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Economic development and income inequality: the role of political institutions and directed technological change in modern economies

Doctoral Thesis of

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Biographical Note

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Abstract

The process of economic growth and its distributional effects have major welfare consequences, creating advanced and developing economies. Modern growth theory highlights the role of capital accumulation, human capital and technology in explaining cross-country economic and income variations. Forefront research exploring these questions emphasizes the primary importance of the institutional factor in determining technological progress and leading to different economic growth outcomes. This thesis aims at bringing its feasible contribution to the on-going research on income inequality and economic growth by considering the fundamental causes of structural, technological and political features of economic organisation.

The first part of the thesis investigates how institutions and policies, as important determinants of economic incentives, may condition economic growth and income inequality. Based on a comprehensive critical assessment of related literature, we first develop a conceptual discussion on how institutional quality may influence the efficiency of redistribution policy specifically associated with human capital accumulation. We identify political rivalry as the main factor negatively affecting the decisive role of political institutions and consequently distorting efficient redistribution policy. Given these theoretical insights, we next study the effects of political rivalry on human capital accumulation and income inequality in a framework of an endogenous growth model with elements of new political economy. Our results suggest that while non-distortionary redistribution *via* public education equalizes income levels and increases human capital accumulation, political rivalry produces negative outcomes in all dimensions of considered economic interactions. The key conclusions of the theoretical model are then tested in a cross-sectional empirical study. Our findings clearly indicate that, for specific groups of countries with similar income and geographical location characteristics, political rivalry has indeed a negative effect on educational investments, individual learning choice, GDP *per capita* and income inequality.

In the second part, the topics of economic growth and income inequality are investigated from a different perspective, namely that of analysing recent changes in the composition of employment, wage structure and aggregate production, which represent an important part of the process of modern economic development. More specifically, we use a standard directed technological change model, extended by complementarities between intermediate goods in production and internal costly investments, to examine the behaviour of economic growth rate, technological-knowledge bias, skill premium and industrial structure. While our analysis suggests that equilibrium growth rate is directly affected by costly investments and complementarities, the latter also influencing equilibrium technological-knowledge bias and industrial structure, equilibrium skill premium is determined solely by workers' productivities. This may imply that the persisting increase in wage inequality observed in several developed countries over the last decades may have been due to increases in productivity advantages of skilled workers favoured by technological development. We then extend our analysis by quantitatively associating empirical facts on the technology and skill structure to the degree of gross substitutability/complementarity between technological goods. This estimation exercise also allows us to quantify the long-run relationship between the Tobin-q and both the degree of complementarity between technology goods and the complexity effect of horizontal R&D, through the impact of the last two factors on the long-run economic growth rate. Our estimation and calibration exercise suggests the existence of a moderate degree of gross complementarity between technological goods and of an elastic relationship between the Tobin-q and key technology parameters.

Keywords: economic growth, inequality, institutions, political rivalry, human capital accumulation, public education, redistribution, technological-knowledge bias, skill premium, industrial structure, complementarities, costly investment.

JEL classifications: E24, H21, H23, H40, H52, I24, J31, O31, O33, O41, O43, O5, P0

Resumo

O processo de crescimento económico e os seus efeitos distributivos têm importantes consequências sobre o bem-estar social, dando origem a economias avançadas e a economias em desenvolvimento. A teoria moderna de crescimento económico realça o papel da acumulação de capital, do capital humano e da tecnologia para explicar as diferenças económicas e de rendimentos entre países. A investigação mais recente neste domínio, por seu turno, releva a importância do factor institucional para o desenvolvimento do progresso tecnológico e para a obtenção de resultados económicos diferentes. Esta tese visa contribuir para a investigação actual sobre desigualdade e crescimento económico, ao considerar as causas fundamentais das características estruturais, tecnológicas e políticas de organização económica.

A primeira parte da tese investiga o modo como as instituições e as políticas, enquanto importantes determinantes dos incentivos económicos, podem condicionar o crescimento económico e a desigualdade. Tendo por base uma análise crítica e exaustiva da literatura, é inicialmente feita uma discussão conceptual sobre o modo como a qualidade das instituições poderá influenciar a eficiência das políticas redistributivas especificamente associadas à acumulação de capital humano. A rivalidade política é identificada como sendo o principal factor afectando negativamente o papel decisivo das instituições políticas, distorcendo, consequentemente, a eficiência das políticas redistributivas. Partindo destes argumentos teóricos, são, de seguida, estudados os efeitos da rivalidade política sobre a acumulação de capital humano e a desigualdade no contexto de um modelo de crescimento endógeno com elementos da nova economia política. Os resultados obtidos sugerem que, enquanto a redistribuição não distorcionária via educação pública permite equilibrar os níveis de rendimentos e aumentar a acumulação de capital humano, a rivalidade politica tem impactos negativos sobre todas as dimensões económicas consideradas. As principais conclusões deste modelo teórico são posteriormente testadas num estudo empírico seccional. Os resultados deste estudo indicam claramente que, para grupos específicos de países com características similares, a rivalidade política tem efectivamente um impacto negativo sobre os investimentos em educação, a decisão individual de aprendizagem, o PIB *per capita* e a desigualdade.

Na segunda parte, os temas do crescimento económico e da desigualdade são investigados a partir de uma perspectiva diferente, em particular, analisando alterações recentes na composição do emprego, estrutura de salários e produção agregada, os quais constituem uma parte importante do desenvolvimento económico moderno. Em particular, é usado um modelo base de *directed technological change*, ao qual são acrescentados os elementos de complementaridades entre bens intermédios na produção e custos de ajustamento no investimento, com o objectivo de analisar o comportamento da taxa de crescimento económico, enviesamento do conhecimento tecnológico, desigualdade salarial e estrutura industrial. Os resultados obtidos sugerem que, enquanto a taxa de crescimento económico é directamente afectada pelos custos de ajustamento e pelas complementaridades, influenciando estas também o enviesamento do conhecimento tecnológico e a estrutura industrial, a desigualdade salarial é determinada unicamente pelas produtividades dos trabalhadores. Isto poderá implicar que o aumento persistente na desigualdade salarial observado em vários países desenvolvidos ao longo das últimas três décadas tem resultado de aumentos na vantagem produtiva dos trabalhadores qualificados, favorecidos pelo desenvolvimento tecnológico. Na sequência desta análise é efectuada uma associação quantitativa dos dados empíricos relativos à estrutura tecnológica e industrial ao grau de substituibilidade/complementaridade bruta entre bens tecnológicos. Este exercício de estimação também permite quantificar a relação de longo prazo do q-Tobin com o grau de complementaridades entre bens tecnológicos, bem como com o efeito de complexidade da I&D horizontal, através do impacto dos últimos dois factores sobre a taxa de crescimento de longo prazo. O exercício de estimação e calibração sugere a existência de um grau moderado de complementaridade bruta entre bens tecnológicos e de uma relação elástica entre o q-Tobin e os parâmetros tecnológicos principais.

Palavras-chave: crescimento económico, desigualdade, instituições, rivalidade política, acumulação de capital humano, educação pública, redistribuição, enviesamento do conhecimento tecnológico, prémio salarial, estrutura industrial, complementaridades, custos de ajustamento no investimento..

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Chapter 1

Introduction

Understanding economic growth and income differences across countries is one of the most interesting, important and challenging tasks facing modern social science. The process of economic growth and its distributional effects have major welfare consequences, creating advanced and developing economies. Modern growth theory highlights the role of capital accumulation, human capital and technology in explaining such cross-country economic and income variations. Forefront research exploring these questions emphasizes the primary importance of the institutional factor in determining technological progress and leading to different economic growth outcomes.

This thesis aims at bringing its feasible contribution to the on-going research on income inequality and economic growth by considering the fundamental causes of structural, technological and political features of economic organization. In the first part we focus on political economy interactions and investigate how institutions and policies, as important determinants of economic incentives, may lead to growth-enhancing policies in some countries and hinder technological change in others. Using both a theoretical and an empirical approach, we analyse how institutional characteristics, being crucial for physical and human capital accumulation and the development and adoption of better technologies, determine aggregate economic performance and the resulting income inequality. In the second part, the topics of economic growth and income inequality are investigated from a different perspective, analysing changes in the composition of employment and aggregate production underlying balanced modern growth, both in the spirit of Schumpeter's creative destruction and Simon Kuznets' theory. Based on theoretical modeling and empirical data on complex structural transformation of the economy, representing an important part of the process of economic development, we analyse recent changes in the wage structure of modern economies.

In the beginning of the first part, in Chapter 2, we develop a comprehensive critical assessment of existent literature on the role of political institutions and policies for economic growth, considered to be one of the fundamental causes in growth and income differences across countries (Acemoglu, 2009). Covering both political economy and economic growth fields, we perform an exhaustive study of related theoretical and empirical works, focusing on the importance of income redistribution for economic growth and the key role that political institutions have in securing growth-enhancing redistribution policies. Based on this extensive literature review, we then develop a conceptual discussion on how the quality of the institutional factor may influence the efficiency of redistribution policy specifically associated with human capital accumulation. We analyse efficient redistribution in terms of the explicit positive externalities that it creates, namely, stimulating human capital accumulation through tax-financed education. In our research context human capital accumulation is provided as a public good and, therefore, related redistributive implications raise awareness for the conflict of interests and demand taking into account the role of public authorities, *i.e.*, political institutions.[1] We then assess how the institutional factor and some of its inherent features may distort or render inefficient a mechanism otherwise regarded (in the endogenous growth literature, *e.g.* Lucas (1988)) as growth-enhancing (Persson

[1]By treating investment into human capital accumulation as a publicly-provided private good, we do not explicitly analyse theoretical aspects of public-goods theory. We simply assume that human capital accumulation results from a publicly-provided private good, since it is financed by tax-revenues generated investments secured by efficient redistribution policy.

and Tabellini, 1992; Alesina and Perotti, 1994; Drazen, 2000; Acemoglu and Robinson, 2006; Acemoglu, 2009). Focusing our analysis on the impact of political rivalry, we identify it as the main factor that may negatively affect the expected decisive role of political institutions and, consequently, distort the effects of efficient redistribution policy. We conclude that the quality of political institutions crucially determines policy efficiency, commanding the relationship between political institutions, human capital and economic outcomes.

In Chapter 3 we develop an overlapping generations model with elements of new political economy to study the effects of political rivalry on human capital accumulation and income inequality and examine how different political incentives and policies may affect the resulting economic allocations. Our research framework relies on the idea that, being the basis for long-term economic development and one of the key factors influencing aggregate productivity and individual income, human capital accumulation is a fundamental macroeconomic policy, the significance of which cannot be neglected and for which political effects have a critical role. We consider that human capital accumulation and economic development are adversely affected by inequality, which is also a barrier to schooling and economic growth (as, for example, in Perotti, 1996; Easterly, 2007). Our model combines elements from the study of Glomm and Ravikumar (2003), extended by the introduction of a final-goods production sector and endogenous new political economy elements as suggested by Acemoglu (2006). Introducing a production sector in the economy allows us to specifically derive the equilibrium income and its growth rate; considering endogenous fiscal and public investments policies allows for a richer analysis of economic results that accounts for the effects of the inherent political mechanisms and political rivalry, and the role of political institutions. In our model, political rivalry arises in the form of political competition against replacement and political incentives in public policy, and distortionary taxes are then beneficial for the elite as a way of impoverishing their political competitors. As such, political rivalry becomes a key distorting factor in the economy and contesting political power induce economic costs due to its growth retarding effects (Dixit and Londregan, 1995; Acemoglu and Robinson, 2001; Scruggs, 2001; Acemoglu, 2006). Success or failure of implemented economic policies then depends on how prevailing institutions manage political rivalry. Our analysis suggests that, on the one hand, non-distortionary redistribution *via* public education equalizes income levels and increases the human capital accumulation in the economy, which has a growth promoting effect; on the other hand, the efficiency of such redistribution policy is distorted by political rivalry, with resulting negative effects on all economic outcomes.

In Chapter 4 we empirically test the main conclusions of our theoretical model in the previous chapter, where we have seen that political rivalry may negatively affect public investments in education, thus discouraging individual learning incentives and human capital accumulation, decreasing aggregate production and aggravating inequality. In particular, using cross-sectional data for a large set of countries, we examine the impact of political rivalry on four selected economic variables: public investments in education, individual learning choice, GDP *per capita* and income inequality. Given that, to our knowledge, there are no previous empirical data on political rivalry (as defined in this work), we first construct a composite political rivalry indicator, comprising the elements of institutional quality and exclusive pecuniary benefits, which we consider crucial for determining the degree of rivalry between the political elite and other social groups. For each country, we compute the political rivalry level and examine how it varies across different groups of countries. The construction and preliminary analysis of this composite political rivalry indicator is one of the key outcomes of our empirical study. We then perform a series of regressions in order to assess the impact of political rivalry on the above referred economic variables. We find that in lower income countries there is indeed a significant negative political rivalry impact, which increases with the poverty level. Our empirical findings also suggest that the relationship between political rivalry and the selected economic variables may imply mechanisms that differ with the level of development.

Chapters 2, 3 and 4 comprise the first part of this thesis, which explores the issues of economic growth and income inequality from a new political economy perspective. In the next two chapters, Chapter 5 and 6, we use a directed technological change framework in order to analyse the distributional effects of endogenous technological progress, that is, determine how production factors and industrial sectors adjust to new technologies that are developed and adopted.

In Chapter 5 we develop an extended directed technological change model in order to study the behaviour of the growth rate, industrial structure and skill premium. Building on the original framework of Acemoglu and Zilibotti (2001) we broaden it by the introduction of physical capital, vertical differentiation following Aghion and Howitt (1992), Hayashi's (1982) internal investment costs in both physical capital and R&D, and complementarities between intermediate goods used in the production of final goods, as in Evans *et al.* (1998). Introducing these new elements into the standard skill-biased technological change model allows us to study economic growth, industrial structure and skill premium in a more realistic environment of modern industrialized economies, and contributes to enriching our analysis. The adopted Schumpeterian approach on temporary monopoly position generating higher profits for the currently innovating firm enables us to endogenize economic processes designated as the causes of modern economic development and recurring structural change (e.g. Howitt, 1999; François and Lloyd-Ellis, 2009). Also, given that a larger number of product lines (horizontal innovation) puts pressure on economy's resources due to the existence of positive fixed and recurrent operating costs, while greater productivity of existing product lines (vertical innovation) does not, we believe that using the two dimensions of technology (e.g., as in Howitt, 1999; Segerstrom, 2000; Peretto and Connolly, 2007) allows us to attain a more comprehensive reflection of the endogenous economic growth and industrial concentration mechanisms. Modeling aggregate economic growth as occurring both through expanding variety and increasing quality of intermediate goods, we then relate horizontal R&D to measures of industrial structure and show that vertical R&D is the ultimate engine of growth. Our findings show that the steady-state economic growth rate is affected by internal investment costs and the degree of complementarities, the latter also influencing industrial structure and technological-knowledge bias, while neither affects skill premium in equilibrium.

Chapter 6 represents an extension to the model developed in the previous chapter having the objective of quantitatively associating the empirical facts on the technology structure and the skill structure to the degree of gross substitutability/complementarity between technological goods. In particular, based on empirical data for a number of developed countries, we identify and quantify the long-run link between the technology structure and the skill structure, by considering an explicit role for the (potential) gross complementarity arising between technological goods. Given the assumption of internal investment costs, we also tackle the long-run relationship between the Tobin-q and the technology characteristics of the firms, such as the degree of complementarity between technological goods, through the impact of the latter on the long-run economic growth rate. The results of our estimation and calibration exercise suggest the existence of a moderate degree of gross complementarity between technological goods and of an elastic relationship between the Tobin-q and key technology parameters.

In Chapter 7 we present the conclusions of this thesis and define some possible venues for future research.

Chapter 2

Efficient redistribution policy: an analysis focused on the quality of institutions and public education

2.1 Overview

The endogenous relationship between political institutions, policy and economic growth is one of the greatest challenges in the new political economy of growth. In this work, based on a comparative critical assessment of an extensive literature covering both political economy and economic growth fields, we attempt to study how the quality of the institutional factor may influence the efficiency of redistribution policy specifically associated with human capital accumulation.

Our conceptual discussion builds on the importance of income redistribution for economic growth and the key role that political institutions have in securing growth-enhancing redistribution policies. With income redistribution being often conceived as one of the key political channels influencing economic performance, the link between income redistribution and economic growth is fundamental for the ongoing debate. While the specific relationship between redistribution and economic growth is endogenously determined by implemented redistribution mechanisms, relevant literature on this particular topic has emphasized a dual effect, reflecting the possibility of an encouraging or an off-putting redistribution effect on growth, and thus making a clear distinction between efficient and inefficient redistribution (Persson and Tabellini, 1992; Alesina and Rodrik, 1992; Perotti, 1992; Perotti, 1996; Dixit and Londregan, 1995; Saint Paul and Verdier, 1996; Acemoglu and Robinson, 2001).

In line with our research objective and in order to sustain our main argumentation, we introduce the element of endogenous growth theory into our analysis by considering human capital accumulation as a fundamental source of economic growth (*e.g.*, Lucas, 1988). Given the similarity in the proposed effects of both human capital accumulation and efficient redistribution,[1] we focus our research on growth-enhancing, *i.e.* efficient

[1] In particular, decrease inequality, correct possible institutional or economic failures and stimulate investments, improve economic performance and increase growth (*e.g.* Dixit and Londregan, 1995; Saint Paul and Verdier, 1996; Drazen, 2000; Acemoglu and Robinson, 2001; Acemoglu, 2009).

redistribution policy specifically aimed at stimulating investments in human capital accumulation. We analyse it in terms of the explicit positive externalities that it creates for economic performance, namely, stimulating human capital accumulation through tax-financed education.

Finally, given that in our research context human capital accumulation is provided as a public good, related redistributive implications introduce issues of public provision of a private good into our analytical frame, raising awareness for the conflict of interests, and demanding taking into account the role of public authorities, *i.e.*, political institutions.[2] Based on this perspective, we assess how the institutional factor may then distort or render inefficient a mechanism otherwise regarded (in the endogenous growth literature) as growth-enhancing (Persson and Tabellini, 1992; Alesina and Perotti, 1994; Drazen, 2000; Acemoglu and Robinson, 2006; Acemoglu, 2009).

We conclude that the quality of political institutions crucially determines the efficiency of redistribution policies, commanding the relationship between political institutions, redistribution and economic outcomes. Focusing on the impact of political rivalry, we identify it as the main factor that may negatively affect the expected decisive role of political institutions and, consequently, distort the effects of efficient redistribution policy. Moreover, the conducted analysis suggests that political rivalry not only disfavours the expected impact of political performance on economic outcomes, but also weakens political institutions *per se*. This reasoning naturally raises the issue of weak *versus* strong states, in the sense that inept or unprotected as well as exceedingly controlling institutions might be just as costly to efficient economic performance and long-run growth (*e.g.* Acemoglu, 2005).

The remainder of this work is organised as follows. Section 2 discusses the link between redistribution and growth, and Section 3 considers, as main building blocks,

[2]By treating investment into human capital accumulation as a publicly-provided private good, we do not explicitly analyse theoretical aspects of public-goods theory. We simply assume that human capital accumulation results from a publicly-provided private good, since it is financed by tax-revenues generated investments secured by efficient redistribution policy.

the relationship between political institutions and redistribution, focusing on social conflict and incentives, and the role of political institutions in defining redistribution policies. Section 4 elaborates on the relation of efficient redistribution to public goods in our research context. A conceptual discussion on the interaction between efficient redistribution, political rivalry and the quality of political institutions through the perspective of human capital accumulation and control-rights institutions is provided in Section 5. Conclusions are presented in Section 6.

2.2 Redistribution and Economic Growth

In this section, we discuss some of the latest studies on redistribution policies and their impact on economic growth that are relevant for our research objective.

Income redistribution is often perceived as one of the key political channels influencing economic performance, regarding which related literature has enhanced a dual effect, as income redistribution may both hinder and stimulate economic growth. More specifically and as will be discussed below, related research distinguishes between efficient and inefficient redistribution, suggesting that the crucial factor determining the particular effect on growth is the aim served by a specific redistribution policy. Therefore, in our analysis we consider efficient and inefficient income redistribution in terms of, respectively, explicit positive or negative externalities that it creates. The latter arise from excessive taxation and from political considerations outweighing economic characteristics; the former generally imply promoting factor accumulation through stimulating investments, thus in particular making efficient redistribution specifically associated with human capital accumulation, our focus of analysis.

Although the objective of our research is not directly related to inefficient redistribution, we believe that a brief presentation of its distinctive features and mechanisms assumes some importance in the view of our subsequent conceptual discussion and analysis of the relationship between redistribution, political institutions and growth. Also, given that most studies on the impact of redistribution policies generally tend to analyse consequences on either productivity or investment, we adopt a similar approach in our presentation of efficient and inefficient redistribution. That is, we consider each type of redistribution depending on its negative or positive impact on either productivity or investment, and consequently on growth. Inefficient redistribution creates distortions by reducing incentives for work or effort, or by compromising and discouraging investment. Symmetrically, efficient redistribution policies may actually have a positive effect on economic growth by stimulating investments and increasing aggregate productivity.

