence of terrorist organisations working to destabilise internal institutions. High values for these political variables imply low level of uncertainty, which, in turn, is favorable to long-term innovative investments and strong checks and balances, political participation and accountability which reduce the ability of special interests to influence policy. Overall, these proxies for good-quality political institutions represent crucial conditions for effective states (Acemoglu, 2000; Acemoglu and Robinson, 2016; Besley et. al., 2012).

We then consider three variables that are related to the state capacity and the quality of governance and reflect the ability of the government to implement efficient policies and the incentives provided to innovation and cooperative interactions in the economic system (Acemoglu and Johnson, 2005; Acemoglu et al., 2005; Besley et al., 2009; Charron et al., 2014; Haggard and Tiede, 2011; Rodriguez-Pose and Di Cataldo, 2014). In more detail, the government effectiveness variable captures perceptions of the quality of public services, the quality of the civil service and its degree of independence from political pressure, the quality of policy formulation and implementation, and the credibility of the government's commitment to these policies. The control of corruption comprises perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as the ”capture” of the state by elites and private interests. The rule of law variable captures perceptions of the extent to which agents have confidence in and abide by the rules of society, in particular, the quality of contract enforcement, property rights, the police and courts, and the likelihood of crime and violence. Finally, to account for the efficiency of economic institutions, we collect data on regulatory quality which capture perceptions of the government's ability to formulate and implement sound policies and regulations that permit and promote private sector development through a reduction in market imperfections and the long-lasting accumulation of monopolistic rents (Acemoglu et al., 2005; Barbosa and Faria, 2011).

4. Results

This section provides an extensive overview of the results obtained following the estimation strategy outlined in Section 2. As a preliminary analysis, Table **??** reports the Levin-Lin-Chu (Levin et al., 2002) and Im-Pesaran-Shin (Im et al., 2003) unit-root test statistics for all of the main variables included in the long-run regression, specified with and without a linear trend. The second test statistic may be more powerful for heterogeneous panels because it is based on an appropriately standardised average of the individual augmented Dickey-Fuller test and thus has a standard normal limiting distribution. Under the null hypothesis the Levin-Lin-Chu test statistic states that there is no unit-root in the series, whereas the Im-Pesaran-Shin test statistic states that there is a unit-root.

Table 1: Levin-Lin-Chu and Im-Pesaran-Shin tests for unit-root in heterogeneous panels

	Levin-Lin-Chu with trend	Levin-Lin-Chu	Im-Pesaran-Shin with trend	Im-Pesaran-Shin
a_{t-1}	-3.644	-3.697	2.013	4.838
	(0.037)	(1.000)	(0.978)	(1.000)
hp_a_{t-1}	-8.521		-3.114	
	(0.999)		(0.000)	
k_{t-1}	-9.543	-11.287	-3.979	-2.922
	(0.012)	(0.057)	(0.000)	(0.002)
γ^c	-8.402	-9.412	-2.800	-1.792
	(1.000)	(1.000)	(0.0039)	(0.037)
γ^a	-8.182	-11.667	-3.175	-3.957
	(1.000)	(1.000)	(0.001)	0.000)
γ^k	-8.402	-9.412	-2.800	-1.792
	(1.000)	(1.000)	(0.003)	(0.037)

Notes: The first two columns report the Levin-Lin-Chu test statistics (Levin et al., 2002) with and without a linear trend, whereas the other two report the Im-Pesaran-Shin test statistics (Im et al., 2003) with the same specification. Three lags are used in the test statistic. The null hypothesis in the Levin-Lin-Chu test statistic is the absence of a unit-root in the series, whereas the Im-Pesaran-Shin test statistic allows for the presence of a unit-root in the series.

In line with Equation (??), we apply these tests to both the level and first difference in private capital and technology and to the per capita GDP growth rate. A comparison of the test statistics shows that the share of private capital in GDP rejects the null hypothesis of stationarity when the Levin-Lin-Chu test statistic without a linear trend is considered, whereas the unit-root hypothesis is rejected by the Im-Pesaran-Shin test statistic in the specifications with and without a linear trend. In contrast, this test statistic does not reject the unit-root hypothesis when technology is considered. To maintain consistency with the specification of (??), instead of first-differencing this variable, we use a standard Hodrick–Prescott filter to extract the linear trend from the series, and then use only the residual component in the long-run estimations, hp_a_{it-1}. As confirmed by the statistics reported in Table **??**, the technology variable obtained from this procedure is stationary.

Table **??** reports the estimates of our baseline specification of the long-run GDP growth rate based on Equation (??) where time fixed effects are included. The set of IVs common to the specifications is dated $t-2$ and earlier to allow for the MA(1) error structure in the first-differenced model specifications. In more detail, we use lagged observations dated $t-2$ to $t-6$ on the log value of per capita GDP and the share of private capital in GDP and technology, and employ lagged observations dated $t-2$ and $t-3$ on a set of additional instruments (trade and government spending as a share of GDP). The IVs are the first lag of the per capita GDP growth rate (γ^c_{it-1}) and the levels and first differences of the shares of private capital (k_{it-1}, γ^k_{it}) and technology (hp_a_{it-1}, γ^a_{it-1}). The instruments chosen in line with Bond et al. (2010) are validated by the Sargan-Hansen test statistics. Standard errors robust to heteroskedasticity and autocorrelation are used across all reported estimates (Cushing and McGarvey, 1999).

The first column in Table **??** reports the results for a general dynamic specification with up to three lags, and the second column excludes one lag from all of the variables. Long-run elasticity measures are reported for each specification at the bottom of the table. The IV estimates produced by our general dynamic model largely suggest that private capital and technology exert significantly positive long-run effects on both the level and slope of the long-run growth path of GDP. The long-run parameters are quite stable along the two specifications.

The range of parameters for k_{it-1} is higher than that estimated by Bond et al. (2010) who find parameters ranging from 0.007 to 0.019 for the same variable. However, unlike Bond et al. (2010), our analysis does not account for lower income countries and uses a different sample period. Moreover, unlike the analysis in Bond et al. (2010), the exclusion of one lag value for each variable (column II) does not change the main results of the analysis.

In particular, when measuring the long-run elasticities, we find that a permanent 1% increase in the technology predicts an upward shift of about 0.117% and 0.772% in the level and slope, respectively, of the

Table 2: Baseline specification: results in first differences

	Full sample		Full sample	
γ^c_{it-1}	0.488	***	0.593	***
	(0.152)		(0.111)	
γ^c_{it-2}	0.077	*	0.052	*
	(0.054)		(0.039)	
γ^c_{it-3}	0.085	*		
	(0.058)			
γ^k_{it}	0.108	***	0.102	***
	(0.024)		(0.022)	
γ^k_{it-1}	-0.019		-0.030	*
	(0.017)		(0.017)	
γ^k_{it-2}	0.004		0.001	
	(0.008)		(0.008)	
γ^k_{it-3}	-0.016	***		
	(0.006)			
γ^a_{it}	0.846	***	0.875	***
	(0.087)		(0.090)	
γ^a_{it-1}	-0.326	***	-0.417	***
	(0.122)		(0.087)	
γ^a_{it-2}	-0.030		-0.009	
	(0.058)		(0.054)	
γ^a_{it-3}	-0.015			
	(0.051)			
k_{it-1}	0.025	***	0.025	***
	(0.010)		(0.009)	
hp_a_{it-1}	0.079	***	0.095	***
	(0.036)		(0.039)	
Time fixed effect	yes		yes	
Long-run elasticity:				
growth effect private capital	0.025		0.025	
level effect private capital	0.692		0.697	
Long-run elasticity:				
growth effect technology	0.726		0.679	
level effect technology	0.117		0.141	
Hansen J test	10.098		10.517	
	0.607		0.651	
Log-likelihood	-613.970		-630.682	
Number of observations	450		450	

Notes: The dependent variable is the growth rate of per capita GDP. Standard errors are reported in parentheses. *, ** and *** represent significance at the 0.10, 0.05 and 0.01 levels, respectively. Standard errors robust to heteroskedasticity and autocorrelation are used across all reported estimates. The set of IVs common to all specifications is dated $t-2$ and earlier to allow for the MA(1) error structure in the first-differenced model specifications. We use lagged observations dated $t-2$ to $t-6$ on the log value of per capita GDP and the share of private capital in GDP and technology, and employ lagged observations dated $t-2$ and $t-3$ on a set of additional instruments (trade and government spending as a share of GDP). The IVs are the first lag of the growth rate of per capita GDP and the levels and first differences of the shares of private capital and technology. The number of lagged values for each specification is chosen in accordance with the Akaike Information Criterion.

long-run GDP growth path. In addition, we find that the growth effects of variations in technology are stronger than those of private capital.