2.2.1 Inefficient redistribution: productivity and investment channels

Productivity is one of the major economic performance and growth determinants that may be negatively affected by inefficient redistribution mechanisms. Most commonly emphasized by specialised research, these may imply political characteristics outweighing economic considerations, or a politically motivated misallocation of resources. Either one will negatively affect aggregate productivity and consequently growth. For example, favouring political *versus* economic considerations implies that politicians are unable to commit to ignoring the political characteristics and making long-term promises to reward economically efficient choices.[3] As expected in this case, future redistribution policy will favour groups of suitable political characteristics disregarding the efficiency of economic choices made by these groups. Similarly, a politically motivated misallocation of resources will exert a distortionary effect on occupational

[3]Following Dixit and Londregan (1995), politically successful and economically efficient characteristics generally are distributed quite differently and do not match.

choices by encouraging individuals to enter a sector where their productivity is likely to be low, thus decreasing aggregate output and consequently, economic growth. Such artificial keeping of workers in an economically disadvantageous industry, and inability to credibly commit to rewarding the move to a more productive occupation can result in serious economic inefficiencies. Anticipation of such a redistributive policy motivated merely by political considerations will reduce or even eliminate economic incentives, which may prevent economically advantageous actions from being taken (Alesina and Perotti, 1994; Dixit and Londregan, 1995; Acemoglu and Robinson, 2001). As it will be discussed in Section 3, from the political economy perspective the referred situations result from an inefficient redistributive policy in most cases motivated simply by the attempt to gain votes.

Also subject to negative inefficient redistribution effects and at the same time crucial for determining efficient economic performance and growth are investment decisions. In particular, redistribution is inefficient when it discourages factor accumulation by excessive taxation, thus generating low returns on investments and depressing economic growth. Analysing how redistribution affects growth when investments are discouraged by excessive taxation, most seminal studies generally focus on size and functional redistribution, and on single *versus* relative factor endowment (Persson and Tabellini, 1992; Alesina and Rodrik, 1992; Acemoglu, 2009). Their results suggest that distinguishing between size and functional income distribution (additionally distinguishing between a single and a relative – labour and capital – factor endowment) is crucial for the choice of an optimal redistributive policy and for determining the tax rate that maximizes the growth rate of the economy. In either case, their findings generally indicate that a higher (capital) tax rate leads to a lower investment rate and, consequently, to a lower growth rate.

Although the analysis of formal modeling lies outside the scope of this work, it is worth noting that the Median Voter Theorem (MVT) is used as a common tool of analysis for studying redistributive implications.[4] Particularly relevant for our research objective is this theorem's implication of the equilibrium policy involving inefficient redistribution when political rather than economic characteristics are rewarded, or when size or functional taxes are employed.[5] Since, as a rule, the median voter's income is below the mean, a higher-tax redistribution policy choice will be induced and investments will be discouraged due to a reduction in the after-tax return on capital (*e.g.* Drazen, 2000; Acemoglu, 2009).[6]

Thus, in general terms, inefficient redistribution creates distortions by reducing incentives for work or effort with a negative impact on aggregate productivity, or by discouraging investment and hampering factor accumulation; in either case, the economic links yields a negative effect on growth. And in the view of the societies' established reliance on redistribution programs, the fundamental question remains how to maximize their efficiency.

2.2.2 Efficient redistribution: investment channel

Contrarily to inefficient redistribution, efficient income redistribution may yield constructive effects when its instruments are not distortionary, thus creating positive externalities and enhancing economic growth (Perotti, 1992; Perotti, 1996; Dixit and Londregan, 1995; Saint Paul and Verdier, 1996; Drazen, 2000; Acemoglu and Robinson,

[4]Developed by Black (1948), this theorem relates the nature of the redistribution program to the characteristics of the electorate and predicts that, provided single-peaked preferences (among other assumptions), the equilibrium policy, conditioned by the median voter's income relative to the mean, would be the one preferred by the median voter.

[5]The median voter takes into account its anticipated effect on the identity of the future median voter and thus on the equilibrium policy in the subsequent periods.

[6]A more recent development is the Probabilistic Voting Theory (Lindbeck and Weibull, 1987), which, contrary to MVT, can explain voting choices even when voters' preferences are not single-peaked. Particularly relevant for political economy research topics is that it can explain, based on the degree of homogeneity or dispersion of voters' preferences, why certain social groups are more politically powerful than others.

2001; Acemoglu, 2009).[7] Some research suggests that the effect of policy on economic growth is induced primarily through the productivity channel (Rodrik, 1999). However, based on the further presented arguments from related research, we argue that the predominance of the productivity channel for policy effects on growth is more likely to be corroborated when negative effects of redistribution policy on growth are considered.[8] In what concerns positive effects, we sustain that investment is the key channel for increasing productivity and spurring economic growth. In fact, studies on the subject consentingly suggest that a positive effect on growth may be induced when redistribution is directed at increasing investment in human capital, increasing investment by the poor while preserving investment by the rich, and generally stimulating investment by securing sustainable industrial markets and reducing crime and social instability (Perotti, 1992; Perotti, 1996; Alesina and Perotti, 1994; Saint Paul and Verdier, 1996; Acemoglu, 2009).

Taking as a working hypothesis one of the key arguments of endogenous growth theory, namely, human capital accumulation as the engine for long-term economic growth (Lucas, 1988; Romer, 1990; Drazen, 2000; Acemoglu, 2009), we construct our analysis of the relationship between redistribution, institutions and economic growth on the basis of efficient redistribution policy specifically associated with stimulating investment in human capital accumulation.[9] In fact, because human capital is seen as an especially important engine of growth in both the theory and empirics of recent growth models (Drazen, 2000; Acemoglu and Robinson, 2001; Acemoglu, 2009), there can be a significant positive growth effect and an aggregate welfare gain from redistribution focusing

[7] As in fact the commonly used term itself, *i.e.* efficient redistribution, is suggestive as regards the expected positive results from such redistribution policy.

[8] Nonetheless, as we have seen in the previous subsection, apart from negatively affecting aggregate productivity through ill-motivated production and occupational choices, inefficient redistribution may also compromise investment decisions and thus induce just as important negative effects on economic growth through the investment channel.

[9] The idea that the accumulation of human capital, if not distorted, reduces inequality, facilitates efficient economic performance and stimulates economic growth is a widely accepted and scientifically documented view (Perotti, 1996; Saint Paul and Verdier, 1996; Drazen, 2000; Acemoglu, 2009); therefore, we do not debate the usefulness of human capital accumulation.

on human capital accumulation. An integration of political economy and endogenous growth thus suggests a positive rather than a negative role for redistribution (Drazen, 2000). In particular, we follow the idea that redistribution aimed at increasing investment in human capital does not hamper factor accumulation, but, on the contrary, encourages it and thus stimulates growth (Perotti, 1992; Perotti, 1996; Saint Paul and Verdier, 1996; Drazen, 2000; Acemoglu, 2009). In this respect, our discussion on efficient redistribution outlines a view on the normative political economy issue of how, given the existing political constraints, societies can be guided to best achieve specific economic objectives. Also, we believe that public education as an instrument for motivating human capital accumulation is most justifiable in our context, since we consider human capital accumulation to be (at least in part) stimulated by public funds, *i.e.* redistribution collected resources.

By subsidizing research, which is intrinsically associated with human capital, the government can increase the growth rate of the economy (*e.g.* Romer, 1990; Aghion and Howitt, 1992). Similarly, redistribution is beneficial for growth when implemented aiming at investing in human capital accumulation *via* public education, increasing the economy's human capital stock and having a growth-promoting effect by balancing income levels across dynasties, *i.e.* decreasing inequality (Saint Paul and Verdier, 1996; Acemoglu, 2009). Also, in support of our view that redistribution associated with investment in human capital accumulation enhances growth, we may refer studies that link economic growth to policy change and technological advance (where human capital is, in effect, the main ingredient), or studies providing empirical evidence on the historical relationship between economic growth, the institutional factor, and educational reforms (Acemoglu and Robinson, 2006; Aghion *et al.*, 2007; Nelson, 2008).

Moreover, defining the link between efficient redistribution and economic growth as a specific structural relationship turns clearer the inherent causality processes (Perotti, 1996). In particular, efficient redistribution aimed at increasing investments in human capital accumulation may have a positive impact on aggregate economic performance in the result of an induced increasing equality effect (Perotti, 1996; Saint Paul and Verdier, 1996; Acemoglu, 2009). This allows us to draw further inference on the fact that efficient redistribution associated with human capital accumulation entails positive effects on inequality, which further strengthens its positive economic impact.[10]

Finally, some of the above referred studies implicitly sustain the idea that, for a positive effect on growth, efficient forms of redistribution should be conditioned on economic actions and not on political characteristics. Independently of the political characteristics of the tax payers, different economic structures induce different effects of redistribution on growth and, in structures where there is government financing of public education, the effect is positive (Perotti, 1992; Dixit and Londregan, 1995; Acemoglu and Robinson, 2001). Thus, efficient redistribution aimed at increasing human capital accumulation may, in fact, help correcting some of the failures of inefficient redistribution, previously discussed.

In sum, when redistribution targets the raise of the possibilities of investing in education, increasing human capital and thus promoting growth, redistributive transfers seem to affect growth positively rather than negatively. An essential condition for that result is for political considerations not to outweigh economic concerns, in which case income redistribution will be efficient in the sense that no production or occupational decisions will be distorted if political power is not contested. In the context of our research, this conclusion offers additional motivation to our interest in the role of political rivalry and the quality of political institutions. In the next section we will develop a critical analysis concerning the idiosyncratic relations between institutions, in the political sense, and redistribution. This will conduct us to our ultimate research goal focused on the role and quality of institutions in stimulating human capital accumulation.

[10] Although we do not pursue this idea here, it may be useful for future, more detailed, directed research on the subject.

2.3 Political Institutions and Redistribution

From our earlier discussion on the relationship between redistribution and economic growth, based on numerous research findings, we conclude that efficient redistribution does not depress aggregate productivity, increases investment in human capital accumulation and stimulates growth. In this section, our case is to present evidence that the specific relationship between income redistribution and economic growth is endogenously determined by the political processes involved. As we will see, efficient political decisions that secure positive redistribution effects on growth, while avoiding policy failure, prove to be a difficult task in reality.

2.3.1 Redistribution and political rivalry

We present our analysis of the relationship between efficient redistribution and institutions from the perspective of intrinsic political incentives and social conflict of interests. We should note that, although we do not focus on specific political regimes, the inherent features of our research imply that the assumption of a pro-democratic regime (in which each voter with individual preferences can contribute to the formation of aggregate public policy) seems more appropriate.[11] We believe that the democratic characteristic of struggling to maintain or expand group size in order to guarantee future political power is fully appropriate for defining the role of political institutions in establishing economic policy in general, and the efficiency of redistribution policies in particular (Dixit and

[11] Note for example that, following Londregan and Poole (1992), in the case of an authoritarian regime a crucial but sufficient condition for non-distortionary policy would be to have a benevolent ruler, *i.e.* a ruler concerned with the well-being of the whole society and not just the political elite. Also, the pro-democratic assumption is strongly supported by the MVT largely applied for formalizing analysis of the relationship between political institutions and redistribution. In particular, it brings evidence regarding the key importance of political parties' size and voting options, naturally suggesting democratic societies, in which distributional conflicts are likely to be resolved in a manner that reflects the majority's preferences.

Londregan, 1995; Dixit *et al.*, 2000; Acemoglu and Robinson, 2001).[12] We also note that among the vast conceptual variety regarding the widely used term "institutions",[13] our main research goal dictates the particular focus on "property-rights institutions", which we do not treat in the innovation approach manner, but rather in the political sense. More specifically, following Acemoglu and Johnson (2005) we assume them to determine the vertical links between various social groups, *i.e.* determine the interactions between groups with different degrees of political power. This particular interpretation has a key importance for our subsequent analysis, and we will later relate it to Rodrik's (2007) discussion on institutions for high-quality growth. Otherwise, in our discussion on political institutions and redistribution we will generally abstract from terminological and ideological issues.

Our focus, thus, is on the view that political institutions are expected to implement efficient redistribution policies that directly contribute to promoting economic growth, and on the analysis of how specific political processes inherent to any regime may distort the efficiency of these interactions. This ideology-neutral approach is additionally motivated by numerous studies suggesting that there are positive efficient mechanisms inherent to any regimes or institutional forms that should be cleverly employed (Przeworski and Robinson, 1993; Scruggs, 2001; Rodrik, 2007; Acemoglu, 2009). Indeed, in the view of the broad class of economic and political institutions, the difference between their various types is not always clear, and thus it is often their combination and not the exclusivity of one or the other that is important (Acemoglu, 2009). Considering the argument that dictatorships are better at mobilizing savings and democracies are better at allocating investment, only a combination of a decentralised market mechanisms and strong institutions allows achieving the economic benefits of social stability,

[12] Some of the studies adopting research frameworks of explicit political regimes for relating political institutions and economic outcomes include: Przeworski and Robinson (1993), Alesina and Perotti (1994), and Aghion, Alesina and Trebbi (2007), among many others.

[13] For examples of specific institutional definitions see Alesina and Perotti (1994), Acemoglu and Johnson (2005), Rodrik (2007) and Nelson (2008).

investment, and competitiveness (Przeworski and Robinson, 1993; Scruggs, 2001; Rodrik, 2007). By these accounts, economic policy seems to result from considerations crucial for any political arrangements and the discussion may be therefore mostly resumed to the problem of policy efficiency as implemented by the prevailing political institutions. As we will show by further arguments from related research, we find these considerations to represent a combination of preference heterogeneity, political power motivations and specific mechanisms of solving the conflicts of interests in the society.

In studying how political institutions may be detrimental to growth, many researchers present arguments invoking property rights, pressures for immediate consumption reducing investments and consequently growth, and the autonomy of political institutions as a crucial factor determining the interest to maximize aggregate output (Przeworski and Robinson, 1993; Acemoglu and Johnson, 2005; Acemoglu and Robinson, 2006; Nelson, 2008; Acemoglu, 2009). Other researchers invoke reasons related to political instability generated by political competition resulting from ex-ante or ex-post heterogeneity in voters' preferences, the strong impact of which creates a persisting tendency for strategic voting and proves to affect economic outcomes. While political institutions may lead to better economic performance when the more productive group holds the power in the society, political instability induced by strong political competition, on the contrary, is incompatible with an efficient execution of the government's functions as regards economic performance (Persson and Tabellini, 1992; Alesina and Rodrik, 1992; Alesina and Perotti, 1994; Drazen, 2000; Scruggs, 2001; Acemoglu, 2009). Thus, most related studies imply that political power and political competition play a central role in the matter. As both empirical and historical findings suggest, shifts between *de jure* and *de facto* political power seem to occur by the decision of the elite, and the net effect of redistributive policies appears to depend on the perception by the ruling power of the costs of distortionary taxation weighed against the benefits of reduced social tensions (Przeworski and Robinson, 1993; Alesina and Perotti, 1994; Acemoglu and Robinson, 2006). In fact, because equilibrium redistribution policy depends on conflicting interests (aggregated through political incentives and political institutions into public policy) over the distribution of income, in the context of political competition higher taxes will be more appealing, consequently having a direct depressing impact on economic growth (Persson and Tabellini, 1992; Acemoglu, 2009). Thus, being intimately linked with conflicts of interest in the society, political competition will necessarily distort the outcomes of economic policies pursued by the institutions in power, being impossible to isolate the resulting resources distribution from the aggregate economic performance. And given that, as the above referred studies indicate, any political regime is primarily concerned with protecting the interests of the groups that have political power, the resulting allocations are inefficient and often involve different types of distortions when political and economic powers are decoupled.[14] The severity of these distortions (compared to those generated by alternative political powers) or whether a particular set of political institutions may lead to non-distortionary, *i.e.* efficient, redistribution policies, depends on the details of how it functions, on the technology and factor endowments of the society, and on which groups benefit from these institutions (Dixit and Londregan, 1995; Acemoglu and Robinson, 2001; Aghion *et al.*, 2007; Nelson, 2008; Acemoglu, 2009).

Given the broad range of possible factors that fall under this category of institutional details, we consider it reasonable to aggregately reflect them in the **quality** of institutions, and consequently the quality of implemented policies that determine the nature of economic outcomes resulting from the link between political institutions and redistribution. And in the view of the above discussion, we conclude that the quality of political institutions explaining economic policy success or failure depends, in its turn, on how prevailing institutions manage political competition, which disturbs the balance

[14] For example, Alesina and Rodrik (1992) conclude that individuals who have access to productive assets of an economy are more likely to be restrained in their desire to tax them, suggesting that it is easier to avoid damaging conflict over redistribution policies when the economy's assets are widely shared.

between political and economic power.

Therefore, we identify political competition, or **political rivalry** between the elite and other political groups as a key factor distorting the efficiency of economic allocations and actions, and leading to distortionary policy in general and distortionary redistribution policy in particular. More specifically, political rivalry is the inter-party political competition for power of both economic and political nature, aimed at keeping the political elite in the office and in control for as long as possible (as in, *e.g.*, Dixit and Londregan, 1995; Dixit *et al.*, 2000; Acemoglu and Robinson, 2001; Scruggs, 2001; Acemoglu, 2006). Political rivalry may arise in both democratic and non-democratic regimes and thus its existence is independent of the political system, varying only in its degrees of intensity and forms of manifestation (see, for example, Acemoglu, 2006).

In this respect our reasoning, as regards political rivalry, outlines a view on the positive political economy concern of how political constraints may explain the choice of policies, and thus economic outcomes. In the framework of our research, there is a strong negative impact of political rivalry when goals pursued by the political elite, instead of economic efficiency considerations, determine the policy choice.[15] Based on our study of related literature, we consider that political rivalry may arise in various forms, be it factor price manipulation or political competition and replacement, or political incentives in public policy and political instability.[16] Political rivalry reflected in the undue use of power by the political elite for increasing its revenues is thus particularly relevant for our further discussion, especially in the view of the considered link to income redistribution. Such rivalry, as it may be expected, will distort the outcomes of efficient redistribution, rendering it inefficient, since in this case the elite will necessarily

[15]Note that, in this case, it implies the possibility of consequences typical for inefficient redistribution, *i.e.* political *versus* economic characteristics, excessive taxation, etc.

[16]More specifically, Acemoglu (2009), distinguishes between political rivalry when enrichment by other groups may pose a threat to elite's ability to use and benefit from their political power in the future (and distortionary taxes are then beneficial for the elite as a way of impoverishing their political competitors); and factor price manipulation, which increases the elite's profits indirectly (when the elite may be engaged in production and recognize that taxes on other producers will reduce the demand for factors and lower their competitors' production level).

redistribute based on political and not economic characteristics. We will then consider that the effects of political rivalry may be, in general, associated with breaking the balance between political power and economic opportunities, thus negatively affecting the relationship between political institutions, redistribution and economic outcomes, and in particular with generating episodes of expropriation. Expropriation, which we will discuss in more detail in the next section, is interpreted in our research context as the failure to employ the taxes levied through efficient redistribution for the originally intended objectives, instead using them for political rivalry related or generated purposes.

In sum, to the extent that redistributive policies are chosen depending on both political interests and incentives that policies are meant to induce, it appears to be directly influenced by political interactions between the elite and other social groups. We believe a crucial aspect of these interactions to be represented by political rivalry, which may considerably weaken the quality of political institutions, fundamental for securing efficient redistribution policies. In Section 4 we will discuss how efficient redistribution, specifically associated with human capital accumulation and assumed to improve economic performance, is conditioned by the ability to overcome political constraints within the existing institutional framework.

2.3.2 Political institutions and efficient redistribution: relation to public goods and government authority

As previously stated, in this work we focus on efficient redistribution policy specifically aimed at stimulating investments in human capital accumulation. Given that, by our assumption, the latter is a crucial determinant of economic growth, it also plays a decisive role in determining aggregate productivity. The same assumption implies that we are considering complex investment measures, often proved to be most efficiently undertaken by the government, *i.e.* by political institutions in power (Drazen, 2000; Acemoglu, 2009). Moreover, because our focus is on human capital investments in the form of publicly provided education, aggregate productivity and economic growth through human capital accumulation depends on government investments in public goods. As follows, this implies a strong mobilization of public authorities in what concerns the allocations of taxes between groups to publicly finance a private good. Moreover, because public policy emerges when political institutions succeed in aggregating conflicting interests of different social groups and because the division between political and economic power has a decisive role for adopted policies, our analysis on efficient redistribution and political institutions, involving public good features, demands accounting for political incentives of public goods provision, possible conflicts of interests, and as a result, the crucial role of political institutions.