Proceeding with the outline described in Section 2, Table **??** reports the estimation results for the dynamic equation of the technology growth rate described in (**??**). The specifications report standard errors that are robust to heteroskedasticity and autocorrelation (Cushing and McGarvey, 1999). Moreover, the use

Table 3: Regression results of a technological shock on the technology growth rate controlling for institutional variables

	I	II	III	IV	V	VI
γ^a_{it-1}	0.107 *	0.156 ***	0.151 ***	0.099	0.088	0.075
	(0.062)	(0.062)	(0.061)	(0.071)	(0.066)	(0.077)
Voice and accountability	1.109 ***					
	(0.140)					
Political instability and absence of violence		1.180 ***				
		(0.159)				
Government effectiveness			0.774 ***			
			(0.094)			
Control of corruption				0.834 ***		
				(0.103)		
Rule of law					1.021 ***	
					(0.118)	
Regulatory quality						1.063 ***
						(0.160)
Technology fixed effect	yes	yes	yes	yes	yes	yes
Short-run elasticities	1.837	1.599	1.716	1.921	1.902	1.442
Hansen J test	16.735	14.493	15.814	15.569	16.042	14.431
	0.541	0.696	0.606	0.623	0.590	0.344
Log-likelihood	-444.172	-413.821	-446.709	-446.155	-445.133	-445.689
Number of observations	225	210	225	225	225	225

Notes: The dependent variable is the technology growth rate. Standard errors are reported in parentheses. * , ** and *** represent significance at the 0.10, 0.05 and 0.01 levels, respectively. Standard errors robust to heteroskedasticity and autocorrelation are used across all reported estimates.The set of IVs common to all specifications is dated $t-2$ and earlier to allow for the MA(1) error structure in the first-differenced model specifications. We use lagged observations dated $t-2$ to $t-6$ on the log value of per capita GDP and the share of private capital in GDP and technology, and employ lagged observations dated $t-2$ and $t-3$ on a set of additional instruments (trade and government spending as a share of GDP). The IVs are the first lag of the per capita GDP growth rate and the levels and first differences of the shares of private capital and technology.

of one lag for endogenous variable γ^a_{it-1} in accordance with the Akaike and Schwarz information criteria (not reported) is avoided by employing the residual serial correlation Lagrange Multiplier test, which accepts the null hypothesis of no serial correlation in the residuals for all specifications (not reported). In line with the empirical outline described in Section 2, the specification includes the country-specific time trends linked to technology ($d\_\bar{g}^a_i$).

The six columns in Table ?? report the results for specifications including the sequential addition of each of the identified variables, describing institutional factors that reflect the theoretical outline. More specifically, we consider voice and accountability (I), political stability and absence of violence (II), government effectiveness (III), control of corruption (IV), rule of law (V) and regulation quality (VI). The sequential inclusion of these variables crucially depends on strong correlations between the various identified elements which may bias the estimated parameters, and accordingly the elasticity measures reported after them.

Looking at all six columns in Table 3, we can see that each institutional variable has a parameter which is positive and significant at the 1% level. This result is in line with the literature that we have quoted in Section 1 on the relationships between institutions, innovation and growth.

The estimated parameters for the six institutional indicators are in a range varying from 0.774 (government effectiveness) to 1.109 (political instability and absence of violence). Since these parameters are not comparable, we consider the elasticity measures for the full-sample analysis at the bottom of the table. To interpret these measures, we recall that each institutional variable ranges from -2.5 to 2.5, with 2.5 describing the best performance. In our sample, only political stability and absence of violence (for Spain and Greece) and the control of corruption (for Greece and Italy) have negative values, whereas in the other cases these variables range from 0 to 2.5. Hence, a unitary increase in these variables represents a large institutional change, representing, for example, the gap between France and Italy, when the control of corruption is accounted for. We have a mean elasticity of about 1.7% which ranges over an interval with extreme values represented by the elasticity of the control of corruption (1.92%) and regulation quality (1.44%.).

Table 4: Regression results of a technological shock on the GDP growth rate controlling for institutional variables

	I		II		III		IV		V		VI	
γ^a_{it-1}	0.865	***	0.897	***	0.949	***	1.017	***	0.972	***	0.887	***
	(0.101)		(0.098)		(0.080)		(0.083)		(0.082)		(0.091)	
Voice and accountability	1.573	***										
	(0.158)											
Political stability and absence of violence			1.707	***								
			(0.205)									
Government effectiveness					1.135	***						
					(0.111)							
Control of corruption							0.997	***				
							(0.114)					
Rule of law									1.302	***		
									(0.136)			
Regulatory quality											1.540	***
											(0.165)	
Private capital fixed effect	yes		yes		yes		yes		yes		yes	
Short-run elasticities	0.621		0.593		0.434		0.374		0.480		0.535	
Hansen J test	12.432		13.706		11.701		13.850		13.741		13.661	
	0.824		0.748		0.862		0.739		0.746		0.751	
Log-likelihood	-437.571		-413.223		-437.428		-440.081		-438.531		-438.096	
Number of observations	210		196		210		210		210		210	

Notes: The dependent variable is the growth rate of per capita GDP. Standard errors are reported in parentheses. *, ** and *** represent significance at the 0.10, 0.05 and 0.01 levels, respectively. Standard errors robust to heteroskedasticity and autocorrelation are used across all reported estimates. The set of IVs common to all specifications is dated $t-2$ and earlier to allow for the MA(1) error structure in the first-differenced model specifications. In more detail, we use lagged observations dated $t-2$ to $t-6$ of the log value of per capita GDP and the share of private capital in GDP and technology, and employ lagged observations dated $t-2$ and $t-3$ on a set of additional instruments (trade and government spending as a share of GDP). The IVs are the first lag of the per capita GDP growth rate and the levels and first differences of the shares of private capital and technology.