In particular, it may be inferred that the provision by the state of the appropriate amount of public goods depends on whether the politically powerful groups have the incentives to invest in their supply. As it may be presumed, this depends primarily on two conditions: political groups' expected future benefits from such investments, and political interactions and conflicting interests in driving such investments.[17] As regards the first condition, recalling our assumption on human capital accumulation being fundamental for inducing a high rate of economic growth, future benefits from investing in the provision of related public goods would be secured and we should expect the government to have a strong incentive for providing them. However, as to the second condition, political rivalry is likely to distort political interactions and aggravate the conflicts of interests between rivaling groups, consequently distorting the effects of efficient redistribution policy and weakening the government's expected role in imple-

[17] As, for example, in Fisman (2001), who considers investment to be distorted not by redistribution but directly by political relations and argues that, when political interests rather than economic fundamentals are the primary determinant of profitability, distorted investment decisions may be taken.

menting aggregate investment measures. Given these considerations and in what public goods provision is concerned, governments subjected to frequent destabilizing episodes of political rivalry may become particularly detrimental to economic performance. This raises the issue of weak *versus* strong states, in the sense that government authority affects to a great extent not only the decision to invest in public goods, but the efficiency of such investments as well. In particular, excessively weak governments may not be able to implement efficient redistribution policies, while the uncontrolled power of excessively strong governments may result in expropriation, either of them being just as costly to economic performance (Persson and Tabellini, 1992; Alesina and Rodrik, 1992; Alesina and Perotti, 1994; Dixit and Londregan, 1995; Acemoglu and Robinson, 2001; Acemoglu, 2005; Acemoglu, 2009). On the one hand, if the state is weak the elite anticipate that they will be unable to reap the benefits of their investments in the future, and thus are unwilling to invest in public goods. On the other hand, if the state is too strong, control over taxes imposed on the population is absent, and even when investing in human capital accumulation increases overall benefits, efficient redistribution specifically associated with such investments will be neither required by the elite, nor supported by other social groups, since individuals have little means to control how the elite will actually use the collected tax revenues.

In sum, when aggregate economic effects are targeted by efficient redistribution policy strongly related to public goods provision, either conditioning investments on political interests or limiting the rents that accrue to the state (*i.e.* hindering efficient redistribution) may lead to the failure of the government to perform its functions in providing public goods, and may have significant negative consequences for aggregate economic performance. The next section provides a closing discussion on these issues.

2.4 Human Capital Accumulation and Control-Rights Institutions: a Political-Economic Equilibrium

In this section, we conclude our analysis on the relationship between efficient redistribution aimed at investments in human capital accumulation and political institutions, by defining a political-economic equilibrium conditioned on public education fully provided by the government and efficient control-rights institutions, which we will determine in the following discussion. Because the argument in this section merges the key points of our comparative critical assessment of directed research presented separately in previous sections, we open our concluding discussion with a bibliographic summary table (see Table 1) and a diagram summarizing the key points of our research (see Figure 1). In Table 1, we sum up the reviewed research works from the perspective of our reading of the literature, structured as to reflect the line of reasoning that supports our research objective.

Table 2.1: **Related research categorization based on our research objective**

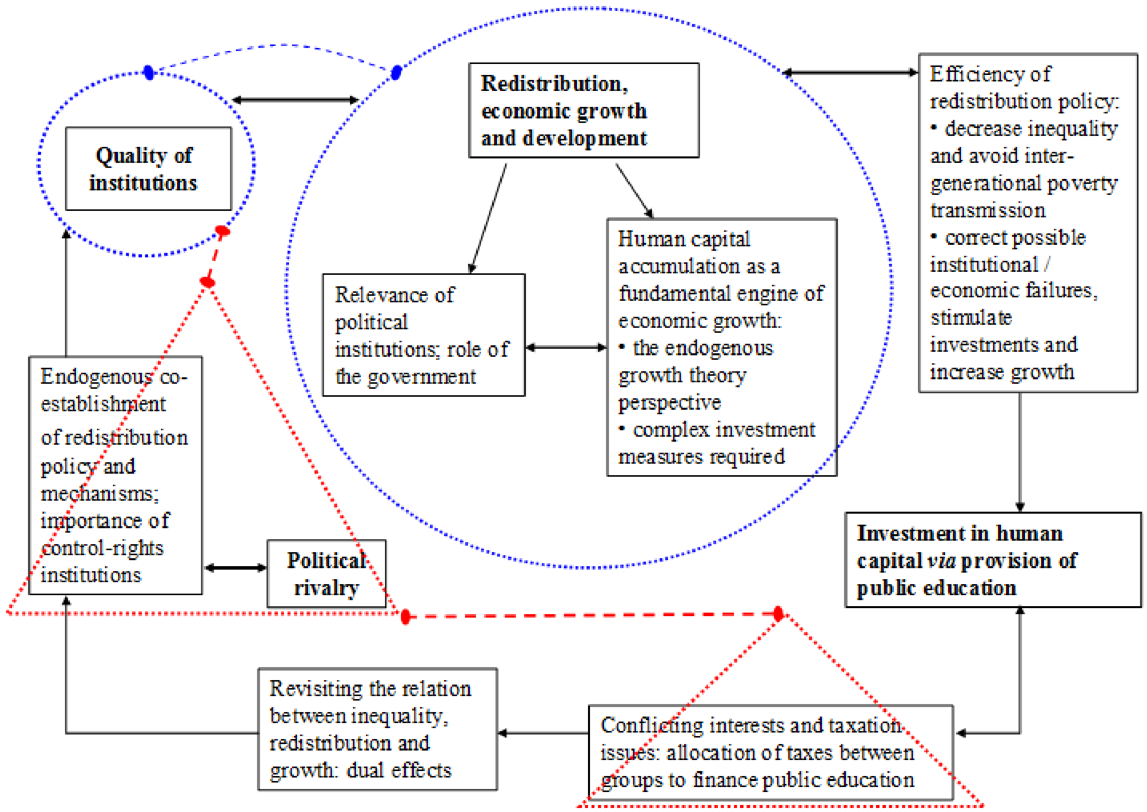
1. Political institutions: impact on economic growth	**Positive impact**	Perotti (1992)*, Alesina and Perotti (1994)*, Perotti (1996)*, Saint Paul and Verdier (1996)*, Drazen (2000)*, Acemoglu and Robinson (2006), Aghion et al. (2007)*, Rodrik (2007)*, Acemoglu (2009)
	Negative impact	Alesina and Rodrik (1992), Persson and Tabellini (1992), Przeworski and Robinson (1993), Dixit and Londregan (1995), Drazen (2000), Dixit et al. (2000), Acemoglu and Robinson (2001), Acemoglu and Robinson (2006), Nelson (2008), Acemoglu (2009)
2. Channel of transmission: redistribution policy	**Efficient redistribution**	Perotti (1992), Perotti (1996), Saint Paul and Verdier (1996), Drazen (2000), Acemoglu (2009)
	Inefficient redistribution	Persson and Tabellini (1992), Alesina and Rodrik (1992), Dixit and Londregan (1995), Drazen, (2000), Acemoglu and Robinson (2001), Acemoglu (2009)
3. Political versus economic characteristics		Dixit and Londregan (1995), Drazen (2000), Dixit et al. (2000), Acemoglu and Robinson (2001), Acemoglu and Robinson (2006), Acemoglu (2009)
4. Political rivalry		Londregan and Poole (1992), Alesina and Perotti (1994), Dixit and Londregan (1995), Drazen (2000), Dixit et al. (2000), Acemoglu and Robinson (2001), Acemoglu and Robinson (2006), Acemoglu (2009)
5. Human capital accumulation and economic growth		Lucas (1988), Perotti (1992), Perotti (1996), Saint Paul and Verdier (1996), Fernandez and Rogerson (1999), Drazen (2000), Blankenau and Simpson (2004), Acemoglu and Robinson (2006), Aghion et al. (2007), Acemoglu (2009)
6. Quality of institutions (efficient redistribution, human capital accumulation)		Przeworski and Robinson (1993), Saint Paul and Verdier (1996), Rodrik (1999), Drazen (2000), Acemoglu and Robinson (2006), Aghion et al. (2007)*, Rodrik (2007), Acemoglu (2009)

* Provided efficient redistribution policy, political stability and efficient growth-oriented policies implementation

Source: Own elaboration

Also, in Figure 1, we systematize the key points of the above discussion on redistribution and economic growth and on political institutions and redistribution in an effort to decompose the major complexity of the phenomena under analysis.

Figure 2.1: Quality of institutional factor and redistribution policies: systematization



Source: Own elaboration

The above discussion on efficient redistribution, aggregate growth determinants and economic role of public goods provided by the government leads us to specifically select full provision of public education to support our conclusions. We particularly overrule partial subsidization of public education because it involves the need to contribute with individual resources, which would most probably prevent the less economically favoured social groups from entering the program, as the total economic costs for them may exceed economic benefits.[18] As this may partially compromise human capital accumulation, an adverse effect on economic growth would be implied and efficient redistribution would become distortionary and similar to the inefficient one. Because this

[18]Supported by studies suggesting a negative effect of public education expenditure on redistribution and economic growth in a framework in which private and public investments are inputs to human capital accumulation, *i.e.* partial subsidization of education (Fernandez and Rogerson, 1999; Blankenau and Simpson, 2004).

contradicts our initial assumption of a "positive" efficient redistribution effect, namely, increasing investment in human capital accumulation and promoting growth, we focus on public education with unconstrained access.[19] More specifically, provided unlimited access, public education is by its nature a public good with all education costs fully covered by the government and requiring no private resource input. Since use of such public education is not impeded by class distinctions, *i.e.* rich or poor, or political characteristics, *i.e.* elite or opposition, we consider that it creates real possibilities for avoiding redistribution inefficiencies by preventing (at least in certain areas) possible conflicts of interests. We sustain that, in the presence of efficient redistribution and human capital accumulation externalities, the growth rate of the economy may actually increase in the tax rate employed for financing human capital accumulation (see Drazen, 2001). Considering this positive expected outcome, efficient redistribution policy specifically associated with investment in human capital accumulation and the provision of related public goods appears to be a desired feature of growth-enhancing institutions. Having reached this stage in our reasoning, let us now outline a conclusion based on the above-presented discussion, as to what can disturb this outwardly straightforward interpretation.

As we have seen, in a political economy context the politically powerful group has no incentives to invest in the public goods when future rents from these goods are expected to be low or no returns are expected at all. Although this is not likely to happen for the particular reason of human capital accumulation assumed to induce a higher rate of economic growth, which also increases returns on investments, it may nevertheless be a consequence of some negative features of the political processes involved. In particular, as we have previously established, in what public goods provision is concerned, governments subjected to frequent destabilizing episodes of political rivalry may become considerably costly to economic performance. This may happen in the case of either a

[19] Provided unlimited access, public education is by its nature a public good with all education costs fully covered by the government and requiring no private resource input.

too weak or a too strong state. The former entails that none of the conflicting political groups is sufficiently strong to gain political control through majority support, and the latter implies that one excessively strong party struggles to keep its political (and economic) control through misguiding practices. Therefore, it can be concluded that only states with intermediate levels of strength may be most capable and most interested to reap the benefits of efficient redistribution by investing in human capital accumulation. We will come back to this conclusion shortly.

Furthermore, to the extent that we have considered political rivalry to distort efficient redistribution so as it may be associated with expropriation, the case of an excessively strong government is of particular interest for our discussion. In the relationship between social groups with different degrees of political power, the issue of property rights protection is directly relevant. When the political elite is virtually unaffected by the authority of property-rights institutions, the available property rights crucial for stimulating and securing investments may not be sufficient *per se*. Because in our political economy context there are no clearly set boundaries between the political elite and property-rights institutions, it is possible that in some cases they are of the same nature, and efficient separation between ex-ante arrangements and ex-post distortions (so as to regulate the relationship between state and individuals in order to avoid policy failures and expropriation threats) will be difficult. Since, as discussed in the previous section, we build a relation between political rivalry, expropriation and the distortionary use of efficient redistribution policy, a negative institutional impact is produced through the political rivalry mechanism when property-rights institutions are inefficient on accounts of an excessively strong government. Thus, when the political constraints that the society may impose on the ruling power are relatively inefficient, individual economic and investment decisions are directly affected, and to the extent that the factor affected by distortionary redistribution policy is a major input into the growth process, as is the case for human capital, the effect on growth is clearly adverse.

We shall come back to discussing the role that political rivalry and political constraints imposed by the society may have in determining the existence of a political-economic equilibrium.

Within this line of reasoning we believe that **control-rights institutions**, rather than property-rights institutions, should play a key role in our research setting. In particular, following Rodrik (2007), we argue that efficient property-rights institutions should secure adequate control rights rather than just ownership rights, because even when individuals have a certain degree of ownership of property rights they do not always have sufficient control over these rights. In our view, apart from preserving the distinctive feature of property-rights institutions, which is determining the vertical relationships between social groups with different degrees of political power, control-rights institutions may actually constrain the elite in their expropriation intents.[20] Thus, the connotation we attribute to control-rights institutions is a **combination** of specific policy mechanisms (which society has at hand to ensure efficiency and non-distortion) with a hierarchical representation of power. In this sense, in our context an efficient redistribution policy by which taxes are particularly used for stimulating human capital accumulation through public education would enable the tax-payers to eventually control how a part of their income given for tax payments is used, since they are in effect the direct beneficiaries of the public education system provided by the government. Therefore, in the decision to accumulate production factors in general and human capital in particular, we attribute a crucial role to control-rights institutions.

From the above discussion and returning to the government authority issue, it can be concluded that a medium strong state could be most conducive to growth-enhancing efficient redistribution policies. In particular, we argue that it implies well-functioning control-rights institutions, a relatively balanced power distribution between the elite

[20]Recall that in our research context we interpret expropriation as the failure to employ the taxes levied by efficient redistribution for investments in human capital accumulation as originally intended, instead being used for political rivalry related purposes.

and other groups, and efficient taxation mechanisms with corresponding levels of public goods provision. It also implies that redistribution policy aimed at investments in human capital accumulation is an efficient and a publicly accepted policy, in the sense that its implementation involves none or minimum political and social distortions. In our context, absence of political distortions means that taxation will be fundamentally different from expropriation, since tax-revenues will be directed for public goods provision, from which aggregate benefits may be generated.[21] On its turn, the degree of social distortions is what determines public acceptance or rejection of a particular redistribution policy, and in our case the absence of the former implies the public acceptance of the latter. This arrangement has in fact, strong economic reasons. The mechanism we emphasize in this work is that when taxation revenues are particularly employed for financing human capital accumulation, *e.g.* through tax-financed public education, increased investment by the direct beneficiaries of redistribution can have a positive effect on those being taxed.[22] Given that the efficiency of political institutions has a strong impact on policies that may enhance growth in the presence of positive redistribution externalities (such as investing tax-revenues into human capital accumulation in the form of public education in the presence of an expected positive impact on growth), human capital accumulation itself becomes strongly related to the quality of the institutional factor. This conclusion is also supported by important empirical evidence presented in Acemoglu (2009), inferring that only countries with relatively good institutions have encouraged the majority of the population to accumulate human capital. Therefore, as regards the efficiency of political institutions, we sustain that relatively large investments in human capital accumulation may be a fair sign of higher-quality institutions.

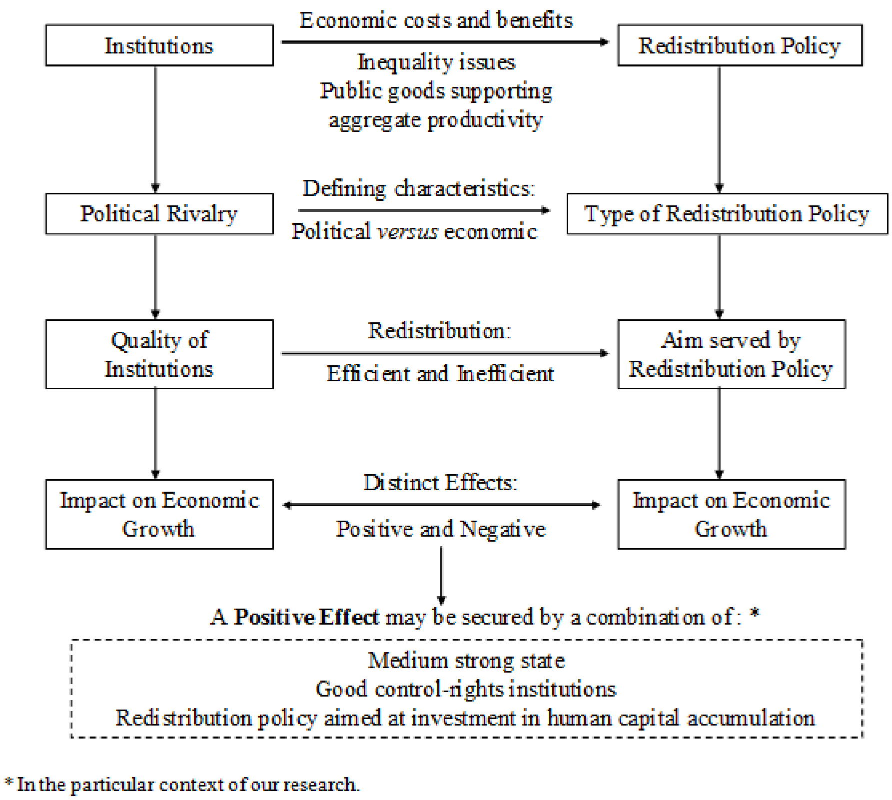
Considering thus the relationship between political institutions, income redistribu-

[21]As opposed to expropriation, when a share of individuals' income is taken by the government for its own consumption.

[22]For examples see Perotti, 1996; Saint-Paul and Verdier, 1996; Drazen, 2000; and Acemoglu, 2009.

tion and economic growth from the perspective of human capital accumulation (endogenous growth theory) and institutional quality (new political economy), a specific mechanism linking the above-mentioned key components can be outlined. We sustain that there is a continuous twofold interaction linking political institutions and redistribution policy to economic growth, which we define as the "cause-consequence" processes. Separately, each one has its own specific characteristics and their particular combinations induce distinct consequences for each level of interaction specifically and for economic growth generally. It should be noted that the entire process, as well as the final impact on economic growth, is endogenously and gradually determined by each level's interactive outcomes. Namely, from the political institutions side the "cause-consequence" sequence we build goes through: political institutions – political rivalry – quality of institutions – economic growth. And from the redistribution policy side the sequence is: redistribution policy – type of redistribution – aim served – economic growth. Figure 2 presents this process in the form of a diagram.

Figure 2.2: Interaction mechanisms between institutions, redistribution policy and economic growth



Source: own elaboration

As regards our "cause-consequence" specification, we sustain that the political institutions block is the initiating factor in the sequence, while the redistribution policy block is the reacting one. Initially, political institutions are responsible for developing redistribution policies. Then, political rivalry distortions influence the choice of the various types of redistribution policies with a direct influence on institutional quality and the aim of a chosen redistribution policy type. Here, relevant for the next level of interaction are the predominant characteristics, *i.e.*, political *versus* economic, jointly determining the efficiency or inefficiency of the implemented redistribution policy and the cumulative, positive or negative, impact on economic growth. We particularly focus on the positive effect, which we consider to result from a combination of medium strong state and good control-rights institutions, generating a balance between political rivalry and people's power, partly secured by redistributive policy aimed at investment in human capital accumulation.

Thus, in the framework of the relationship between efficient redistribution and political institutions that we specifically analyse through the link between human capital accumulation and political rivalry, we arrive at the definition of a political-economic equilibrium. We particularly define it as a combination of a medium strong state, reliable control-rights institutions and efficient redistribution aimed at human capital accumulation such that, on the one hand, individuals have sufficient control-rights to ensure them from expropriation, and, on the other hand, the state is guaranteed to follow on its redistribution policy engagements. In such a political-economic equilibrium, efficient growth-enhancing institutions imply not only that appropriate public good investments will be undertaken to support aggregate productivity, increase human factor accumulation and stimulate growth, but when combined with the above-emphasized importance of control-rights institutions also provide sufficient security of control rights for individuals, thus avoiding expropriation in the form of ex-post redistributive distortions. It should be noted that apart from a positive economic growth effect, this political-economic equilibrium implies also a positive development effect. Complementing pure growth strategies (insufficient as dominant solutions for achieving development), the implied education policy would improve the standard of living and welfare of the population through guaranteed equal access to public education, increased human capital stock, etc. Given a redistribution policy that distributes more equally the possibilities to invest in human capital accumulation, the education policy envisaged in the above-defined equilibrium becomes both an economic growth and an economic development strategy.

We also emphasize that the existence of this political-economic equilibrium is primarily determined by the key factors of political rivalry and political constraints imposed by the society from the perspective of redistribution policy and human capital accumulation, as discussed above. In particular, political rivalry may generate imperfections in the functioning of control-rights institutions and introduce expropriation threats, affecting thus the security of investment in human capital accumulation, the efficiency of redistribution policies, and consequently affecting growth. In a dynamic framework, this may occur when pressures from political rivalry introduce previously absent limitations (in some dimension) of the voting rights over redistribution policies. This may result in limited franchise and generate disproportionate weights in the decision process, which will necessarily bias the final policy choice and result in inefficient redistribution (Drazen, 2000).[23] In these circumstances, the well-functioning of control-rights institutions becomes especially important, and the relative degree of constraints on political monopoly power determines the adoption of efficient redistribution policy, thus allowing for a (new) political-economic equilibrium. Relating the efficiency of control-rights institutions (from the perspective of political rivalry and expropriation) to the degree of constraints on political monopoly power, we can interpret the implicit economic costs in terms of forgone investments in human capital accumulation and economic growth opportunities. In particular, because political rivalry generates distortions that negatively affect the quality of institutions, the resulting less efficient control-rights institutions will imply that imposing political constraints will present higher social costs, lowering investments and reducing economic growth. This reasoning strongly emphasizes the importance of the quality of political institutions, in the sense that qualitative changes in control-rights institutions will induce level changes in the social costs of political constraints, so that depending on the particular combination of efficient control-rights institutions, the political power of the elite, and the role attributed to efficient redistribution aimed at stimulating investment in human capital accumulation, the above defined political-economic equilibrium may exist. When

[23]These limits on voting rights may be imposed based on income or other observable criteria, may depend on the degree of inequality or on factor disproportionate ownership, especially relevant for capital intensive sectors.

political rivalry distorts the elite's commitment to the efficient, growth-enhancing redistribution policy, consequently distorting the balance between the key equilibrium components, qualitative changes in control-rights institutions could either help the convergence or induce the divergence from the political-economic equilibrium. We leave the question of whether different equilibrium solutions are possible in such a political economy setting for further, more formalized, research.