In more detail, the first column in Table 3 shows that a 1% variation in voice and accountability lifts the technology growth rate by about 1.837%, whereas a 1% increase in political stability and the absence of violence increases it by about 1.599%. These results confirm that long-term investment in innovation in the EU require a stable policy environment and an accountable political system that deliver policies in the interests of society as a whole (Aisen and Veiga, 2013; Besley et al., 2013).

Columns III and IV report the results for the influence of government effectiveness and corruption control on the technology growth rate. In both cases, the literature suggests that the effect of low-quality institutions is to reduce the incentives to productive investment, innovation activity and economic performance (Salinas-Jimenez and Salinas-Jimenez, 2006, d'Agostino et. al., 2012, 2016). Our estimates are consistent with previous results and suggest that corruption conditions the rate of technological progress in the 15 EU countries in the sample. When short-run elasticities are considered, we find that a 1% variation in the control of corruption and government effectiveness produces an increase in the technological growth of about

1.716% and 1.921%, respectively.

Similarly, as expected (Acemoglu and Johnson, 2005; Haggard and Tiede, 2011), we find that the elasticity measure for the rule of law variable is 1.902%, capturing both the canonical impact of property rights and contract enforcement on innovative investments and the role of personal security. Last, the elasticity of technology with respect to the regulation quality variable is about 1.442%, in line with the literature that predicts that a reduction of long-lasting accumulation of monopolistic rents boost innovation diffusion (Acemoglu et al., 2005; Barbosa and Faria, 2011; Blind, 2012).

Table **??** reports the estimated results for the regression of a technological shock on the per capita GDP growth rate when the six variables related to the quality of government institutions are taken into account. The table is organised in the same way as Table **??**. Accordingly to the empirical outline described in Section 2, the table includes the country-specific time trends linked to private capital ($d\_\bar{g}_i^k$).

The first row in the table shows that a shock on technology has a positive and significant impact on the per capita GDP growth. If we convert these parameters into elasticity measures (not reported), we find that a unitary increase of γ_{t-1}^a has an effect on the per capita GDP growth of between 0.240 and 0.588, with a mean value of 0.508. As a consequence, a unitary shock on γ_{t-1}^a increases, on average, γ_t^c by less than half a percentage point. However, under the perspective of this paper, the omission of the institutional effect understimate the impact of technology on economic growth.

To gauge the net effect of the technological shock on the GDP growth rate, we have to control for the effect of the institutional variables that mediate the impact. At the bottom of the table, we report the elasticity measures, ($d_{22}\frac{\bar{\gamma}^a}{\bar{\gamma}^c}$), described in the second part of Equation (8). These measures show that the institutional variables amplify the technological shock on the economic growth with an effect ranging from 0.383 to 0.657 and with a mean value of 0.506. By summing the mean elasticity and the elasticity that does not account for the institutional quality variables (0.508), we have a net elasticity (Equation 8) equal to 1.014. This result confirms that the institutional variables that proxy inclusive institutions strongly amplify the way in which a technological shock propagates its effect on the GDP growth rate, with a positive influence that redoubles the initial impact.

Lastly, Table 5 reports the net elasticities of a technological shock on the GDP growth rate, controlling for each institutional variable. The table also reports bootstrapped standard errors and the standard significance levels. The table shows little variation for the specific effects of different institutions, even if the variable related to political stability and absence of violence looks more important than the others (with an elasticity measure of 1.139). This result is in line with the literature and shows that political instability, by increasing uncertainty for risky investments and by shortening the horizon of policy-makers, leading to sub-optimal policies, is seriously harmful to economic performance (Aisen and Veiga, 2013; Besley et al., 2012, 2013).

Table 5: Net elasticities of a technological shock on the GDP growth rate, controlling for institutional variables

Voice and accountability		Political stability and absence of violence		Government effectiveness		Control of corruption		Rule of law		Regulation quality	
0.862	***	1.139	***	0.989	***	0.962	***	1.049	***	1.091	***
(0.131)		(0.151)		(0.098)		(0.097)		(0.116)		(0.127)	

Notes: The net elasticity measures are obtained from the coefficients presented in Table 4. These elasticity measures are carried out at the interquartile mean of the sample. Bootstrapped standard errors (10.000 replications) are in parenthesis, while the asterisks give the *p-value* significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

5. Conclusions

The main contribution of this paper is to explore the empirical relationship between institutions, innovation and economic growth for a sample of European countries. We use a non-scale R&D-based growth model proposed by Steger (2005a, 2005b) as a theoretical framework for the empirical analysis.

We apply a two-step strategy for the estimation of the effect of a technological shock (i.e. a positive variation in the stock of knowledge) on economic growth, controlling for the quality of institutions. In this perspective, we first estimate the balanced growth path for the 15 European countries and, secondly, we estimate the short-run transitional dynamics of a technological shock. We use the mean intercept and slope of the balanced growth path to estimate the short-run linkages between inclusive institution, technology and economic growth. Our methodology corrects for omitting variable bias, allowing us to omit several control variables that may distort the estimation results in the short-run analysis.

The empirical findings confirm that the quality of government institutions, and the stability of the political system and government effectiveness in particular, have significant positive effects on the growth of both technology and GDP.

These findings have a number of policy implications. Overall, our results suggest that, to be effective, traditional policies of subsidising firms for innovation and providing incentives to innovate must be accompanied by appropriate institutional conditions that deliver the kind of interactions and feedbacks needed to translate innovative efforts into economic growth. As a consequence, reforming institutions with the aim of improving the quality of governance and political systems as a whole may generate strong incentives for knowledge diffusion and the adoption of technological innovation, thus promoting economic growth.

Finally, this analysis can be considered a preliminary step for further research and suggest that to fully capture the process of technological advance and economic growth, we need to explain the microeconomic level of the relationship between institutional variables and innovation and integrate the standard neoclassical growth model with a broader analysis of the interplay between market and non-market factors that drive technological change.

Appendix A: Theoretical framework

Let's consider a sector comprising a large number of firms, n_{FO}, ordered on the interval $[0, 1]$. The firms produce a single homogeneous good that is sold in a competitive market and can be consumed or invested. The production function faced by the firms in the FO sector is:

$$Y = (\theta L)^{\sigma_L} \int_0^A [\phi x(i)]^{\sigma_K} \, di \quad with \, \sigma_L, \sigma_k < 1 \, and \, \sigma_L + \sigma_k = 1, \tag{A.9}$$

where Y is the final output and L is the stock of labour in the entire economic system which grows at constant rate $\dot{L} = nL$ (where n is the sum of the labour employed in the FO and the R&D sectors). The variable $x(i)$ is the number of intermediate capital goods of type i produced in the CG sector that are ordered in the interval $[0, A]$, where A describes the availability of intermediate capital goods at every point in time. In addition, θ and ϕ are the shares of intermediate goods and labour employed in the FO sector $[0 \leq \theta, \phi \leq 1]$, where $[1 - \theta, 1 - \phi]$ are the shares of the same variables in the R&D sector.

Since the elasticity of substitution between different capital goods is constant and equal to $\epsilon = (1/1 - \sigma_K)$[5] and given the symmetry of $x(i)$ [6], the technology behind the production of final output (**??**) can be rewritten as:

$$Y = A^{1-\sigma_K} (\theta L)^{\sigma_L} (\phi K)^{\sigma_K} , \tag{A.10}$$

which states that total factor productivity A may change according to the number of intermediate capital goods. Consequently, given that the FO sector is a perfect competition sector[7], the optimal demand price for capital goods is given by $P_D^{FO} = \left[\frac{(\epsilon-1)}{\epsilon} \frac{Y}{\phi K}\right]$[8]. Given Equation (**??**), the dynamic of the aggregate capital stock is given by:

$$\dot{K} = Y - C = A^{1-\sigma_K} (\theta L)^{\sigma_L} (\phi K)^{\sigma_K} - C, \tag{A.11}$$

where C is total consumption.

The different varieties of capital goods $x(i)$ are produced in a separate sector comprising a large number of

[5] The last equation leads to the definition $\sigma_k = \frac{\epsilon-1}{\epsilon}$.

[6] Following d'Agostino and Scarlato (2015), the solution for the profit maximisation process in the CG sector states that every firm sets the same price and sells the same quantity of the durable good it produces. Since intermediate goods and capital are linked by the relation $K = \int_0^A xdi = Ax$, where x is the optimal quantity of intermediate goods sold, this leads to the symmetry of $x(i)$.

[7] The production function in (**??**) is required to exhibit constant returns to scale in private inputs to guarantee competitive equilibrium in the FO sector.