2.5 Concluding remarks

In this chapter, based on a comparative critical assessment of an extensive literature covering both political economy and economic growth fields, we have studied how the quality of the institutional factor may influence the efficiency of redistribution policy specifically associated with human capital accumulation. We have seen that efficient redistribution creates positive externalities by enabling investment in human capital accumulation, and is therefore essentially different from inefficient redistribution, which creates negative externalities by lowering factor endowments and decreasing aggregate productivity. Positive redistribution policy effects may be secured when tax-revenues are appropriately allocated to stimulate investment in human capital accumulation in the form of public tax-financed education, increasing productivity and improving aggregate economic performance.

In the decision to accumulate production factors in general and human capital in particular, we have attributed a crucial role to control-rights institutions, which we have defined as a combination of specific policy mechanisms and a hierarchical representation of power. We have also argued that the quality of these institutions is the decisive factor in the final outcome, in the sense that efficient growth-enhancing institutions should not only imply that appropriate public good investments will be undertaken to support aggregate productivity, increase human factor accumulation and stimulate growth, but also provide sufficient security of control rights for individuals, thus avoiding expropriation in the form of ex-post redistributive distortions. We have then defined a political-economic equilibrium as a combination of a medium strong state, reliable control-rights institutions and efficient redistribution aimed at human capital accumulation. We also emphasized that its existence is primarily conditioned by political rivalry generating distortions that negatively affect the quality of institutions. We concluded that when political rivalry distorts the elite's commitment to the efficient, growth-enhancing redistribution policy, consequently distorting the balance between the key equilibrium components, qualitative changes in control-rights institutions could either help the convergence or induce the divergence from the defined political-economic equilibrium. We leave the question of whether different equilibrium solutions are possible in such a political economy setting for further, more formalized, research.

We also identify several other possible topics for future work. For example, in alternative to the largely employed Median Voter Theorem, the more recent Probabilistic Voting Theorem could be applied in order to deepen the understanding of mechanisms linking political institutions, inequality and redistribution policies (including publicly provided education) with a direct effect on economic growth. We have also seen that the analysis on the mechanisms of efficient redistribution associated with human capital accumulation goes closely in hand with issues of inequality and its role on economic growth. Therefore, another possible venue of future research could be oriented towards emphasizing the specific effects of inequality in a redistribution aiming at increasing investment in human capital accumulation, which reduces inequality and increases growth. And, as a final point, a challenging task would be to develop an analytical model incorporating the institutional impact mechanisms suggested in this work.

Chapter 3

Political rivalry effects on human capital accumulation and inequality: a New Political Economy approach

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3.1 Overview

Understanding how political institutions influence and determine economic outcomes has become one of the most challenging questions of modern economic theory. Related economic analysis of political institutions attributes considerable importance to their role in defining aggregate economic performance both from a theoretical and a practical, policy-making perspective. For example, studies of political incentives and political institutions argue that policy cannot be viewed as an exogenous process, playing a central role in explaining differences in growth rates across countries (*e.g.* Persson and Tabellini, 1992; Acemoglu and Robinson, 2000; Acemoglu, 2006). In many contexts of new political economy, the need to jointly model political and economic mechanisms and their interaction is emphasized (see, for example, Sayer, 2000). Existing empirical evidence also indicates that political processes have a crucial impact on resulting economic policies and outcomes (*e.g.* Alesina and Rodrik, 1992; Perotti, 1996).

Following our theoretical discussion in Chapter 2, here we propose an overlapping generations model with elements of new political economy to study the effects of political rivalry on human capital accumulation and income inequality and examine how different political incentives and policies may affect the resulting economic allocations. With this objective, we combine elements of endogenous growth theory and new political economy by considering human capital accumulation as the engine of endogenous growth and accounting for the crucial role of institutions in securing undistorted economic outcomes. In analysing the impact of political institutions we focus on two important policies affecting economic performance: fiscal policy and provision of public goods in the form of investments in human capital accumulation *via* publicly provided education. This choice is motivated by the similarity in the targeted effects of both human capital accumulation and efficient redistribution, such as decreasing inequality, correcting possible institutional or economic failures, stimulating investments, improving economic performance and increasing growth. Our research framework relies on the idea that, being the basis for long-term economic development and one of the key factors influencing aggregate productivity and individual income, human capital accumulation is a fundamental macroeconomic policy, the significance of which cannot be neglected and for which political effects have a critical role. We also consider that understanding the determinants of income and income inequality is particularly important in what regards vertical and inter-generational social mobility.

The present work relates to the increasing literature on: (i) the relationship between income redistribution, inequality and growth; (ii) the political economy of growth. In particular, as regards the possible effects of redistribution on income inequality and growth, our model accommodates some of the important conclusions of existing theoretical and empirical research (see Chapter 2). Considering the negative effects, in consistency with the hypothesis advanced by the theories, early cross-country analyses has established a negative association between the level of inequality and economic growth through the distortionary nature of taxation, emphasizing that anticipated distortionary redistribution will lower the incentives to accumulate and thus may hamper growth (*e.g.* Alesina and Rodrik, 1992; Persson and Tabellini, 1992; Perotti, 1996; Drazen, 2000). Our model's results verify these findings. As for the positive effects, Perotti (1992) shows how in economic structures with public investments in education the effect of taxes on growth is positive, a conclusion also supported in the research works by Alesina and Rodrik (1992) and Persson and Tabellini (1992).[1] In a later study, Perotti (1996) also shows that higher inequality is indeed associated with a lower level of human capital accumulation, and lower human capital accumulation is associated with lower levels of economic growth. Recently, the cross-country analysis of Easterly

[1] They conclude that efficient redistribution policies limit the degree of distortions in investment decisions and promote economic growth.

(2007) reaffirmed that human capital accumulation and economic development are adversely affected by inequality, which is a barrier to schooling and economic growth. An inverse relationship is modeled in Chatterjee and Turnovsky (2010), who consider public investments in education both as the growth engine and an important determinant of inequality. Finally, there are some studies that integrate both positive and negative effects, by considering that, at different levels of economic development, inequality may have a dual impact on growth (for example, Saint Paul and Verdier, 1996;[2] Perotti, 1996; and Galor and Moav, 2004[3]), which is also accommodated by our model.

Regarding the political economy of growth, directed research that combines eco-

[2] In the study performed by Saint Paul and Verdier (1996), the authors reconsider the conventional political economy view that more unequal societies tend to redistribute more, and more redistribution is harmful to growth. In particular, using a simple voting model, Saint Paul and Verdier (1996) show that: (*i*) higher inequality does not necessarily lead to more redistributive taxation (without detailing, they briefly enumerate some mechanisms that may generate a negative relation between inequality and taxation, such as progressive taxes and transfers, endogenous political participation, and particularities of the median/mean ratio); and (*ii*) more redistribution is not necessarily harmful for growth through the conventionally accepted mechanism, namely that more redistribution means higher tax rates on investment returns, which in turn reduces investment and growth. On the contrary, their analysis suggests that inequality does not have to be always positively correlated with redistribution, arguing that particular transfers may affect growth positively rather then negatively.

[3] Similarly, the study in Galor and Moav (2004) suggests that the replacement of physical capital accumulation by human capital accumulation as the prime engine of economic growth has changed the qualitative impact of inequality on the process of development. In early stages of industrialization, as physical capital accumulation was a prime source of economic growth, inequality enhanced the process of development by channeling resources towards individuals whose marginal propensity to save is higher. In later stages of development, however, as human capital became the prime engine of economic growth, a more equal distribution of income, in the presence of credit constraints, has stimulated investment in human capital and promoted economic growth.

nomic analysis with political economy elements refers to political rivalry as a key element affecting economic performance (see, for example, Dixit *et al.*, 2000; Scruggs, 2001; Acemoglu, 2006). The effects of political rivalry are generally associated with breaking the balance between political power and economic opportunities, thus negatively affecting the relation between political institutions, redistribution and economic outcomes.[4] For example, Rodrik (1999) suggests that disagreements between political groups may inflict the extra cost on the economy, as well as Acemoglu and Robinson (2001) and Dixit and Londregan (1995), who suggest that contesting political power (resulting in inefficient redistribution) may induce economic costs due to its growth retarding effects. Success or failure of implemented economic policies then depends on how prevailing institutions manage political rivalry. This is a crucial assumption in our model. As regards the specific concept of political rivalry adopted in this work, we follow Acemoglu (2006), who defines political rivalry as (negative) political competition arising when enrichment by other social groups poses a threat to the elite's ability to benefit from their political power in the future. It also implies a strong negative impact when goals pursued by the political elite, instead of economic efficiency considerations, determine the policy choice. In this respect, it reflects how political constraints may explain the choice of policies, and thus economic outcomes. In particular, in our model political rivalry arises in the form of political competition against replacement and political incentives in public policy, and we consider that distortionary taxes are then beneficial for the elite as a way of impoverishing their political competitors. As such, political rivalry becomes a key distorting factor in the economy.

In line with our research objective, this framework is adopted to illustrate that (*i*) non-distortionary redistribution *via* public education equalizes income levels and increases the human capital accumulation in the economy, which has a growth promoting effect;[5] (*ii*) the efficiency of such redistribution policy is distorted by political rivalry,

[4] See Chapter 2 for a more detailed definition of political rivalry in our research.

[5] This kind of redistribution facilitates investment by the poor without impeding investment by the

with resulting negative effects on economic outcomes.

Our model combines elements from the study of Glomm and Ravikumar (2003), extended by the introduction of a final-goods production sector and endogenous new political economy elements as suggested by Acemoglu (2006). Introducing a production sector in the economy allows us to specifically derive the equilibrium income and its growth rate; considering endogenous fiscal and public investments policies allows for a richer analysis of economic results that accounts for the effects of the inherent political mechanisms and political rivalry, and the role of political institutions. As in Glomm and Ravikumar (2003), we examine the evolution of inequality in an overlapping generations model with human capital accumulation. However, our specific focus on endogenous fiscal policy and political rivalry enables us to show how political processes may distort the efficiency of economic interactions. Our analysis suggests distinct perspectives as regards public policies targeting investments in education and inequality. In particular, we find that increasing the tax rate will increase public investments in education only when taxes are non-distortionary. When taxes are excessively increased due to political rivalry, the result will be lower educational investments, reduced individual learning incentives and limited human capital accumulation, which will lower production, wages and consequently may deepen or prolong income inequality. This implies that only in the absence of political rivalry, can public investments in education be used as an efficient social mobility promoter, enabling income convergence and overcoming inequality. Thus, although being attenuated by public policy oriented towards education and human capital accumulation, we find that political rivalry produces negative outcomes in all dimensions. We also find that the elasticities of human capital accumulation with respect to public and private investments have crucial implications for the role of political institutions and require particular attention to the political rivalry effects.

rich, and therefore is again positively associated with growth.

The structure of this chapter is the following. In Section 2 we outline our model's specifications and derive equilibrium values for our main variables regarding productive activities, human capital accumulation, optimal policy choice, and income inequality. Section 3 includes the comparative statics analysis focusing on the effects of public investments policy and political rivalry. In Section 4 conclusions and references for possible future research are presented. Mathematical detail for the comparative statics analysis of Section 3 is provided in the Appendix.

3.2 Model specifications

We consider an overlapping generations economy with constant population where individuals live for two periods. The economy consists of a continuum of risk-neutral agents $1 + S^e + S^m$, each with a discount factor equal to $\beta \in (0, 1)$. We assume there is a total of S^e elite agents, S^m middle-class agents and a continuum of workers,[6] with a measure normalized to 1, being that each agent's social group membership (*i.e.* elite, middle-class or worker) does not change over time.[7] In this model, the elite, denoted by e, represents the social group of agents that hold the political power in the society, decide on policies and do not take part in productive activities. We make this assumption in order to emphasize the effects of political economy and show how a decoupling between political and economic power can lead to political rivalry, distortionary policy and poor

[6] We divide our model's agents into these three social groups following the terminology frequently used in the new political economy literature.

[7] Although the mechanisms and processes of political power distribution in the society is an independent research question *per se*, here we take as given the assumed distribution and, instead, focus on how challenging it may lead to different policies and thus to different economic paths.

economic outcomes.[8] The middle class, denoted by m, are the entrepreneurs in the economy with access to the final good production technology. The workers, who supply their labour inelastically, are employed by the middle-class entrepreneurs for producing the final good. Finally, we also assume that in each period workers are differentiated by the amount of parental income invested in their education and by the human capital stock they accumulate depending (among other things) on their individual learning choice and on fiscal and public education policies adopted by the elite.

3.2.1 Middle-class entrepreneurs and productive activities

For producing the final good, each middle-class entrepreneur has access to the following Cobb-Douglas Harrod-neutral production function:

$$Y_{i,t} \equiv F(K_{i,t}, G_{i,t}) = (K_{i,t})^{\alpha}(A_t \cdot G_{i,t})^{(1-\alpha)} \tag{3.1}$$

where $Y_{i,t}$ is the final-good output produced in t by entrepreneur i, $K_{i,t}$ is capital used, A_t is the aggregate labour-augmenting productivity term, and $G_{i,t}$ is the total contribution of workers of different skill levels to final good production, such that $G_{i,t} =$

[8] When political and economic powers are decoupled, the conflicts of interest in the society are more likely to result in political rivalry that will necessarily distort the outcomes of economic policies pursued by the institutions in power. Being impossible to isolate the resulting resources distribution from the aggregate economic performance, the resulting allocations will be inefficient and will often involve different types of distortions. For example, Alesina and Rodrik (1992) conclude that individuals who have access to productive assets of an economy are more likely to be restrained in their desire to tax them, suggesting that it is easier to avoid damaging conflict over redistribution policies when the economy's assets are widely shared. Similarly, the discussion in Dixit and Londregan (1995) suggests that positive results can be achieved when redistribution is done according to economic criteria and not political characteristics.

$L_{i,t} \cdot H_{i,t}$, with $L_{i,t}$ being the total amount of labour used in t and $H_{i,t}$ the total amount of human capital that each worker (of a specific skill level) is endowed with in period t. The use of a Cobb-Douglas production technology allows us solving for the political equilibrium analytically and, as it will be seen further, also links equilibrium taxes and public education investments to the elasticity of output with respect to capital.

In order to derive the steady-state capital stock *per* unit of human capital and final output, we assume that, at each t, the economy starts with two predetermined variables: the output tax rate, τ_t, and the capital stocks of the middle-class entrepreneurs, K_t. We assume that the linear tax on output, τ_t, is applied by the elite to middle-class production for raising state revenues. As it will be shown in Section 2.3, τ_t is endogenously determined in our model depending on political rivalry considerations of the politically powerful social group, *i.e.* the elite. As in Acemoglu (2006), we also assume that taxes are set before the entrepreneurs make their investment decisions, namely, that their capital and labour stocks for the next date are chosen after observing the tax rate previously announced by the elite. Then, final output is produced, and a fraction τ_t of the output is collected as tax revenue.

Denoting by $k \equiv \frac{K}{G}$ the capital stock *per* unit of human capital, we can rewrite equation (3.1) as $f(k_i) = A^{(1-\alpha)} \cdot k_i^{\alpha}$. Then, assuming that a fraction δ of capital depreciates, we can write the utility of an entrepreneur with a capital stock *per* unit of human capital k_i at time t as a function of the announced fiscal policy.[9] In particular, given a predetermined tax rate on output, τ_t, the utility of a middle-class entrepreneur can be written as:

[9] In defining the middle-class entrepreneurs' utility we assume that preferences are linear, and thus the value function can be written as a discounted sum of gross production levels (*i.e.* before subtracting labour costs).

$$U^m(k_t, \tau_t, \delta) = \sum_{s=t}^{\infty} \beta^{s-t} \left((1-\tau_s) f(k_s) + (1-\delta)k_s - k_{s+1}\right) \tag{3.2}$$

Maximizing (3.2) with respect to each entrepreneur's choice of the next period capital stock *per* unit of human capital, k_{t+1},[10] yields the steady-state capital stock *per* unit of human capital that must satisfy:

$$\beta \left[(1-\tau) f^{'}(k_{t+1}) + 1 - \delta\right] = 1 \tag{3.3}$$

Because of linear preferences, expression (3.3) applies for all t and using the above defined production function, $f(k_i)$, implies:

$$k^* = A_t \cdot \left(\frac{\beta^{-1} + \delta - 1}{\alpha(1-\tau)}\right)^{\frac{1}{\alpha-1}} \tag{3.4}$$

$$F(K^*, G) = A_t \cdot G_t \cdot \left(\frac{\beta^{-1} + \delta - 1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}} \tag{3.5}$$

From expressions (3.4) and (3.5) we can see that, given the announced fiscal policy, output produced by the middle-class entrepreneurs will be reduced (in advance) by a fraction τ and the steady-state output and capital stock *per* unit of human capital will be strictly lower than they would be in an economy without taxation. In fact, in a political economy context, anticipation of a redistributive policy motivated merely by political considerations can reduce economic incentives and prevent economically advantageous actions from being taken (*e.g.* Alesina and Perotti, 1994; Dixit and Londregan, 1995; Acemoglu and Robinson, 2001). This implies that, with a tax rate increased by political rivalry, economic incentives for production activities will be more reduced, as we will see further in this chapter.

[10] For the sake of simplicity, we suppress the index i.

3.2.2 Human capital accumulation and wages

By our model's assumptions, workers are the only economic agents who receive wages and accumulate human capital individually. Assuming that workers are paid their marginal product for the labour they supply to middle-class entrepreneurs, the wage at time t , accounting for the above derived capital stock *per* unit of human capital (3.4), is given by:

$$w_t(K^*) = (1-\alpha) \cdot A_t \cdot H_t \cdot \left(\frac{\beta^{-1} + \delta - 1}{\alpha(1-\tau)} \right)^{\frac{\alpha}{\alpha-1}} \tag{3.6}$$

Next, we assume that each worker's human capital stock at time $t+1$ results from a combination of factors devoted to its accumulation and, following Lucas (1988) and Glomm and Ravikumar (2003),[11] we derive the human capital accumulation function, H_{t+1}, as:

$$H_{t+1} = E_t^{\zeta} w_t^{\gamma} (1 - l_{j,t}) \tag{3.7}$$

where $1 - l_{j,t}$ denotes time devoted to learning; w_t, weighed by γ, denotes parental income (wages of individuals old enough to work in t) invested in children education; and E_t, weighed by ζ, is a compound variable that denotes investments in public education designed to improve its quality, expand infrastructure, and provide equality of access and opportunity. Elements such as educational material provision, teaching quality improvement and individual support and incentives through merit scholarships and means-testing subsidies, are examples of various aspects of educational investments

[11] On empirical evidence supporting this specification for the human capital accumulation function see Coleman *et al.* (1966), Heyneman (1984), Lucas (1988), Card and Krueger (1992), Meghir and Palme (2005), Carneiro *et al.* (2010) and Chatterjee and Turnovsky (2010).

captured by E_t.[12] To capture the effect of (initial) income distribution, we assume that individuals differ in parental income invested in their education, from which they benefit by a factor of γ. They will also differ ex-post in the human capital they accumulate through the public education system, from which they benefit by a factor of ς. Although both parameters γ and ς are assumed exogenous in our current study, their role in human capital accumulation should not be underestimated. For example, the closer the parameter ς is to 1, the more dominating is the weight of public education in human capital accumulation. Also, it is important to emphasize, that even when $\gamma = 0$ (*i.e.* when parents do not or can not invest in their children education), there is still human capital accumulation in the economy because of the publicly provided education. The economic and political implications of different magnitudes of γ and ς will be discussed in more detail in the next sections.

Furthermore, given that young workers accumulate human capital and old workers are employed and remunerated for producing the final good, we assume that time devoted to learning, $1 - l_{j,t}$, is determined by each worker's individual preferences over leisure when young and consumption when old given by the standard constant-relative-risk-aversion utility function:[13]

$$\frac{l_{j,t}^{1-\sigma} + c_{j,t+1}^{1-\sigma}}{1-\sigma}, \quad 0 < \sigma < 1 \tag{3.8}$$

where $l_{j,t}$ is leisure at time t, $c_{j,t+1}$ is consumption at time $t+1$, which we assume to be given by $w_{j,t+1}$, and σ is the usual coefficient of relative risk aversion, which we

[12] As it will be shown in the next section, E_t is determined by a (weighed) proportion of tax revenues collected by the elite from the middle-class entrepreneurial activity.

[13] The use of this standard functional form ensures the existence of a balanced growth path.

refer to throughout the model as the individual preferences parameter.[14]

The young agent's problem at time t is to choose the optimal time allocation between leisure, $l_{j,t}$, and learning, $1-l_{j,t}$. This choice (along with public investments in education and parental income) will determine the worker's human capital accumulation and corresponding wage (and consumption) in $t+1$. Formally, we maximize (3.8) subject to $c_{j,t+1} = w_{j,t+1}$, where $w_{j,t+1}$ is given by (3.6) in $t+1$ together with (3.7). Then, for a standard constant-relative-risk-aversion utility function and assuming an interior solution to workers' maximization problem, the optimal learning choice, $(1-l_t)^*$, is given by:

$$(1-l_t)^* = \frac{\left((1-\alpha)\cdot A_{t+1}\cdot E_t^{\zeta} w_t^{\gamma}\cdot\left(\frac{\beta^{-1}+\delta-1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}}\right)^{\frac{1-\sigma}{\sigma}}}{1+\left((1-\alpha)\cdot A_{t+1}\cdot E_t^{\zeta} w_t^{\gamma}\cdot\left(\frac{\beta^{-1}+\delta-1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}}\right)^{\frac{1-\sigma}{\sigma}}} \tag{3.9}$$

Given E_t, the choice of $1-l_{j,t}$ allows us to (recursively) fully derive H_{t+1}, w_{t+1}, and c_{t+1}.

Again, because our objective in this chapter is to analyse the effects of political economy, we note that, depending on the specific value of τ, a dual effect on the workers' optimal learning choice (given the effects of an increase in the output tax on w_t and E_t,) is possible. Various implications of distinct fiscal policies will be discussed in more detail in the next sections.

3.2.3 Elite utility and optimal policy choice

In this section, we characterize the "policy" block of our model by looking at the fiscal and public investment policy choices of the elite. Recall that, in this chapter, we

[14] We impose the restriction $0 < \sigma < 1$ to guarantee that a worker's lifetime utility is increasing in $l_{j,t}^{1-\sigma}$ and $c_{j,t+1}^{1-\sigma}$ and is globally positive.

have assumed that the elite does not take part in productive activities, its only role in the economy being purely political. This assumption is crucial for separating economic and political power, thus allowing for political rivalry effects. Considering the specific fiscal and public policy and the incentives of the elite, we then derive the optimal tax rate for each t under different scenarios of future political power distribution.

Fiscal and public policy and the incentives of the elite

As regards fiscal policy, we consider available two instruments: a linear tax on output, $\tau_t \in (0,1)$, and lump-sum transfers to the elite, T_t^e.[15] As regards public investments policy, we assume that the elite devotes part of the collected tax revenues to investments in public education, through which human capital accumulation is done. We consider that the elite's incentive for implementing this policy is supported (as for any type of public investments) by its expectations to reap the benefits of these investments in the future. Being closely related to economic development through its inherent features of increasing competencies, knowledge and other qualitative attributes, when incorporated in workers' performance, human capital accumulation produces increased economic value and leads to both quantitative and qualitative progress, from which (in a political economy context) the elite benefits directly. In particular, we consider that the elite's motivation for making public education investments is twofold. On the one hand, besides increasing wages paid to workers, accumulated human capital also makes them more productive and increases the final output produced by middle-class entrepreneurs, thus enabling the elite to collect higher tax revenues. This part refers to the revenue extraction motive (Acemoglu, 2006) and, as we will further show, does not

[15] Because the elite initially holds the political power in our model, we can restrict our analysis to the sequence of policies that imply no direct redistribution either to the middle-class entrepreneurs or workers.

entail distortionary economic outcomes. On the other hand, human capital accumulation also offers exclusively to the political group in power additional revenues, resulting from innovations, property rights, patents, etc. In our political economy context, this strengthens the elite's intention to secure its politically dominating position in order to be able to access future (including elite exclusive) revenues from productive activities and human capital accumulation.

Thus, there are two opposing forces that determine the elite's optimal policy choice. On the one hand, there is an elementary revenue extraction motive, so it is in the elite's interest to have a highly productive middle-class and growing human capital accumulation, as this would enable higher output-tax and additional elite exclusive revenues. This determines the elite to choose non-distortionary fiscal policies that promote human capital accumulation and economic growth.[16] On the other hand, because in the next period the elite do not want to lose power and all the benefits it entails, they will recur to political rivalry mechanisms. In particular, the elite will set an excessive tax rate that will lower production and reduce human capital accumulation, impeding the middle class from becoming richer and consequently more powerful. With these considerations and in what public goods provision is concerned, political rivalry may become particularly detrimental to economic performance. By generating distortions that negatively affect the resulting economic outcomes, political rivalry implies higher social costs,[17] lower investments and reduced economic growth.

[16] Throughout this chapter, we use the terms "economic growth" and "final output growth" as synonymous, since both imply positive variations in $F(K,G)$.

[17] In our research context, the implicit economic costs of the failure to employ tax revenues for the originally intended purpose (instead using them for political rivalry related reasons) can be interpreted in terms of forgone investments in human capital accumulation and economic growth opportunities.

Maximization problem of the elite

Following Acemoglu (2006) and with the above considerations in mind, we can derive the utility of the elite (the net present discounted utility of a representative elite agent). We start by calculating the elite transfer $T_t^e \geq 0$ subject to the government budget constraint as:

$$T_t^e \leq \frac{\omega}{S^e} \tau_t \int F(K_{i,t}, G_{i,t}) di \tag{3.10}$$

where the left-hand side denotes government expenditures in transfers *per* one elite agent and the right-hand side are the revenues raised through taxing the middle-class output. As in Acemoglu (2006), we also include the parameter $\omega \in [0, 1]$ as a measure of state capacity to raise and redistribute revenues, such that it captures how much of the tax revenue can be redistributed, with the remaining $1 - \omega$ being waisted.[18] Then, the elite choose the tax rate for the period t, τ_t, so as to maximize their current value accounting for the transfer amount, investments in public education, exclusive elite revenues and the probability of loosing power in the next period.

We can write the maximization problem of an elite agent when choosing the tax rate τ_t at $t - 1$ recursively as:

[18] Governments subjected to frequent destabilizing episodes of political rivalry may become considerably costly to economic performance, in particular as concerns the provision of public goods. This may happen in the case of either a too weak or a too strong state. The former entails that none of the conflicting political groups is sufficiently strong to secure control over implemented policies, and the latter implies that one excessively strong social group struggles to keep its political (and economic) control through misguiding practices. From this perspective, states with intermediate levels of strength, *i.e.* intermediate values of ω, can be viewed as most capable (and most interested) to reap the benefits of public policies.

$$V^e(E) = \max_{\tau_t} \{T_t^e - E_t + \pi_t^e(H) + \beta [(1-\theta(\tau))V^e(E) + \theta(\tau)V^e(M)]\} \tag{3.11}$$

where $T_t^e = \omega\tau_t \cdot A_t G_t \cdot \left(\frac{\beta^{-1}+\delta-1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}} \frac{S^m}{S^e}$ is the transfer to one elite agent given the output produced by S^m middle-class entrepreneurs , $E_t = \left(\frac{1-\alpha}{\alpha} \cdot \frac{\varsigma}{\gamma}\right) \cdot T_t^e$ is the fraction of state tax revenues, weighed by the factor $\frac{1-\alpha}{\alpha} \cdot \frac{\varsigma}{\gamma}$, destined for financing public education,[19] and $\pi_t^e(H)$ denotes rents from human capital, available to the party in power exclusively. Note that, for a given level of tax-collected revenues, T_t^e, the elite's choice of the investment amount in public education is further adjusted by the ratio between output elasticities with respect to human and physical capital, $\frac{1-\alpha}{\alpha}$, on the one hand, and the relative importance of public education for human capital accumulation, $\frac{\varsigma}{\gamma}$, on the other hand.[20] Finally, the component $\beta [(1-\theta(\tau))V^e(E) + \theta(\tau)V^e(M)]$ relates to the likelihood of political replacement and generates the political rivalry effects in the model. In particular, $\theta(\tau)$ denotes the probability that in period t political power will permanently shift from the elite to the middle-class social group, and $V^e(E)$ and $V^e(M)$ denote the utility of the elite when they and the middle-class are in control of politics, respectively. Note that exclusive access to rents from human capital accumulation and natural resources, $\pi_t^e(H)$, ensures that the utility of the politically powerful social group is higher than the utility of any other social group, implying that $V^e(E) > V^e(M)$ in our model.

The probability of the elite loosing political power in the next period as modeled as

[19]Thus, higher tax revenues (resulting from a higher tax rate) increase public investments in education and, consequently, human capital accumulation, as in Bethecourt and Perera-Tallo (2012). However, as we will show in our comparative statics analysis in Section 3.3, this positive relationship is verified only when taxes are non-distortionary, that is, not affected by the presence of political rivalry. Taxes increasing on account of political rivalry episodes decrease tax revenues and public investments in education, consequently hampering human capital accumulation and deepening inequality.

[20] In our model, any possible variations in these ratios is assumed exogenous.

a function of the magnitude of the middle-class social group and the net income level (*i.e.* revenues from productive activities deducted of labour costs) of a representative middle-class entrepreneur:

$$\theta(\tau) = S^m \cdot C^m(\tau) \in [0, 1] \tag{3.12}$$

which captures the potential political power of the middle class and where $C^m(\tau) = \alpha A_t \cdot G_t \cdot \left(\frac{\beta^{-1}+\delta-1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}}$ with $\frac{\partial\theta(\cdot)}{\partial C^m} > 0$, implying that when the middle-class entrepreneurs are richer they are more likely to gain power.[21] Although it is also true that $\frac{\partial\theta(\cdot)}{\partial S^m} > 0$, as previously stated, S^m is exogenous in our model (as is the number of all social groups members).[22]

Optimal policy choice

The first order condition for an interior solution for the tax rate, τ_t, is $\frac{\partial V^e(\cdot)}{\partial \tau} = 0$. We can solve the elite's maximization problem first, for an equilibrium policy without political economy considerations, and then accounting for the effects of political rivalry on optimal policy choice.

***i)* without political rivalry**, the probability that the elite will lose power is exogenous to the model, *i.e.* $\frac{\partial\theta}{\partial\tau} = 0$ and the elite's maximization problem is given by:

$\frac{\partial V^e(\cdot)}{\partial \tau} = \frac{\partial T^e}{\partial \tau} - \frac{\partial E}{\partial \tau}$

[21] With greater resources the middle class may be more successful in attaining their collective interests (see Acemoglu, (2006))

[22] We follow this assumption because our main goal is not to examine how and why S^m and S^e change, but rather their influence on the political power distribution and the resulting different policies and growth paths.

Solving this for an interior solution, in period $t-1$ the elite will choose for period t an output tax of:

$$\tau^* = 1 - \alpha \tag{3.13}$$

As we will show in our comparative statics analysis, this is the optimal tax policy that at the same time maximizes elite's utility and does not generate political rivalry effects and economic distortions.

ii) **with political rivalry**, the probability that the elite will lose power in the next period is endogenous, *i.e.* $\frac{\partial \theta}{\partial \tau} < 0$, and new political economy effects arise. In this case, the elite's maximization problem becomes $\frac{\partial V^e(\cdot)}{\partial \tau} = \frac{\partial T^e}{\partial \tau} - \frac{\partial E}{\partial \tau} - \beta \frac{\partial \theta}{\partial \tau}\left[V^e(E) - V^e(M)\right]$, with $\frac{\partial \theta}{\partial \tau} = -S^m \cdot \frac{\alpha^2}{1-\alpha} \cdot A_t G_t \cdot \left(\frac{\beta^{-1}+\delta-1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}} \cdot [1-\tau]^{-1}$. This yields an optimal output tax of:

$$\tau^*_{PR} = \Theta + 1 - \alpha \tag{3.14}$$

Comparing the two optimal solutions, (3.13) and (3.14), it can be seen that τ^*_{PR} is strictly higher than τ^* by the factor $\Theta \equiv \frac{\alpha^2 S^e \beta[V^e(E)-V^e(M)]}{\left(1-\frac{\varsigma}{\gamma}\frac{1-\alpha}{\alpha}\right)\omega}$.[23] Yet, setting a higher tax rate does not bring more tax revenues for the elite and has distortionary effects on the resulting economic outcomes. In fact, it can be verified that the elite's current income, T^e, increases with τ only for $\tau < 1-\alpha$, the maximum tax revenue being collected when $\tau = 1-\alpha$. As we will show in our comparative statics analysis, all economic allocations in the presence of political rivalry become inefficient. Nevertheless, in a political economy context the elite will still choose to set higher, distortionary taxes

[23] Note that, because in each period $[V^e(E) - V^e(M)]$ assumes an infinitesimal value, the condition $\tau^*_{PR} < 1$ is satisfied.

as this would weaken its potential political rivals - the middle class,[24] thus increasing the probability of the elite to remain in power for the next period and continue taking profit from all the benefits implied.

3.2.4 Income inequality

This section is devoted to the analysis of income inequality in our model based on two endogenously defined key variables - the income growth rate (derived based on equilibrium wages and human capital accumulation calculated in Section 2.2) and the critical level of income (derived following the approach in Glomm & Ravikumar (2003)).

Income growth rate and critical level of income

Considering the wages of two workers from the same generation, it can be easily seen, from expression (3.6), that differences in the level of incomes can only arise from different levels of accumulated human capital. Although in line with endogenous economic theory and our model's assumptions such an analysis of inequality is not very interesting. On the other hand, the analysis of income inequality between two different generations is much more insightful. In particular, recalling expression (3.6), we can use the human capital accumulation function (3.7) together with the optimal learning choice (3.9) to define individual income at $t+1$, w_{t+1}, and, consequently, the income growth rate of a workers' family, $\frac{w_{t+1}}{w_t}$, as follows:[25]

[24] Recall that, in our model, the potential political power of the middle-class is captured by (3.12), which is decreasing in τ.

[25] Note that the analytical expression obtained for the income growth rate is similar to that in Glomm and Ravikumar (2003), although the economic mechanisms considered for its derivation are distinct.

$$\frac{w_{t+1}}{w_t} = \frac{\left[(1-\alpha)\cdot E_t^{\zeta}\cdot A_{t+1}\cdot\left(\frac{\beta^{-1}+\delta-1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}}\right]^{\frac{1}{\sigma}}}{w_t^{1-\frac{\gamma}{\sigma}}+\left[(1-\alpha)\cdot E_t^{\zeta}\cdot A_{t+1}\cdot\left(\frac{\beta^{-1}+\delta-1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}}\right]^{\frac{1-\sigma}{\sigma}}\cdot w_t^{1-\gamma}} \tag{3.15}$$

Inspection of expression (3.15) shows that the relation between preferences and parental income parameters, σ and γ, is crucial for defining the behaviour of $\frac{w_{t+1}}{w_t}$ over time. In this respect, as in Glomm & Ravikumar (2003), we need to consider two distinct situations: *i)* $\gamma < \sigma$, and *ii)* $\sigma < \gamma$.

In the first case, when $\gamma < \sigma$, we have that expression (3.15) is decreasing in w_t. Then, comparing the income growth rate for a poor and a rich working family, we can see that income will grow at superior rates for workers with lower incomes than for those with higher incomes. Consequently, over time, incomes will converge and income inequality will decline. The intuition behind this result is simple. The parameter γ can be interpreted as the sensitivity of a worker's human capital investments to his or her parents' income. Thus, with a small γ, parental income does not have a strong influence on their children accumulation of human capital. This means that, for a worker, parental heritage is less important than his or her own individual preferences regarding education, and there is a high potential for social mobility even for workers coming from a less favourable background.

In the second case, when $\sigma < \gamma$, parental income has a greater role and affects more strongly the next generation's human capital accumulation than when $\gamma < \sigma$. Because parents with higher income can devote more resources to their children education and their contribution weighs more, human capital accumulation for families with lower parental incomes is more limited. Such conditions on initial income distribution are more propense to deepening income inequality over time. More specifically and contrary to the first case, the behaviour of $\frac{w_{t+1}}{w_t}$ over time is not monotonic: when $\sigma < \gamma$, we can see from expression (3.15) that w_t has a dual (positive and negative) effect on the income growth rate. The critical level of income, w^{CT}, can then be used to represent an inflection point, below which $\frac{w_{t+1}}{w_t}$ is increasing in w_t and above which $\frac{w_{t+1}}{w_t}$ is decreasing in w_t:

$$w^{CT} = \left(\frac{\gamma - \sigma}{\sigma(1-\gamma)}\right)^{\frac{\sigma}{\gamma(1-\sigma)}} \cdot \left[(1-\alpha) \cdot E_t^{\zeta} \cdot A_{t+1} \cdot \left(\frac{\beta^{-1} + \delta - 1}{\alpha(1-\tau)}\right)^{\frac{\alpha}{\alpha-1}}\right]^{-\frac{1}{\gamma}} \tag{3.16}$$

Comparing the income growth rate for a poor and a rich working family, their actual income relative to the critical income level in the economy will now define the behaviour of $\frac{w_{t+1}}{w_t}$ over time. In particular, when both poor and rich working families' incomes are below the level of w^{CT}, income will grow at inferior rates for workers with lower incomes than for those with higher incomes. Consequently, incomes will continue diverging and income inequality will increase. However, this pattern is inverted when both working families' incomes exceed w^{CT}. Once the critical income level is overcome, the behaviour of the income growth rate induces income convergence (as in the case when $\gamma < \sigma$), the gap between higher and lower incomes narrows and income inequality starts to decrease.

In the context of our research, critical income effects are considered accounting for the endogenous fiscal and public investments in education policies, in a political rivalry environment. Moreover, the lower (higher) is the critical income level, the easier (more difficult) it is to attain income convergence, and, in this sense, w^{CT} can be treated as an income inequality indicator. Naturally, from a public policy perspective, the time necessary to achieve and overcome a given critical income level by both poor and rich families is rather important for inequality concerns. For example, when w^{CT} in the economy is high relative to actual wages paid to (poorer) workers and economic conditions are unfavourable and do not improve, inequality may persist indefinitely. We develop a more detailed analysis of these issues below.

In sum, when $\sigma < \gamma$, the income growth rate $\frac{w_{t+1}}{w_t}$ is a strictly decreasing function of w_t only if $w_t > w^{CT}$. Consequently, it is easier to achieve income convergence over time for lower values of w^{CT} or for more rapidly increasing values of w_t. This dynamic analysis is similar to that in Glomm and Ravikumar (2003). However, our model's extended analytical framework enables a richer analysis and a detailed consideration of political implications, as regards income inequality and public policy.

The role of public policy

Because in this chapter we adopt a political economy perspective to study income inequality, the above discussed elements have important institutional implications to be considered. In particular, in order to illustrate the importance of public policy in the framework of our model, we can compare two countries with different characteristics as regards individual preferences for learning and the importance of parental heritage. More specifically, we consider country A with $\gamma < \sigma$ and country B with $\sigma < \gamma$.

As referred above, the relation $\gamma < \sigma$ implies that individual preferences on learning have a dominating role relative to parental income in a worker's human capital accumulation. In this light, in country A where parental heritage is less important (either for cultural, economic or other reasons), the role of public policies implemented by the political elite is crucial, since individual learning choice is directly affected by the adopted fiscal and public education investment policies.[26] In particular, as regards income inequality and economic growth concerns, these policies can either promote or discourage human capital accumulation and inequality can be either deepened or reduced. For example, as we will further show, the presence of political rivalry can discourage both the individual learning choice and public investments in human capital accumulation. The effect of fiscal and public education investment policies on inequality and growth

[26] See the comparative statics analysis in Section 3.

will be positive only as long as taxation is non-distortionary, that is, there is no political rivalry.

Now consider country B with $\sigma < \gamma$. In this case, human capital accumulation for families with lower parental income is more limited, and, we have seen above, there exists a critical income level, which further conditions the path of inequality evolution over time. Consequently, even more than in the previous case, for country B, fiscal and public education investments policies pursued by the political elite are primarily important. Securing efficient policies that would either lower the critical income level or improve economic environment so as to facilitate social mobility and accelerate achieving and overcoming w^{CT}, thus reducing inequality and promoting growth, becomes fundamental. And, as we will show in our comparative statics analysis, investing in public education can achieve both a lower w^{CT} and a better economic environment. Indeed, when fiscal policy is directed towards human capital accumulation and is non-distortionary, inequality decreases and economic growth increases.

These implications for public policy resulting from the relation between income inequality and parameters γ and σ could also provide an interesting perspective and motivation for an empirical cross-country study.

3.3 Comparative statics analysis: effects of public investments and political rivalry

In our comparative statics analysis we will focus on the effects of the two endogenously derived policies, pursued by the elite, on the key variables of our model: the analysis in Section 3.1 is dedicated to the effects of public investments in human capital accumulation, while Section 3.2 focuses on the discussion of fiscal policy effects under conditions of political rivalry. The full expressions of all the derivatives presented in Sections 3.1 and 3.2 can be found in the Appendix.

3.3.1 Effects of public investments in human capital accumulation

One of our main objectives in this chapter is to show that public investments in human capital accumulation are beneficial for economic growth and development and for reducing inequality. In fact, recalling expressions (3.5), (3.6), (3.7), (3.9) and (3.16), it can be verified that $\frac{\partial F(K^*,G)}{\partial E}$, $\frac{\partial w_{t+1}}{\partial E}$, $\frac{\partial H_{t+1}}{\partial E}$, $\frac{\partial(1-l)}{\partial E}$ are all positive and $\frac{\partial w^{CT}}{\partial E}$ is negative.

The intuition behind these results is the following. As it should be expected, higher investments in public education, E, stimulate the individual learning choice, $(1-l_t)$, since the availability of a better public education system in its complex nature (as specified in Section 2.2) is more appealing to the young population. That is, increasing investments in public education not only improves the instrument for human capital accumulation - public education, but also increases personal motivation to use it. Consequently, the stock of accumulated human capital, H, grows both directly with higher E and with increased individual learning incentives. The endogenous growth theory classic effects of an increased human capital stock are further verified, *i.e.* higher worker productivity, wages and final output. Moreover, the inverse relation between E and w^{CT} emphasized above implies that inequality is more easily overcome with public education investments, which serve as a social mobility promoter. This is particularly important in what regards vertical and inter-generational social mobility.