[8] From an algebraic point of view, the last equation is obtained by the first derivative of (**??**) with respect to K where we substitute $\epsilon = 1/1 - \sigma_K$.

firms ordered in an interval $[0, A]$. To start producing capital good x, each firm needs to buy a blueprint from the R&D sector, to become the only producer of that variety of good in a monopolistic regime. Consequently, each firm determines the optimal quantity of capital goods to sell to the FO and R&D sectors to maximise its operating profit given by $\pi = [p(x) - r]\, x$, where $p(x)$ is the price of the good and r is the gross interest rate. The standard solution for maximising profit defines the optimal quantity x and price $p(x)$ in the CG sector. Moreover, because the other two sectors include a large number of firms, the elasticity of substitution amongst capital goods is equal to the respective price elasticities of demand in the FO (denoted by ϵ_1) and R&D sectors (denoted by ϵ_2). Accordingly, we can simplify the model by assuming that $\epsilon = \epsilon_1 = \epsilon_2$[9], such that $P_D = P_D^{R\&D} = P_D^{FO} = \left[\frac{(\epsilon-1)}{\epsilon} \frac{Y}{\phi x}\right]$ [10] where $P_D^{R\&D}$ is the demand price in the R&D sector. Given that the demand and supply prices are the same ($P_D = P_S$) in equilibrium, we can rearrange the operating profit function as $\pi = \left[\frac{(\epsilon-1)}{\epsilon} \frac{Y}{\phi x}\right] x - rx$, which yields the optimal capital goods supply price $P_S = \left[\frac{\epsilon}{\epsilon-1} r\right]$ and the gross interest rate $r = \left[\frac{(\epsilon-1)}{\epsilon}\right]^2 \frac{Y}{\phi K}$. Following Steger (2005b), each firm becomes the only producer of a single variety i of a capital good. Consequently, the CG sector is characterised by monopolistic competition, which leads to positive mark-up of prices over the marginal cost.

The last sector of the economy is the the R&D sector which is characterised by a large number of firms, ordered on the interval $[0, 1]$ that operate in a perfect competition regime. In accordance with Steger (2005b), the growth rate of the stock of knowledge (or technology) in the economy is linked to the level of technological knowledge and the shares of labour and private capital employed in the sector[11]. This function can be expressed as follows:

$$\dot{A} = J = A^{\eta_A} \left[(1-\theta)\, L\right]^{\eta_L} \left[(1-\phi)\, K\right]^{\eta_K}, \tag{A.12}$$

with $\eta_L = \eta_L^P + \eta_L^e$, $\eta_K = \eta_K^P + \eta_K^e$, η_A^{so}, $\eta_K^P\, \eta_L^P > 0$, where $\eta_K^e\, \eta_L^e < 0$ and $\eta_A = \eta_A^{SO} + (1-\eta_K)$. This model formulation allows for constant returns to scale in private inputs ($\eta_K^p + \eta_L^p = 1$), but decreasing returns to scale across the entire system which is guaranteed by the negative externalities associated with economy-wide averages of private resources (η_k^e, $\eta_L^e < 0$). In addition, η_A^{SO} describes the degree of diffusion of the technological knowledge already accumulated in the R&D sector (Jones, 1995; Steger, 2005a). Increasing values of η_k^e and η_L^e reduce the overall productivity of private capital $(1-\phi)$ and labour $(1-\theta)$ but, because $\eta_A = \eta_A^{SO} + (1-\eta_K)$, these externalities also constrain the spread of existing knowledge on the accumulation of new technology.

[9]This assumption guarantees that the CG producer has no incentive to differentiate prices across the FO and R&D sectors.
[10]Remembering that $K = Ax$, this expression is equivalent to $P_D = \left[\frac{(\epsilon-1)}{\epsilon} \frac{Y}{\phi K}\right]$.
[11]Symmetrically to Equation (??), R&D technology is defined by $\dot{A} = A^{\eta^{SO}} \left[(1-\theta)\, L\right]^{\eta_L} \int_0^A \left[(1-\phi)\, x(i)\right]^{\eta_K} di$.

The price of one design or blueprint in the R&D sector is given by $V(t) = \int_t^{\infty} \pi(\tau) e^{-\int_t^{\tau} r(u)du} d\tau$ which becomes $\dot{V} = rV - \pi$ by differencing the last equation with regard to time. Substituting r and π in the latter then gives the rate at which the price of one design or blueprint grows:

$$\dot{V} = \left[\frac{(\epsilon - 1)}{\epsilon}\right]^2 \frac{Y}{\phi K} - \frac{(\epsilon - 1)}{\epsilon^2} \frac{Y}{\phi A}, \tag{A.13}$$

which shows that including only private returns in the price of one design or blueprint leads to the emergence of a market distortion (i.e. the mark-up of blueprint prices). Furthermore, given the market structure of the R&D and FO sectors in equilibrium, factor prices are equalised across these sectors such that $w_{FO} = w_{R\&D}$ and $P_{FO}^D = P_{R\&D}^D$, thus allowing us to define the optimal allocation of labour and private capital across the two sectors as follows:

$$\frac{(\epsilon - 1)}{\epsilon} \frac{Y}{\theta} = V \frac{\eta_L^p J}{(1 - \theta)} \tag{A.14}$$

and

$$\frac{(\epsilon - 1)}{\epsilon} \frac{Y}{\phi} = V \frac{\eta_K^p J}{(1 - \phi)}. \tag{A.15}$$