3.3.2 Effects of political rivalry

In this section, we will focus on political rivalry between the elite and other potentially politically powerful groups as a key factor distorting the implemented fiscal policy. More specifically, we will show that there is a strong negative impact of political rivalry on economic allocations and actions when goals pursued by the elite, instead of economic efficiency considerations, determine the policy choice. We divide the political rivalry effects into three groups: 1) equilibrium output, wages and elite transfer; 2) public investment in education, equilibrium schooling choice and human capital accumulation; and 3) critical income level and income inequality.

3.3.2.1 Equilibrium output, wages, and elite transfer

As it should be expected, equilibrium output, (3.5), and wages, (3.6), decrease when taxes increase and our model in fact yields $\frac{\partial F(K^*,G)}{\partial \tau} < 0$ and $\frac{\partial w_t}{\partial \tau} < 0$. Since, as we have shown above, the tax rate corresponding to a political rivalry case is necessarily higher than the optimal, non-distortionary tax rate, and it is known in advance, it is straightforward that political rivalry has a direct negative impact on equilibrium output and wages. That is, anticipating a politically motivated excessive tax rate discourages the economic incentives of the middle class. Similarly, it also directly negatively affects the current income of the elite since for $\tau > 1 - \alpha$ we get $\frac{\partial T_t^e}{\partial \tau} < 0$. Nevertheless, recalling (3.12) and that $V^e(E) > V^e(M)$, the elite is willing to accept the trade-off between a decrease in their current tax income and an increase of the probability to remain in power, thus maintaining control over policy and preserving exclusive access to rents from human capital accumulation.

3.3.2.2 Public investment in education, equilibrium learning choice and human capital accumulation

In Section 3.1 we have seen that an increase in the tax rate, *ceteris paribus*, increases the investments in public education, which increases the optimal learning choice. However, this positive result is verified only for $\tau < 1 - \alpha$ and is maximized at $\tau = 1 - \alpha$. Once political rivalry is introduced, it can be verified that investments in public education are negatively affected by further increases in the tax rate, *i.e.* $\frac{\partial E_t^e}{\partial \tau} < 0$ for $\tau > 1 - \alpha$. This happens because, under conditions of political rivalry, investments in public education are distorted, given that the amount corresponding to $\frac{1-\alpha}{\alpha} \cdot \frac{\varsigma}{\gamma}$ of collected tax revenues, T_t^e, is now lower, since $\frac{\partial T_t^e}{\partial \tau} < 0$ for $\tau > 1 - \alpha$. This relation between τ and E is of a particular importance given that, as mentioned in Section 3.1, public investments in education influence all variables in our model. Thus, when political pressure for redistribution and not economic considerations determine the policy choice, induced negative variations in public education investments are reflected in distorted values of the main economic variables.

Furthermore, an increase in the tax rate has a dual effect on the learning choice: a negative impact, both directly and *via* a decrease in the workers' wage ($\frac{\partial w_t}{\partial \tau} < 0$), and a positive impact *via* an increase in public investments in education ($\frac{\partial E_t}{\partial \tau} > 0$ for $\tau < 1 - \alpha$). It can be verified that below a certain level of τ (inferior to $1 - \alpha$), the positive effect of increased public investments in education predominates and the individual learning choice is encouraged. However, increasing the tax rate beyond a certain level cancels out the positive public education investments effect and negatively affects individual learning choice, reducing potential human capital accumulation and future income and deepening income inequality. This is verified by the negative partial derivative of the optimal learning choice with respect to τ, namely $\frac{\partial(1-l_t)}{\partial \tau} < 0$ for $\tau > \frac{\varsigma(1-\alpha)}{\varsigma(1-\alpha)+\alpha(\gamma+2)}$ and, thus, for $\tau > 1 - \alpha$.

This result presents two important conclusions. On the one hand, it indicates that even for values of τ inferior to the political rivalry level, increases beyond a certain point will discourage the optimal learning choice for young individuals and will condition potential human capital accumulation. Consequently, occurring episodes of political rivalry will severely aggravate these negative impacts. On the other hand, it shows that the parameters ς and γ play an important role in determining the changes in the individual learning choice induced by changes in fiscal policy. More specifically, the closer the parameter ς is to 1, the closer the values of τ, from which $\frac{\partial(1-l_t)}{\partial \tau} < 0$ verifies, are to the optimal tax rate level, $\tau = 1 - \alpha$ and, consequently, the more it is possible to minimize $\frac{\partial(1-l_t)}{\partial \tau} < 0$. Thus, even the negative impacts of increasing the tax rate above a certain level can in fact be attenuated by a higher importance of public education for human capital accumulation.[27] In its turn, the weight of parental income in human capital accumulation, γ, has an opposite effect. Namely, the closer the parameter γ is to 1, the further the values of τ, from which $\frac{\partial(1-l_t)}{\partial\tau} < 0$ verifies, are from the optimal tax rate level, and, consequently, the effect of $\frac{\partial(1-l_t)}{\partial\tau} < 0$ is amplified. Therefore, when excessive importance is attributed to parental income in what regards human capital accumulation, negative impacts on individual learning choice (and future human capital accumulation) can be caused even by small increases of the tax rate above a certain level.

The effect of an increase in the output tax rate on human capital accumulation, $\frac{\partial H_{t+1}}{\partial\tau}$, is inferred by observing the effects on its constituting elements, E_t, w_t and $1-l_t$. As it was shown above, $\frac{\partial E_t}{\partial\tau} < 0$ for $\tau > 1-\alpha$, $\frac{\partial w_t}{\partial\tau} < 0$, and $\frac{\partial(1-l_t)}{\partial\tau} < 0$ for $\tau > \frac{\varsigma(1-\alpha)}{\varsigma(1-\alpha)+\alpha(\gamma+2)}$. Consequently, for certain values of τ (even below the political rivalry level), the effect of an increase in the output tax rate on human capital accumulation is negative, $\frac{\partial H_{t+1}}{\partial\tau} < 0$, and will be aggravated by the presence of political rivalry.

3.3.2.3 Critical income level and income inequality

Excessive taxation generated by political rivalry also increases the critical income level, thus making it more difficult to achieve income convergence and prolonging income inequality over time:

$\frac{\partial w^{CT}}{\partial\tau} > 0$ for $\tau > \frac{\varsigma(1-\alpha)}{\alpha+\varsigma}$ and implicitly for $\tau > 1-\alpha$.

The analysis of this result is similar to the analysis regarding the political rivalry impact on individual learning choice. In particular, the result obtained here indicates

[27] Naturally, even when the role of public education is primarily important in human capital accumulation, the option of private investments, captured by parental income, should not be discarded. Families with higher incomes can always profit from their favourable conditions.

that even increases of τ below the political rivalry level but beyond a certain point will raise critical income and deepen inequality. These negative impacts will be severely aggravated by the presence of political rivalry. Similarly, the result of $\frac{\partial w^{CT}}{\partial \tau} > 0$ for $\tau > \frac{\varsigma(1-\alpha)}{\alpha+\varsigma}$ shows that the perceived importance of public education determines the magnitude of changes in the critical income level induced by different fiscal policies. In particular, the closer the parameter ς is to 1, the closer the values of τ, from which $\frac{\partial w^{CT}}{\partial \tau} > 0$ verifies, are to the optimal tax rate level, $\tau = 1 - \alpha$, which allows minimizing $\frac{\partial w^{CT}}{\partial \tau} > 0$. This means that even the negative impacts of increasing the tax rate above a certain level can in fact be attenuated by a higher importance attributed to public education in human capital accumulation.

3.4 Concluding remarks

In this chapter, based on the theoretical insights provided in Chapter 2, we developed an endogenous growth model with elements of new political economy. In this framework, our research was directed towards first, studying the effects of political rivalry on the evolution of human capital accumulation and income inequality and, second, examining how different political incentives may affect the resulting policies and economic allocations.

Regarding our first research objective, we have found that occurring episodes of political rivalry reduce human capital accumulation through their negative impact on public investments in education, workers' wages and individual learning choice, and increase income inequality, by decreasing wages, raising the critical income level and affecting the income growth rate.

As regards our second research objective, we have found that different political incentives have distinct effects on the resulting policies and economic allocations. When the incentives of the elite refer to elementary revenue extraction, it is in their interest to have a highly productive middle-class and increasing human capital accumulation, as this enables collecting higher output-tax and additional elite exclusive revenues. This determines the elite to choose non-distortionary fiscal policies with an optimal tax rate that does not generate political economy effects, *i.e.* inequality is not deepened and both human capital accumulation and economic growth are not distorted. Consequently, the resulting public education investments policy is non-distortionary, generating positive effects by motivating individual learning choice, increasing human capital accumulation, wages and final output, and also fighting inequality. In fact, public education investments can be used as a social mobility promoter (most importantly as regards vertical and inter-generational social mobility), enabling income convergence and overcoming inequality.

However, when there is a decoupling between economic and political power, goals pursued by the elite, instead of economic efficiency considerations, will determine the policy choice. In this case, the elite's incentive to remain in power for the next period generates political rivalry. This political rivalry induces excessive taxation, which leads to an inefficient redistribution policy and reduces public education investments, both resulting in distortionary economic allocations and actions. Consequently, human capital accumulation and the associated positive growth effects are distorted, and inequality is deepened.

Also, we have shown that the public education investments and parental income parameters play an essential role in determining the next generation's human capital accumulation, thus having relevant public policy implications especially under conditions of political rivalry. In particular, we have found that when excessive importance is attributed to parental income, negative impacts on individual learning choice and future human capital accumulation can be caused even by small increases of the tax rate above a certain level. A greater role of parental income also implies that human capital accumulation for families with lower parental income is more limited and a more uneven income distribution is more propense to deepening income inequality over time. On the contrary, when parental income is less important than a worker's individual preferences regarding education, the availability of a publicly provided education offers a high potential for social mobility even for workers coming from a less favorable background. These results and conclusions provide an interesting perspective and motivation for empirical testing.

Moreover, we can also identify some venues for future research. For example, the skill biased technological change theory can provide a new approach to analysing the political rivalry effects on inequality and human capital accumulation through the composition of the labour force. In particular, depending on political distortions, economic growth can be biased towards a more or less skilled labour. We can also consider including population growth in the model, assuming that the increase in income, resulting from persistent human capital accumulation, could be devoted to raising more children. Another research possibility is to consider the growth rate of aggregate labour-augmenting productivity, as an endogenous variable interacting with human capital accumulation. Also, since parameters defining the importance of public investments in human capital, parental income and individual learning preferences are crucial for some of the results obtained in this chapter, another future challenge could be to endogenize them, taking into account their determining factors and how they can be influenced by public policy.

Chapter 4

Effects of political rivalry on public educational investments and income inequality - an empirical study

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4.1 Overview

Uncovering the mechanisms of how political institutions may affect and determine economic performance is one of the most challenging research questions in modern economics. Related research on political institutions emphasizes their central role in defining economic policies and the resulting outcomes. Studies focusing on political and economic interactions argue that policies cannot be viewed as exogenous and, as important determinants of economic incentives, should be regarded crucial in explaining differences in economic performance across countries (*e.g.* Persson and Tabellini, 1992; Acemoglu and Robinson, 2000; Sayer, 2000; Acemoglu, 2006).

In this chapter we intend to empirically examine how different political institutions may define the long-term economic development, determined by educational investments and income inequality. With this objective, we will assess the impact of political rivalry on several fundamental macroeconomic indicators, selected based on the main conclusions of the theoretical endogenous growth model with new political economy elements, developed in the previous chapter. Following Acemoglu (2006, 2009), we will specifically regard political rivalry as the inter-party political competition for power of both economic and political nature, aimed at keeping the political elite in the office and in control for as long as possible (as in, *e.g.*, Dixit and Londregan, 1995; Dixit *et al.*, 2000; Acemoglu and Robinson, 2001; Scruggs, 2001; Acemoglu, 2006).[1]

Our present work relates to the increasing literature on the new political economy of growth, combining economic analysis with new political economy elements and referring to political rivalry as a key factor affecting economic performance (see, for example, Dixit et al., 2000; Scruggs, 2001; Acemoglu, 2006). The effects of political rivalry are generally associated with breaking the balance between political power and economic opportunities, thus negatively affecting the relation between political institutions and

[1] See Chapter 2.

economic outcomes. For example, Rodrik (1999) argues that disagreements between political groups may inflict the extra cost on the economy. Similarly, Acemoglu and Robinson (2001) and Dixit and Londregan (1995) suggest that contesting political power may induce economic costs due to its growth-retarding effects. Inconsistencies between economic and political powers will cause the goals pursued by the elite and the political rivalry thus generated, instead of economic efficiency considerations, to determine social and economic policy choice. Success or failure of implemented economic policies then depends on how prevailing institutions manage political rivalry.

Given that the key variables of the model in Chapter 3, which we intend to empirically analyse in this study, reflect specific macroeconomic policies and indicators, political rivalry can be expected to influence them. In particular, the model developed in the previous chapter suggested that non-distortionary redistribution *via* public education equalizes income levels and increases human capital accumulation in the economy, which has a growth promoting effect. On the other hand, it also illustrated that the efficiency of such redistribution policy is distorted by political rivalry, with resulting negative effects on economic outcomes. Motivated by these theoretical results, in this chapter we will empirically examine the impact of political rivalry on four selected economic variables: public investments in education, individual learning choice, GDP *per capita* and income inequality.

In choosing these specific variables for our empirical analysis we also relate to some studies on the relationship between human capital accumulation, inequality and economic growth. For example, as emphasized by Perotti (1996) and Saint Paul and Verdier (1996), higher inequality is indeed associated with a lower level of human capital accumulation, and lower human capital accumulation is associated with lower levels of economic growth. More recently, the cross-country analysis of Easterly (2007) reaffirmed that human capital accumulation and economic development are adversely affected by inequality, which is a barrier to schooling and economic growth. A study by Galor and Moav (2004) indicated a change in the qualitative impact of inequality on the process of development, resulting from the replacement of physical capital accumulation by human capital accumulation as the prime engine of economic growth. Their results suggested that, in later stages of development, a more equal distribution of income stimulates investment in human capital and promotes economic growth. An inverse relationship between these variables is modeled in Chatterjee and Turnovsky (2010), who consider public investments in education both as the growth engine and an important determinant of inequality.

To our knowledge, there are no previous empirical data on political rivalry as defined in our research. Therefore, we first construct a composite political rivalry indicator, comprising the elements of institutional quality and exclusive pecuniary benefits, which we consider crucial for determining the degree of rivalry between the political elite and other social groups. For this purpose, we use data from the Worldbank Governance Indicators on government effectiveness, regulatory quality and control of political power for private gains, together with data on rents from natural resources. In this way, we compute the political rivalry level for each country and examine how it varies across different groups of countries. The construction and preliminary analysis of this composite political rivalry indicator is one of the key outcomes of our empirical study. This analysis revealed a high level of political rivalry heterogeneity by income and geographical location, indicating that higher-income countries have much lower levels of political rivalry, mainly due to their high institutional quality. On the contrary, exclusive resources rents appear to be responsible for increasing the level of political rivalry in countries more abundant in natural resources.

Using cross-sectional data for a large set of countries, we then perform a series of regressions in order to assess the impact of political rivalry on the above referred economic variables. Our empirical findings indicate that in lower income countries there is indeed a significant negative political rivalry impact, which increases with the decrease in the development level. Such results, however, are not confirmed for higher-income countries, which may suggest that the relationship between political rivalry and the selected economic variables may, in fact, be weaker in these countries, or that the relevant mechanisms may differ with the level of development.

The structure of this chapter is the following. In Section 2 we construct and analyse the composite political rivalry indicator. Section 3 describes our data sets and the models' specifications. In Section 4 we present and discuss the main empirical findings, as well as the robustness analysis results. Concluding remarks are presented in Section 5. Detailed information on our sample countries and included variables is provided in the Appendix.

4.2 Political rivalry indicator

4.2.1 Definition and construction of the political rivalry indicator

As previously mentioned, relevant theoretical research generally associates political rivalry with disagreements between political groups, generating political constraints and conditioning the choice and implementation of policies (Acemoglu and Robinson, 2001; Acemoglu and Johnson, 2005). When goals pursued by the political elite, instead of economic efficiency considerations, determine the policy choice, a strong negative impact of political rivalry is implied. The resulting relation between political institutions and economic outcomes is then characterised by lower efficiency and higher economic costs (Alesina and Rodrik, 1992; Alesina and Perotti, 1994; Dixit and Londregan, 1995, Acemoglu and Robinson, 2001; Acemoglu, 2006). As such, political rivalry becomes a key distorting factor in the economy. Moreover, related theoretical research refers that political rivalry is aggravated when there are extra interests to consider, such as exclusive revenues accessible only to the political group in power - the elite, guaranteeing that the elite's utility is higher than the utility of any other social group (Acemoglu, 2009). To our knowledge, data on political rivalry (as defined in this work, see Chapter 2) do not exist. Therefore, the above-referred theoretical considerations represent the starting point for defining and constructing a measure of political rivalry for this empirical study.

In particular, the *composite political rivalry indicator*, PR, includes two elements: institutional quality, IQ, which basically defines the level of political rivalry in a country; and exclusive pecuniary benefits, EPB, which can additionally aggravate this level. The institutional quality element reflects the balance between political power and economic opportunities; exclusive pecuniary benefits are the exclusive elite revenues from natural resources. Based on these criteria, we select the existing empirical data as follows.

First, in order to obtain a measure of institutional quality we make use of the Worldbank Governance Indicators, which are aggregate indicators of six broad dimensions of governance, as presented in Table 1 below:

Table 4.1: Worldbank Governance Indicators

Indicator	**Description**
1. *Voice and Accountability*	Reflects perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.
2. *Political Stability and Absence of Violence*	Reflects perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism.
3. *Government Effectiveness*	Reflects perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.

4. *Regulatory Quality*	Reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.
5. *Rule of Law*	Reflects 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.
6. *Control of Corruption*	Reflects perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.

Source: www.govindicators.org , accessed in November, 2012.

These indicators are constructed in the framework of the Worldwide Governance Indicators (WGI) project and are compiled in a data set summarizing the views of a large number of worldwide enterprises, citizens and expert assessments on the quality of governance. Gathered from over 30 underlying data sources, the six aggregate indicators are based on a number of survey institutes, think tanks, non-governmental organizations, international organizations, and private sector firms.[2] The Worldwide Governance Indicators published in 2012 are available for 211 countries for the years 1996-2011, all estimates' values ranging from approximately -2.5 (weak) to $+2.5$ (strong) governance performance.[3]

For the construction of the first component of our composite political rivalry indicator, IQ, we restrict our attention to indicators 3, 4 and 6 from Table 1, that is, *Governance Effectiveness*, *Regulatory Quality* and *Control of Corruption*. Based on the Worldbank's specification, we consider that these three indicators capture the key ideas of political rivalry in line with the theoretical definition adopted in our empir-

[2]Details on the underlying data sources, the aggregation method, and the interpretation of the indicators can be found in the WGI methodology paper: Kaufmann *et al.* (2010), "The Worldwide Governance Indicators: A Summary of Methodology, Data and Analytical Issues". *World Bank Policy Research Working Paper No. 5430* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1682130

[3]The Worldwide Governance Indicators update incorporates revisions to data for previous years, and so the data release in the year 2012 supersedes data from all previous releases. Full interactive access to the aggregate indicators and the underlying source data is available at www.govindicators.org.

ical study. More specifically, given that our empirical study considers public policies on educational investments and human capital accumulation to be crucial for economic development through their relation to income inequality, it is very important to account for the ability to formulate, implement and commit to sound public policies. This is captured by indicators 3 and 4. On its turn, indicator 6 captures institutional quality in what regards the degree of government independence from political pressures, exercise of public power for private gain and control of the state by elites and private interests. The IQ component of our composite political rivalry indicator is then computed as a simple average of the three selected Worldbank governance indicators. It is important to note that, given the Worldbank's specification, the IQ component of our composite political rivalry indicator is inversely related to our definition of political rivalry, in the sense that values closer to $+2.5$ (*i.e.* stronger governance efficiency) imply lower political rivalry, while values closer to -2.5 (*i.e.* weaker governance efficiency) imply higher political rivalry. As noted above, IQ is the principal element defining the degree of political rivalry.

Second, in order to proxy the effect of exclusive pecuniary benefits, EPB, on political rivalry, we focus on natural resources rents, represented by the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest received by the public as the owner of natural resources, or the government on behalf of the public, given as a percentage of GDP.[4] From this perspective, the higher are the exclusive natural resources rents received by the political group in power, the more valuable it becomes continuing to control political power. Consequently, political rivalry will increase. EPB are therefore included in the composite political rivalry indicator with a negative sign, that is, decreasing overall governance performance and, correspondingly, increasing political rivalry. Given that the units of measure of natural resources rents are different from the units of measure of IQ, we normalize EPB to the interval $[-2.5, 0]$,

[4]Empirical data on the components of natural resources rents where collected from the World Bank online database.

with -2.5 corresponding to 100%.