Equations (**??**) and (**??**) crucially determine the channels through which the interplay between the stock of knowledge and institutions indirectly affect private capital and private consumption. An improvement in the quality of institutions produces an increase in the productivity of labour and physical capital, requiring a smaller amount of these two factors to produce the same amount of new technology. Consequently, a greater amount of physical capital and labour is available for use in the CG and FO sectors.

To complete the model, we introduce representative household behaviour and assume that, at any point in time, the representative household will supply one unit of labour and maximise its intertemporal utility by controlling for private consumption per capita. Given a constant relative risk aversion (CRRA) instantaneous utility function, the overall utility maximised by the representative household is:

$$U(c) = \frac{c^{1-\sigma} - 1}{1 - \sigma} e^{-\rho t}, \tag{A.16}$$

where $c = C/L$ is per capita consumption, ρ is the intertemporal discount rate and σ is the inverse of the intertemporal elasticity of substitution, such that high values of σ imply more uniform intertemporal consumer behaviour. Moreover, given the identified structure of the three sectors composing the economy, we can rewrite the private capital accumulation function, constraining the decisions of the representative household as:

$$\dot{K} = rK + wL + A\pi - V\dot{A} - C. \tag{A.17}$$

Given the structure of the utility of the representative household and the private capital accumulation function, we can derive the market solution for the model which differs from the social planner solution (Eicher and Turnovsky, 1999) in terms of the balanced growth rate (Steger, 2005a, 2005b), but not in terms of the long-run growth rate. The implication is that the centralised (social planner) solution is superior to the decentralised (market) solution in terms of welfare. The gap between the two solutions depends on the monopolistic competition structure of the CG sector, on the negative externalities linked to the fishing out effect and on the positive spillovers from institutional factors. Public policies that reduce these distortions may raise the level of the balanced growth path, even if they cannot modify the long-run growth rate.

Hence, by solving the household intertemporal optimisation process using Equations (**??**) and (**??**) with $K(0) > 0$ and $A(0) > 0$) and applying the Ramsey-Keynes rule of optimal consumption[12], we obtain:

$$\gamma = \frac{\dot{C}}{C} = \frac{1}{\sigma}\left[r - \rho - (1-\sigma)n\right], \tag{A.18}$$

which states that when the real interest rate is equal to the intertemporal discount rate, it is optimal to maintain consumption at a constant level. Furthermore, the solution to the household optimisation problem leads to identification of the dynamic system that drives all sectors of the economy, defined by Equations (**??**), (**??**) and (**??**), and the allocations of inputs (**??**) and (**??**). The dynamic system thus derived serves as the basis for the analysis of the transitional dynamics. The general stability properties can be analysed and the speed of convergence determined. For this purpose, we need to derive the balanced growth path[13]. As is standard in the literature, we simplify the model by employing an auxiliary assumption whereby $\dot{Y}/Y = \dot{K}/K$ which states that by dividing Equation (**??**) by K, we have $\dot{Y}/Y = \dot{K}/K = \dot{C}/C$ on the balanced growth path. Hence, we can unequivocally determine $\dot{K}/K$ and $\dot{A}/A$, which are given by[14]:

$$\frac{\dot{K}}{K} = \beta_K n, \;\; where \; \beta_K = \frac{\sigma_L(1-\eta_A) + \eta_L\sigma_A}{(1-\sigma_K)(1-\eta_A) - \eta_K\sigma_A} \tag{A.19}$$

$$\frac{\dot{A}}{A} = \beta_A n, \;\; where \; \beta_A = \frac{\eta_L(1-\sigma_K) + \eta_K\sigma_L}{(1-\sigma_K)(1-\eta_A) - \eta_K\sigma_A}. \tag{A.20}$$

[12] Since we need to obtain the growth rate of private consumption in terms other than per capita we calculate the first difference of c over time and obtain $\dot{c} = \frac{(\dot{C}L - C\dot{L})}{LC} = \gamma - n$ where γ is the growth rate of private consumption.

[13] As is normal, the balanced growth path is defined by the constant (possibly different) growth rates of the endogenous variables. This definition implies that the allocation variables (θ and ϕ) must be constant along the balanced growth path.

[14] The balanced growth rates of K and A can be derived from $d[Y/K]/dt = 0$ and $d[J/A]/dt = 0$ by noting that, on the balanced growth path, the allocation variables (θ and ϕ) are constant and $\dot{L}/L = n$.

Following Eicher and Turnovsky (1999), using Equations (**??**) and (**??**) enables us to determine the conditions for positive and balanced growth by applying the social planner solution to a general R&D-based growth model. The result is equally applicable here because the underlying production function and resulting balanced growth rates are structurally identical for the decentralised and centralised solutions (Steger, 2005b). Accordingly, $(1-\sigma_K)(1-\eta_A)-\eta_K\sigma_A>0$ and $\sigma_K<1$ are necessary and sufficient conditions for positive growth. In addition, there are three conditions related to the production function: (i) constant returns to scale; (ii) a condition of the Cobb-Douglas type; and (iii) homogeneous separability in the exogenously and endogenously growing factors. The model shows even growth ($\dot{K}/K=\dot{A}/A$) in the first and third cases and uneven growth ($\dot{K}/K\neq\dot{A}/A$) in the second. Provided that one of the preceding conditions for balanced growth applies, the balanced growth rates can be written as $\dot{Y}/Y=\dot{K}/K=\dot{C}/C=\beta_K n$ and $\frac{\dot{A}}{A}=\beta_A n$.

Following these conditions, we can write the dynamic system driving the overall economy as:

$$\dot{a}=j-\beta_A na \tag{A.21}$$

$$\dot{k}=y-c-\beta_K nk \tag{A.22}$$

$$\dot{c}=\frac{c}{\sigma}\left[r-\rho-(1-\sigma)n\right]-\beta_k nc \tag{A.23}$$

$$\dot{v}=v\left[r-(\beta_K-\beta_A)\right]-\pi \tag{A.24}$$

$$\frac{(\epsilon-1)}{\epsilon}\frac{y}{\theta}=v\frac{\eta_L j}{(1-\theta)} \tag{A.25}$$

and

$$\frac{(\epsilon-1)}{\epsilon}\frac{y}{\phi}=v\frac{\eta_K j}{(1-\phi)}. \tag{A.26}$$

where all of the variables are now expressed as scale-adjusted variables such that $y=Y/L^{\beta_K}$, $k=k/L^{\beta_K}$, $c=C/L^{\beta_K}$, $a=A/L^{\beta_A}$, $j=J/L^{\beta_A}$ and $v=V/L^{\beta_K-\beta_A}$.

Appendix B: Descriptive statistics

Country	γ^c	γ^a	γ^i	a_{it}	k_{it}	Voice and accountability	Political stability and absence of violence	Government effectiveness	Control of corruption	Rule of law	Regulatory quality
Austria	2.20	1.14	-0.29	87.70	23.02	1.42	1.12	1.87	1.99	1.86	1.55
Belgium	2.00	1.04	0.08	88.95	24.26	1.41	0.92	1.77	1.37	1.29	1.22
Denmark	1.66	0.91	0.36	86.06	20.61	1.58	1.22	2.07	2.42	1.88	1.76
Finland	2.20	1.67	-0.81	81.96	24.40	1.57	1.51	2.09	2.42	1.95	1.74
France	1.75	0.95	-0.49	89.08	20.13	1.22	0.61	1.56	1.35	1.40	1.06
Germany	1.80	0.88	-0.90	91.28	21.29	1.39	.	1.77	1.96	1.63	1.48
Greece	2.11	0.60	-1.05	95.42	23.85	1.02	0.47	0.70	0.53	0.80	0.78
Ireland	3.04	1.89	-0.65	74.41	22.94	1.38	1.28	1.67	1.60	1.59	1.70
Italy	1.70	0.83	-0.26	88.14	23.06	1.05	0.68	0.72	0.41	0.67	0.87
Luxembourg	3.38	0.95	-0.39	81.52	23.00	1.50	1.42	1.93	1.99	1.80	1.70
The Netherlands	1.94	1.04	-0.93	88.58	18.24	1.59	1.19	1.98	2.20	1.74	1.85
Portugal	2.57	1.46	0.34	83.92	25.82	1.38	1.11	1.07	1.23	1.18	1.14
Spain	2.15	0.77	0.02	92.54	24.08	1.24	0.19	1.50	1.22	1.27	1.24
Sweden	1.58	1.03	-0.39	87.88	18.34	1.57	1.28	1.99	2.29	1.83	1.48
United Kingdom	1.90	1.27	-0.05	85.59	15.32	1.33	0.58	1.82	2.02	1.68	1.84
Mean	2.13	1.10	-0.36	86.87	21.89	1.38	0.97	1.63	1.67	1.51	

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