In sum, the composite political rivalry indicator, PR, is obtained by simply adding the two above specified elements, IQ and EPB. Note that, although no specific weights were attributed to either IQ or EPB, the former is naturally dominant, given that the latter actually never take values very distant from zero.[5] In this way, political rivalry in a country is primarily determined by the state of its institutional quality, and may be additionally intensified by the exclusive pecuniary benefits generated from its resources.[6] We also note that, due to lack of data on natural resources and R&D rents for some countries, our final PR data set includes a total of 202 countries.

4.2.2 Preliminary analysis of the political rivalry indicator

Before proceeding to the main regressions of our study, it is important to analyse the values we obtain for the composite political rivalry indicator in the PR data sample (*i.e.* for 202 countries).

To start with, and considering the complete PR data set, the mean value of the composite political rivalry indicator is -0.2155. This, however, gives a rather incomplete characterization of the data because of specific characteristics of our data set. In fact, by simply considering the PR sample range, which goes from -2.65 (for Eritreia) to $+2.13$ (for Denmark), we can infer that there is a high degree of heterogeneity in the data. This is further confirmed by the high values of variance, standard deviation and coefficient of variation, given by $\sigma^2 = 1.1078$, $\sigma = 1.0525$ and $C.V. = -488.31$ respectively. These statistical measures illustrate that the dispersion around the mean

[5]Since natural resources rents are initially given as a percentage of GDP, their values are far from 100% and consequently, EPB generally takes values closer to zero. For example, in countries where natural resources are a main source of revenue, these values are around 40%-50% on average, corresponding to $EPB \approx -1$. In the remaining countries, these values are much lower, with EPB close to zero.

[6] Given that EPB is always negative, PR may drop below -2.5 in countries where IQ is very low.

is very high, as the standard deviation is almost 4.9 times greater than the absolute value of the mean. Based on this result and in order to handle the uncovered data heterogeneity, we want to explore how the political rivalry indicator differs across groups of countries with similar characteristics.

Thus, we divide the countries from our sample into separate groups, using two distinct criteria: *(i)* income *per capita* and *(ii)* geographic location, by region. This choice is motivated by two main factors: income inequality being one of our key research objectives, and the fact that geographical proximity generally reflects cultural, economic, social and political similarities in the institutional organization of countries. Our initial sample is then disaggregated into four income and seven geographic region (geo) sub-samples:

Income groups		**Geo groups**	
$income_1$	high-income	geo_1	Western Europe, USA, Canada and Oceania
$income_2$	upper-middle	geo_2	East Asia and Pacific
$income_3$	lower-middle	geo_3	Europe and Central Asia
$income_4$	low-income	geo_4	Latin America and Caribbean
		geo_5	Middle East and North Africa
		geo_6	South Asia
		geo_7	Africa

For this disaggregation we follow the group categories and composition used by the World Bank, and we associate each country of our complete sample to a specific income or geo group. The complete list of countries by income and geo groups is provided in the Appendix.

Next, for each of the above referred groups, we compute the mean values of PR and test for the significance of differences between them. A straightforward way to perform this analysis is to estimate two simple regressions (one for each analytical category) of PR on several dummy variables, as follows:

1) Income per capita:

$$PR_i = \alpha_1 Inc_{1,i} + \alpha_2 Inc_{2,i} + \alpha_3 Inc_{3,i} + \alpha_4 Inc_{4,i} + u_i \quad (4.1)$$

2) Geographic region:

$$PR_i = \beta_1 Geo_{1,i} + \beta_2 Geo_{2,i} + \beta_3 Geo_{3,i} + \beta_4 Geo_{4,i} + \beta_5 Geo_{5,i} + \beta_6 Geo_{6,i} + \beta_7 Geo_{7,i} + v_i \quad (4.2)$$

where: PR_i is the value of the composite political rivalry indicator in country i;
$Inc_{j,i}$ for $j = 1, 2, 3, 4$, is a dummy variable assuming the value 1 if country i belongs to income group j, and the value 0 otherwise;
$Geo_{k,i}$ for $k = 1, 2, ..., 7$, is a dummy variable assuming the value 1 if country i belongs to geo group k, and the value 0 otherwise;
u_i and v_i are the usual error terms.

Regressions (4.1) and (4.2) are the main regressions for the analysis of the composite political rivalry indicator. The OLS (Ordinary Least Squares) estimation results are presented in column [1] of Tables 2 and 3. Additionally, we also perform two auxiliary regressions for each analytical category, where the dependent variables are the two elements of PR, that is, institutional quality, IQ, and exclusive pecuniary benefits, EPB. These additional regressions will allow us to perform a more in-depth analysis of the composite political rivalry indicator. The results for these auxiliary regressions are presented in columns [2] and [3] of Tables 2 and 3.

Table 4.2: PR regressions by income

Moderator variables	**Coefficient estimates, $\hat{\alpha}$**		
	Dependent variables:		
	(1) PR_i	(2) IQ_i	(3) EPB_i
Inc_1	0.9540^{***}	1.1346^{***}	-0.1806^{***}
	(8.6101)	(15.8345)	(−3.3396)
Inc_2	-0.3617^{***}	-0.0933	-0.2685^{***}
	(−3.1208)	(−1.2440)	(−4.7469)
Inc_3	-0.8352^{***}	-0.5933^{***}	-0.2419^{***}
	(−7.2728)	(−7.9891)	(−4.3169)
Inc_4	-1.1119^{***}	-0.9513^{***}	-0.1606^{**}
	(−8.0150)	(−10.6046)	(−2.3718)

R^2	*0.48*	*0.68*	*0.01*
N	*202*	*202*	*202*

Notes: the level of significance is denoted by ***, ** and *, for 1%, 5% and 10% respectively; $t - statistics$ are reported in brackets.

Table 4.3: PR regressions by geographical location

Moderator variables	**Coefficient estimates, $\hat{\beta}$**		
	Dependent variables:		
	(1)	(2)	(3)
	PR_i	IQ_i	EPB_i
Geo_1	1.2332***	1.3082***(14.0076)	−0.0749
	(9.8590)		(−1.2909)
Geo_2	−0.6211***	−0.4907***	−0.1305
	(−3.5902)	(−3.7986)	(−1.6251)
Geo_3	−0.4446***	−0.1799	−0.2647***
	(−2.9348)	(−1.5903)	(−3.7653)
Geo_4	−0.1930	−0.0736	−0.1195*
	(−1.2526)	(−0.6394)	(−1.6704)
Geo_5	−0.8869***	−0.2514*	−0.6354***
	(−4.6592)	(−1.7693)	(−7.1928)
Geo_6	−0.7434***	−0.6523***	−0.0911
	(−2.6877)	(−3.1590)	(−0.7094)
Geo_7	−0.9912***	−0.7181***	−0.2731***
	(−8.2766)	(−8.0313)	(−4.9136)
R^2	*0.51*	*0.60*	*0.15*
N	*202*	*202*	*202*

Notes: see Table 2

Note that, the coefficient estimates, $\hat{\alpha}$ and $\hat{\beta}$, represent the mean values of PR by income and geo groups respectively. For example, from Table 2, we can see that the mean value of PR in the high-income countries, *i.e.* for group $income_1$, is 0.9540, which is substantially higher than the mean values of PR in all the other groups, where it is negative. This implies that in high-income countries political rivalry is considerably lower than in other countries, which is mainly explained by their comparatively higher institutional quality, again with a positive mean value of 1.1346.

The same result is verified for regression (4.2). Group geo_1, comprising the developed countries, exhibits a higher mean value of PR (*i.e.* a lower average degree of political rivalry) also mainly due to its high institutional quality level. Additionally, in this regression we can identify two other sets of countries: one, comprising groups geo_2, geo_3, geo_5, geo_6 and geo_7, in which the mean value of PR is negative and significantly different from zero, and another, comprising group geo_4, in which the mean value of PR is negative, but not significantly different from zero. In fact, in group geo_4 neither the value of institutional quality nor the value of exclusive pecuniary benefits are statistically different from zero. On its turn, the high significance level of PR in groups geo_3 and geo_5 is due to exclusive pecuniary benefits instead of institutional quality, and the opposite is verified for group geo_6 (as can be seen in the results reported in columns [2] and [3] of Table 3). In fact, groups geo_3 and geo_5 include countries from Eastern Europe, Central Asia, Middle East and North Africa, characterized by high levels of natural resources endowments, contrarily to groups geo_4 and geo_6, which include countries from Latin America and Caribbean, and South Asia.

In order to objectively assess the significance of the differences of political rivalry between various income and geo groups, we perform Wald tests on coefficients' equality of regressions (4.1) and (4.2). The results we obtain generally confirm the ideas advanced in the previous paragraph. Namely, in regression (4.1), only for groups $income_1$ and $income_2$ the mean value of political rivalry indicator is statistically different from the mean value of the other groups. The same is verified for groups geo_1, geo_4 and geo_7 in regression (4.2). Table 4 below summarizes the results of the Wald equality tests on every pair of coefficients α, and Table 5 on every pair of coefficients β.

Table 4.4: Wald tests on coefficients' equality of Regression **(4.1)**

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Coefficients	α_1	α_2	α_3	α_4
α_1	–	***(67.3293)	***(125.7134)	***(135.3953)
α_2	***(67.3293)	-	***(8.4188)	***(17.2193)
α_3	***(125.7134)	***(8.4188)	-	(2.3614)
α_4	***(135.3953)	***(17.2193)	(2.3614)	-

Notes: *** denotes rejection of tested hypothesis $\alpha_i = \alpha_j$, $i \neq j$, for 1% of significance; statistic χ^2 reported in brackets

Table 4.5: Wald tests on coefficients' equality of Regression **(4.2)**

Coefficients	β_1	β_2	β_3	β_4	β_5	β_6	β_7
β_1	–	***(75.4444)	***(72.9378)	***(51.6450)	***(86.6385)	***(42.4013)	***(164.9966
β_2	***(75.4444)	-	(0.5895)	*(3.4154)	(1.0673)	(0.1404)	*(3.0932)
β_3	***(72.9378)	(0.5895)	-	(1.3557)	*(3.3056)	(0.8977)	***(8.0129)
β_4	***(51.6450)	*(3.4154)	(1.3557)	-	***(8.0283)	*(3.0220)	***(16.7310
β_5	***(86.6385)	(1.0673)	*(3.3056)	***(8.0283)	-	(0.1827)	(0.2152)
β_6	***(42.4013)	(0.1404)	(0.8977)	*(3.0220)	(0.1827)	-	(0.6763)
β_7	***(164.9966)	*(3.0932)	***(8.0129)	***(16.7310)	(0.2152)	(0.6763)	-

Notes: *** and * denote rejection of tested hypothesis $\beta_i = \beta_j$, $i \neq j$, for 1% and 10% of significance respectively; statistic χ^2 reported in brackets.

Given this preliminary analysis, we can proceed to the main objective of this chapter, that is, to assessing the PR effect on selected economic variables. To do so, first, in Section 3, we specify the regressions to be estimated and describe the data set used, and then, in Section 4, we present and discuss the obtained estimation results.

4.3 Model specification and data set

In this section, we specify all the regressions to be estimated for each of the economic variables we want to study, and describe the data sets used. As previously mentioned, we intend to test the main theoretical conclusions in Chapter 3, regarding the impact of political rivalry on four selected variables: public investments in education, individual learning choice, GDP *per capita* and inequality.

4.3.1 Model specification

In order to assess the PR effect on selected economic variables, we begin by estimating standard linear regressions of the form:

$$Y_i = \gamma_0 + \sum_{m=1}^{M} \gamma_m X_{m,i} + \delta PR_i + e_i \tag{4.3}$$

where: subscript i denotes again the country included in the sample; Y is the dependent variable; X_m is the m^{th} variable from the M explanatory variables most often referred by the literature as important determinants of Y; PR_i is the composite political rivalry indicator; and e is the usual error term.

We are primarily interested in the estimation of parameter δ, which captures the effects of political rivalry. In order to assess these effects, we will perform four baseline regressions as defined in 4.3, one for each economic variable of interest, included as the dependent variable. According to the specifications defined below, we first examine the effects of political rivalry on public investments in education and individual learning choice, and, then, on GDP *per capita* and inequality.

Public investment in education

In the first regression, denoted by (4.3)-e, the dependent variable is public investments in education, E, which is proxied by the pupil-teacher ratio in secondary education, so as to reflect both quantitative and qualitative characteristics of such investments (similarly to Barro, 1991; Hanushek, 1997; Bernal *et al.*, 2012). Thus, higher and more efficient public investments in education correspond to lower values of E. As explanatory variables, besides PR, we include tax revenues, T, income inequality, $GINI$, human capital accumulation, HCA, population density, POP, and a dummy for democracy, DEM (taking the value 1 if the country is a democracy, and 0 otherwise). We select these particular variables both based on the theoretical model developed in the previous chapter and following Sylwester (2000), who also refers them as important determinants of public investments in education.

Accounting for our measure of E, the direction of the explanatory variables' effects should be read inversely to their coefficients' signs. In particular, we expect negative coefficients for variables T and DEM, since a higher level of income tax revenues increases public investments in education, while in democracies a more equal distribution of political power favours allocating more resources to public goods in general and public education in particular.

On the contrary, the effects of the variables $GINI$ and POP on public investments in education are expected to be negative (that is, their coefficients are positive). For $GINI$ it is explained by the fact that, in highly unequal societies, there is a more pressing need to deviate public expenditures for urgent social policies directed to alleviating inequality. On its turn, a naturally increased pupil-teacher ratio when there is high population concentration, as well as the fixed costs savings resulting from agglomeration effects, may explain the positive coefficient sign for POP.

As for HCA, given our framework of endogenous economic growth, its effect on E can be ambiguous. On the one hand, for obvious reasons, lower human capital endowment motivates higher investments in education. On the other hand, a higher level of human capital can also motivate continuous investments in order to ensure that human capital keeps high in the future.

Regarding the impact of PR, based on the conclusions suggested in Chapter 3, we expect that higher political rivalry reduces public investments in education, due to its overall distortionary effects. Recalling that a higher value of PR stands for a lower degree of political rivalry, the implied sign will be negative.

In sum, regression (4.3)-e is expected to yield the following relations:

$$E_i = f\left(T_i(-),\, GINI_i(+),\, HCA_i(?),\, DEM_i(-),\, POP_i(+),\, PR_i(-)\right)$$

Individual learning choice

Individual learning choice, $LEARN$, is the dependent variable in the second regression, denoted by (4.3)-*learn*. The variable $LEARN$ reflects the individual choice between education and working and is naturally proxied by the school enrollment rate in secondary education. As before, explanatory variables are selected based on the endogenously derived expression for the individual learning choice in the previous chapter, as well as following some empirical findings on the subject (for example, Nachmias, 1975; Munk, 2011). In particular, in addition to PR, we include public investments in education, E, human capital accumulation, HCA, the *log* of GDP *per capita*, $log(GDP)$,[7] schooling grades, $GRAD$, and again a dummy for democracy, DEM.

Regarding the effect of these variables on individual learning choice, we expect the following: lower educational investments and efficiency (that is, a higher E) provide less motivations for studying; more value is usually attributed to education in countries with higher human capital, GDP *per capita* and more democratic regimes; finally, individuals with less success in school are generally more prone to give up education prematurely.

As regards PR, lower political rivalry creates better economic and social conditions, improves the efficiency of the educational system and promotes aggregate human capital accumulation, thus encouraging individual learning choice. In sum, from regression (4.3)-*learn*, we expect the following coefficients' signs:

$$LEARN_i = f\left(E_i(-),\, HCA_i(+),\, log(GDP)_i(+),\, DEM_i(+),\, GRAD_i(+),\, PR_i(+)\right)$$

GDP *per capita*

We evaluate the impact of political rivalry on the level of GDP *per capita* in regression (4.3)-*gdp*. As in the previous regression, using the *log* of GDP *per capita* allows

[7] We opt for using the *log* of GDP *per capita* because it allows for a more adequate interpretation of its coefficient, as it is more appropriate to consider the relative (rather than unit) variation in GDP *per capita*.

for a more adequate interpretation of the coefficients.[8] As explanatory variables, apart from PR, we select some of the regressors specified in the seminal paper of Barro (1991), testing the determinants of economic growth in a cross-section of countries, chosen following the specific context of the theoretical model in Chapter 3. These are: public investments in education, E, human capital accumulation, HCA, high-technology exports *per capita*, H_TECH,[9] and the usual dummy for democracy, DEM.

For well-recognized reasons, all the above variables, except PR, are expected to have a positive effect on the level of GDP *per capita*. On its turn, the predicted effect of political rivalry on GDP *per capita* is negative, due to its discouraging impact on aggregate production (as suggested in the previous chapter). Regression (4.3)-*gdp* is then expected to yield the following coefficients' signs:

$$log(GDP)_i = f\,(E_i(-),\, HCA_i(+),\, H\_TECH_i(+),\, DEM_i(+),\, PR_i(+))$$

Inequality

In this final regression, (4.3)-*gini*, we assess the impact of political rivalry on income inequality, measured by the Gini Index. Here, along with PR, we consider five explanatory variables (following the empirical study by Odedokun and Round (2004) on the determinants of income inequality): social benefits, S_BEN, public investments in education, E, the *log* of GDP *per capita*, $log(GDP)$, openness to foreign trade, $TRADE$, and sectoral labour allocation, $SECTOR$.

While the evidence regarding the effects of GDP *per capita* and openness to foreign trade on income inequality is ambiguous (see, for example, Kuznets, 1955; Bourguignon and Morrisson, 1998; and Barro, 2000), the same does not apply to the other explanatory variables. Social benefits, including government subsidies and transfers, are an

[8] That is, taking into account the nature of the explained variable we analyse the relative (rather than unit) variation in GDP *per capita*, resulting from unit variations in the explanatory variables.

[9] Given that high-technology exports *per capita* require substantial amounts of investment in physical capital, this variable proxies the real domestic capital investments considered in Barro (1991) and reflected in Sochirca *et al.* (2012) in physical capital used in production, additionally capturing the efficiency and the aggregate production impact of such investments.

instrument largely applied in the common practice of many countries for reducing inequality. Similarly, public investments in education and human capital accumulation serve as social mobility promoters, enabling income convergence and overcoming inequality. Contrarily, sectoral labour allocation, here measured by the share of agricultural sector in the total labour force, is often associated with increasing income inequality, as it accentuates economic dualism in income distribution (see, for example, Bourguignon and Morrisson, 1998; and Odedokun and Round, 2004).

Political rivalry is expected to increase income inequality due to its negative effects on all economic mechanisms that ensure equity and promote social mobility (see Chapter 3). Consequently, in regression (4.3)-*gini*, we expect to obtain:

$$GINI_i = f\,(S\_BEN_i(-),\, E_i(+),\, log(GDP)_i(?),\, TRADE_i(?),\, SECTOR_i(+),\, PR_i(-))$$

Furthermore, in order to assess the impact of political rivalry by different geo and income groups, for each of the four baseline regressions specified above, *i.e.* (4.3)-*e*, (4.3)-*learn*, (4.3)-*gdp* and (4.3)-*gini*, we perform the following two supplementary regressions:

$$Y_i = \gamma_0 + \sum_{m=1}^{M} \gamma_m X_{m,i} + \delta PR_i + \sum_j \theta_j PR_i \cdot Inc_{j,i} + e_i \tag{4.4}$$

$$Y_i = \gamma_0 + \sum_{m=1}^{M} \gamma_m X_{m,i} + \delta PR_i + \sum_k \phi_k PR_i \cdot Geo_{k,i} + e_i \tag{4.5}$$

where $\sum_j$ and $\sum_k$ include, respectively, the income and geo groups j and k, for which PR has a statistically significant effect on Y. The identification of the income and geo groups belonging to $\sum_j$ and $\sum_k$ will be explained in detail in Section 4 (see Tables 6 and 7).

These two supplementary regressions will be subsequently denoted by: (4.4)-e and (4.5)-e, (4.4)-$learn$ and (4.5)-$learn$, (4.4)-gdp and (4.5)-gdp, and (4.4)-$gini$ and (4.5)-$gini$ respectively. In sum, for each dependent variable E, $LEARN$, $log(GDP)$ and $GINI$, we will perform a series of three regressions: (4.3), (4.4) and (4.5).

4.3.2 Data sets

Each three-regression series specified in Section 3.1 is estimated using a different sample of countries. In particular, given the data availability for some of the considered variables, 89, 52, 68 and 103 countries are included in the regressions for E, $LEARN$, $log(GDP)$ and $GINI$ respectively. The four samples comprise a 15 year period from 1996 to 2011, conditioned by the Worldbank Governance Indicators available only starting from year 1996 (which we use to construct the composite political rivalry indicator, PR, in Section 2).

The employed data structure is a cross-section, as we use only one observation for each variable-country pair, corresponding to the average of available years for one variable in one country between 1996-2011. Our rule for including a country in any of the four samples was finding data for at least three years between 1996-2011 for all variables included in the respective three-regression series. The four samples include relatively balanced data for all income and geo groups, as specified in Section 2.

The choice of a cross-section structure is motivated by three main reasons: first, the existence of a limited 15 year time-period for the key variable in our research, PR; second, missing data for some countries / variables for the time period 1996-2011; and third, the nature of the variables employed and of the socio-economic processes examined, which produce effects in a medium-long term. Moreover, a cross-section analysis allows us to compare differences between countries resulting from their specific characteristics, which is in fact our main objective.

All data have been collected from the World Bank online database. A detailed description of the variables used in all regressions and the complete list of countries included in each sample is provided in the Appendix.

4.4 Empirical findings and robustness analysis

In this section, we present the empirical findings of all the regressions defined in Section 3.1, estimated by OLS. We also conduct diagnostic testings and a robustness analysis, the results of which are discussed at the end of the section.

4.4.1 Empirical findings

Before presenting and discussing our main estimation results, we must identify the income and geo groups to be included in the estimation of regressions (4.4) and (4.5). As previously mentioned in Section 3.1, these are the groups for which the effect of PR on the dependent variables is statistically significant.[10] They are identified by regressing each of our four dependent variables on PR multiplied, in turn, by all Inc or Geo dummies. The results of this selection procedure are presented in the following tables:

Table 4.6: Results of regressions for selecting the income groups

Dependent variables: E_i, $LEARN_i$, $log(GDP_i)$ **and** $GINI_i$				
Explanatory variables	***Coefficient estimates (by regression)***			
	E_i	$LEARN_i$	$log(GDP_i)$	$GINI_i$
$constant$	14.8493***	81.6432***	9.1684***	38.0870***
	(18.4448)	(26.4753)	(65.9648)	(38.2950)
$PR_i \cdot Inc_1$	0.3069	-6.4805	0.0699	-1.8719
	(0.2701)	(-0.8757)	(0.3394)	(-1.0806)

[10]Note that, given the heterogeneity of the composite political rivalry indicator detected in the preliminary analysis in Section 2, the PR effects may not be the same across different income and /or geo groups of countries.

$PR_i \cdot Inc_2$	-2.0379 (-1.4557)	1.0154 (0.2061)	0.7698^{***} (2.8964)	-5.2578^{***} (-3.1296)
$PR_i \cdot Inc_3$	-3.2049^{*} (-2.0223)	12.9533^{***} (2.8656)	1.3699^{***} (4.5501)	-3.1504^{*} (-1.8917)
$PR_i \cdot Inc_4$	-16.5381^{***} (-3.6238)	59.9001^{***} (3.5637)	5.4541^{***} (5.2333)	-1.0816 (-0.4204)
N	89	53	68	106
R^2	0.18	0.32	0.44	0.12
$F - statistic$	4.5692^{***}	5.5210^{***}	12.4911^{***}	3.4587^{**}

Notes: see Table 2

Table 4.7: Results of regressions for selecting the geo groups

Dependent variables: E_i, $LEARN_i$, $log(GDP_i)$ **and** $GINI_i$				
Explanatory variables	***Coefficient estimates (by regression)***			
	E_i	$LEARN_i$	$log(GDP_i)$	$GINI_i$
constant	13.8280^{***} (19.7718)	83.7009^{***} (21.7357)	9.2329^{***} (64.0977)	37.5496^{***} (41.1192)
$PR_i \cdot Geo_1$	0.3019 (0.2196)	-17.8621 (-0.9647)	0.0360 (0.1457)	-1.3599 (-0.6318)
$PR_i \cdot Geo_2$	-2.8991^{*} (-2.0296)	6.2763 (0.7808)	0.6886^{**} (2.5335)	-1.9434 (-1.0402)
$PR_i \cdot Geo_3$	1.3607 (0.9725)	-6.7516 (-0.7674)	1.5228 (1.6461)	-0.7643 (-0.3876)
$PR_i \cdot Geo_4$	-6.0177^{***} (-3.4947)	10.0751 (1.6443)	1.0066^{***} (3.7334)	-10.0821^{***} (-5.0343)
$PR_i \cdot Geo_5$	-1.0880 (-0.6931)	8.4095 (1.3084)	0.9728^{*} (1.6801)	1.9174 (0.5602)
$PR_i \cdot Geo_6$	-	-8.4228 (-0.4222)	-	4.9945 (1.2613)
$PR_i \cdot Geo_7$	-12.3015^{***} (-5.2826)	13.2701 (1.3951)	4.9044^{***} (5.3048)	-5.8607^{***} (-3.1556)

N	87	54	67	106
R^2	0.34	0.15	0.44	0.27
$F-statistic$	6.9021***	1.1111	7.7312***	5.1656***

Notes: see Table 2; the explanatory variable $(PR \cdot Geo_6)$ was excluded from regressions reported in columns [1] and [3] due to data constraints.

In the next regressions we will consider the income and geo groups for which the PR effects are statistically significant at 5%, as reported in Tables 6 and 7.

Tables 8-11 below report the estimation results of the regressions defined in Section 3.1. In particular, a separate table is constructed for each of the three-regression series of the dependent variables E, $LEARN$, $log(GDP)$ and $GINI$ and all four are presented below in the same order as follows: column [1] shows the results for the baseline regressions (4.3), and columns [2] and [3] for regressions (4.4) and (4.5) (by the above selected income and geo groups) respectively.[11]

4.4.1.1 Results of regressions for public investments in education, E

As it can be seen from the results reported in column [1] of Table 8, with the exception of PR, all coefficients' estimates have the expected sign. Regarding HCA, the estimation results suggest that its positive effect on public investments in education predominates over its negative effect (the estimated coefficient sign is negative), thus eliminating the above referred ambiguity. That is, higher levels of human capital continue motivating further investments in education. As for PR, its coefficient is not statistically different from zero ($\hat{\delta} = 0.6710$, with a *p-value* of 0.4535). This can re-

[11] Recall that, taking into account the definition of variables E and PR, the direction of their effects should be read inversely to their coefficients' signs presented in the tables.

sult from the heterogeneity detected in the composite political rivalry indicator, which implies possible distinct PR effects by different income and geo groups.[12]

In order to capture these possible effects by income groups, we perform regression (4.4)-e, the results of which are presented in column [2]. We can see that political rivalry has a statistically significant negative effect on public investments in education in countries from group $income_4$, as the coefficient associated to $(PR \cdot Inc_4)$ is negative and clearly statistically different from zero $\hat{\theta}_4 = -14.3967$, with a *p-value* of 0.0011. These results suggest that only in low-income countries, political rivalry considerations are relevant for influencing public policy on education. Given our definition of PR, the intuition behind this result is straightforward. Recall that in our context political rivalry may arise, for example, in the form of exercising public power for private gain, "capture" of the state by elites and private interests, and the resulting lack of quality of public policy formulation and implementation. Consequently, in poor countries the functioning of social policies (including public investments in education), being typically in early development stages, is more vulnerable to such episodes of political rivalry. Although we would expect a similar mechanism for higher-income countries, albeit on a smaller scale, it is not confirmed by our estimation results. This suggests that the relationship between political rivalry and public investments in education may in fact be weaker in higher-income countries, or that the mechanisms linking the two variables may be more complex than those considered in our study.

Column [3] reports the estimation results of regression (4.5)-e, accounting for possible distinct political rivalry effects by geo groups. The statistically significant negative effect of political rivalry on public investments in education in countries from group geo_7 is captured by $\hat{\phi}_7 = -9.4404$, with a *p-value* of 0.0016. Given that countries from group geo_7 have levels of development similar to those of countries included in group

[12]Note that, although having the expected coefficient signs, the variables T and POP are not statistically significant. Similarly to PR, their disaggregation by income and geo groups indicates that there are statistically significant effects on E for some of these groups. However, we do not explore this further given that evaluating their specific impact on E is not the objective of this study.

$income_4$, the intuition behind this result is similar to that presented in the previous paragraph. As for the effect of political rivalry in countries from group geo_4, it is not statistically significant: $\hat{\phi}_4 = -2.5483$ with a *p-value* of 0.3256. This occurs because including the variable $(PR \cdot Geo_4)$, which captures the political rivalry effect in highly unequal Latin American countries, together with the variable $GINI$ lowers the level of significance of both, due to the high correlation between them (correlation coefficient of -0.62). In fact, removing the variable $GINI$ from the regression, almost doubles the magnitude of the effect of $(PR \cdot Geo_4)$ and decreases its *p-value* to 0.0346.[13] Thus, the results of regression (4.5)-e suggest that political rivalry has a significant effect on public investments in education not only in countries with high poverty levels, but also in countries with high levels of inequality.

Table 4.8: Results of regressions (4.3)-e, (4.4)-e and (4.5)-e

Dependent variable: E_i			
Explanatory variables	***Coefficient estimates***		
	Regression (3)	**Regression (4)**	**Regression (5)**
constant	14.0949*** (3.4912)	12.4336*** (3.2447)	17.4982*** (2.6651)
T_i	-0.1014 (-1.0048)	-0.0916 (-0.9641)	-0.1396 (-1.4284)
$GINI_i$	0.2233*** (2.7399)	0.2473*** (3.2104)	0.1110 (1.0927)
HCA_i	-0.1561** (-2.4803)	-0.1252** (-2.0894)	-0.1217** (-1.9828)
POP_i	0.0002 (0.3177)	0.0002 (0.3104)	0.0004 (0.5215)

[13] We will further refer to this result in our robustness analysis in Section 4.2.

DEM_i	-3.0629^{*} (-1.8390)	-3.1392^{**} (-2.0020)	-2.8055^{*} (-1.7609)
PR_i	0.2294 (0.2451)	0.6710 (0.7533)	0.6800 (0.7534)
$PR_i \cdot Geo_4$	-	-	-2.5483 (-0.9891)
$PR_i \cdot Geo_7$	-	-	-9.4404^{***} (-3.2743)
$PR_i \cdot Inc_4$	-	-14.3967^{***} (-3.3956)	-
N	89	89	89
R^2	0.26	0.35	0.35
$F-statistic$	4.7461^{***}	6.2376^{***}	5.2790^{***}
$White\,(\chi^2)$	20.9092	32.5245	39.5225
$Breusch-Godfrey\,LM\,(\chi^2)$	2.5506	4.9781^{*}	3.2662
$Ramsey\,RESET\,(F)$	0.8052	3.2680^{*}	3.3780^{*}

Notes: see Table 2.

4.4.1.2 Results of regressions for individual learning choice, $LEARN$

Results of regression (4.3)-*learn*, reported in column [1] of Table 9, indicate that, with the exception of PR, all coefficients' estimates have the expected sign and all, except $GRAD$ and PR, are statistically different from zero. As regards PR, similarly to the previous case, its effect on $LEARN$ is not important for the entire sample due to its heterogeneity; as for the variable $GRAD$, it is not statistically significant because of its relatively high correlation with another explanatory variable, E (correlation coefficient of-0.43). However, when considered individually, each of them is statistically significant for explaining $LEARN$ (for a 1% level of significance), and thus both are kept in the regression.

Furthermore, before proceeding to regression (4.4)-*learn* to account for the effect of PR by specific income groups identified in (4.4.1),[14] it is worth noting that political rivalry generates two distinct effects on the variable $LEARN$. On the one hand, there is a negative effect, captured by the coefficients associated to PR, caused by an unfavourable political environment. Such environment can discourage individual learning incentives due to disfunctions in the specific areas comprised by the composite political rivalry indicator (see Section 2). In our subsequent analysis we use the term "direct" to designate this kind of influence, to which we refer as the *direct effect*. On the other hand, as it was shown in regression (4.3)-e, political rivalry negatively affects public investments in education, which also reduces motivation and possibilities for studying. Thus, there is another negative effect of political rivalry on individual learning choice *via* the variable E, which we designate by *indirect effect* and which is captured by the increase in the magnitude of the coefficients associated to political rivalry, once E is excluded from the regression.[15]

More specifically, regarding the direct effect, we can see that the coefficients associated to $PR \cdot Inc_3$ and $PR \cdot Inc_4$ are positive and clearly statistically different from zero: $\hat{\theta}_3 = 9.6855$ and $\hat{\theta}_4 = 24.5303$, with *p-values* of 0.0055 and 0.0001 respectively (see column [2] of Table 9). These results again suggest that only in lower-income countries political rivalry considerations influence the individual learning choice.

As for the indirect effect, it is obtained by computing the difference between the direct and the total effects of PR on $LEARN$.[16] To do so, we compare the coefficients associated to political rivalry in groups $income_3$ and $income_4$ in regression **(4.4)**-*learn* (which give its direct effect) to its coefficients after excluding E (which give the total effect of political rivalry). This comparison reveals that the indirect estimated negative effect of political rivalry on individual learning choice represents on average approx-

[14]Note that we only consider disaggregation by income groups, given that the differences in the effects of political rivalry on individual learning choice by geo groups are not statistically significant.

[15]Consequently, it should be emphasized that, rigorously speaking, the coefficient used here to assess the direct effect captures the impact of all potentially existent mechanisms (other than E) through which political rivalry may affect individual learning choice.

[16]The total effect is thus given by the sum of the direct and indirect effects of PR on $LEARN$.

imately 25% of the overall estimated effect, keeping the other explanatory variables constant.[17] This implies that, for lower-income countries, public investments in education, negatively affected by political rivalry, will necessarily generate a lower beneficial influence on individual learning choice (note that the coefficient associated to E is negative and statistically different from zero at 1%). In other words, to the extent that E includes elements considered crucial for determining the individual learning choice,[18] the negative political rivalry impact on public investments in education will necessarily amplify the total negative political rivalry impact on individual learning choice.

Here, we note again that in higher-income countries political rivalry does not appear to affect individual learning choice. This is likely to occur because in these countries larger possibilities for private contributions (enabled by a higher income level *per capita*) turn social policies less crucial for determining individual learning choice, or because other potential mechanisms that may be relevant for higher-income countries are not captured in this regression.

Table 4.9: Results of regressions (4.3)-*learn*, (4.4)-*learn* and (4.5)-*learn*

Dependent variable: $LEARN_i$		
Explanatory variables	***Coefficient estimates***	
	***Regression* (3)**	***Regression* (4)**
constant	21.3126 (0.5363)	18.8642 (0.4539)
E_i	-0.8549^{***} (-3.7127)	-0.7671^{***} (-2.6119)
HCA_i	0.3361^{**} (2.3269)	0.2818^{**} (2.1497)

[17] This value is obtained by computing the simple average of the increase in the coefficients $\hat{\theta}_3$ and $\hat{\theta}_4$.

[18] Such as infrastructure, educational material provision, teaching quality and individual support, and equality of access and opportunity, see Chapter 3.

$log(GDP_i)$	3.9901^{**} (2.4189)	3.5505^{***} (3.0392)
$GRAD_i$	0.3176 (0.8818)	0.3685 (1.0231)
DEM_i	10.8625^{***} (3.4872)	11.1135^{***} (3.8139)
PR_i	1.7133 (0.5870)	-3.1254 (-1.2610)
$PR_i \cdot Inc_3$	-	9.6855^{***} (2.9260)
$PR_i \cdot Inc_4$	-	24.5303^{***} (4.1725)
N	52	52
R^2	0.65	0.72
$F-statistic$	14.0721^{***}	13.7185^{***}
$White\ (\chi^2)$	30.2220	33.8163
$Breusch-Godfrey\ LM\ (\chi^2)$	7.2757^{**}	10.0385^{***}
$Ramsey\ RESET\ (F)$	1.9716	0.1784

Notes: see Table 2; $t-statistics$, calculated from autocorrelation consistent standard errors, using the Newey-West procedure, are reported in brackets.

4.4.1.3 Results of regressions for GDP *per capita*, $log(GDP)$

Table 10 below presents the results of the three-regression series for $log(GDP)$. As in the previous cases, all coefficients' estimates in regression (4.3)-*gdp*, reported in column [1], have the expected sign and, except PR, are statistically significant. It is worth noting that the strongest effect comes from our dummy for democracy, DEM, followed by public investments in education, E, and human capital accumulation, HCA (all for 1% level of significance). As regards political rivalry, similarly to the previous series of regressions for $LEARN$, we distinguish between two types of effects. On the one hand, there is the so-called direct effect of PR on $log(GDP)$, generated, among other possible causes, by its discouraging impact on aggregate production. On the other hand, there is the so-called indirect effect *via* E, due to lower investments in education. Additionally, in the three-regression series for $log(GDP)$, there is another channel of transmission of political rivalry indirect effects, as follows. As we have seen above, public investments in education affect individual learning incentives and both are negatively influenced by political rivalry. Because both are crucial determinants for human capital accumulation, included in the regressions for $log(GDP)$, we should assess the indirect effect of political rivalry also *via* HCA.

Regarding the direct effect, accounting for the political rivalry effects by income and geo groups again yields interesting results. In particular, as reported in columns [2] and [3], we can see that the coefficients associated to $(PR \cdot Inc_3)$, $(PR \cdot Inc_4)$ and $(PR \cdot Geo_7)$ are positive and clearly statistically different from zero: $\hat{\theta}_3 = 0.7947$, $\hat{\theta}_4 = 2.7383$ and $\hat{\phi}_7 = 2.1432$, with *p-values* of 0.0083, 0.0038 and 0.0138 respectively. Although groups $income_2$, geo_2 and geo_4 were also reported significant in Tables 6 and 7, their effects are not statistically significant in regressions (4.4)-*gdp* and (4.5)-*gdp*.[19] Thus, given that groups in which the PR effect on $log(GDP)$ is statistically significant include lower-middle and low-income countries, we again confirm that, in lower income countries, political rivalry considerations may have serious implications for economic growth and development. For example, restricting our attention to the income groups, the results of regression (4.4)-*gdp* imply that a unit difference in PR between two countries belonging to group $income_3$ ($income_4$), *e.g.* $PR = -0.5$ and $PR = +0.5$, translates into a difference in the GDP *per capita* of approximately 80% (274%), keeping the other explanatory variables constant. And because a unit variation in PR reflects very different political environments (recall that the composite political

[19] This occurs because, accurately speaking, while the PR, $(PR \cdot income_j)$ and $(PR \cdot geo_k)$ coefficients of the three-regression series for $log(GDP)$ give only the direct political rivalry effect on the dependent variable, initial disaggregation of the PR effect on $log(GDP)$ reported in (4.4.1) and (4.4.1), comprises both direct and indirect effects. Thus, once controlling for other explanatory variables, whose coefficients may capture possible indirect effects of PR, it is not surprising that the statistical significance of PR for some groups is reduced.

rivalry indicator ranges between -2.5 and $+2.5$), small differences in its values imply considerable GDP *per capita* asymmetries between countries. Clearly, such influence should not be disregarded.

As for the indirect effect, using the same procedure as for the series of regressions for $LEARN$, we compute it for disaggregation by income and geo groups separately. In particular, after excluding E and HCA from regressions (4.4)-gdp and (4.5)-gdp, the coefficients associated to $(PR \cdot Inc_2)$, $(PR \cdot Inc_3)$ and $(PR \cdot Inc_4)$ increase on average by approximately 29%, while those associated to $(PR \cdot Geo_2)$, $(PR \cdot Geo_4)$ and $(PR \cdot Geo_7)$ indicate an average increase of around 36%. Again, as in the series of regressions for $LEARN$, the total PR effect on $log(GDP)$ is amplified and its indirect effect, transmitted *via* E and HCA, accounts for around one third of the total, this being particularly relevant for lower income countries.

Table 4.10: Results of regressions (4.3)-gdp, (4.4)-gdp and(4.5)-gdp

Dependent variable: $log(GDP_i)$			
Explanatory variables	***Coefficient estimates***		
	Regression (3)	**Regression (4)**	**Regression (5)**
constant	7.8535*** (17.2449)	7.9746*** (18.8718)	7.8179*** (17.5639)
E_i	−0.0655*** (−3.8808)	−0.0444*** (−2.6598)	−0.0475*** (−2.6718)
HCA_i	0.0329*** (3.1572)	0.0274*** (2.7233)	0.0267** (2.4847)
H_TECH_i	0.0003** (2.1792)	0.0003** (2.6301)	0.0003** (2.4697)
DEM_i	1.2912*** (4.6429)	1.0358*** (3.7666)	1.2304*** (4.4605)
PR_i	0.1854 (1.4849)	−0.0226 (−0.1444)	0.0282 (0.1604)

$PR_i \cdot Geo_2$	-	-	0.2493 (0.8545)
$PR_i \cdot Geo_4$	-	-	0.4385 (1.5366)
$PR_i \cdot Geo_7$	-	-	2.1432** (2.5394)
$PR_i \cdot Inc_2$	-	0.3285 (1.1934)	-
$PR_i \cdot Inc_3$	-	0.7947*** (2.7323)	-
$PR_i \cdot Inc_4$	-	2.7383*** (3.0194)	-
N	68	68	68
R^2	0.65	0.72	0.70
$F - statistic$	19.1500***	16.4957***	14.4543***
$White\ (\chi^2)$	23.6091	31.0300	37.2332
$Breusch - Godfrey\, LM\ (\chi^2)$	3.1523	0.5735	4.3509
$Ramsey\ RESET\ (F)$	2.8592	0.2465	0.6827

Notes: see Table 2.

4.4.1.4 Results of regressions for inequality, $GINI$

Results of our last three-regression series for $GINI$, are reported in Table 11. As reported in column [1], expected signs are verified for the estimated coefficients of the variables S_BEN, E and PR, and are not verified for the variable $SECTOR$, for which the estimated coefficient yields negative. This inverse relationship between sectoral labour allocation and income inequality is likely to occur because there are less sources for inequality in countries where the share of the agricultural sector in the total labour force is larger. All variables, except $TRADE$ and $log(GDP)$, have statistically significant effects on income inequality. As regards political rivalry, we find that, contrarily to the previous regressions, its direct effect on inequality is statistically significant (for 5% significance level) even without disaggregation by geo and income groups. We will refer to this result in more detail in our analysis below. As for its indirect effect, as before, we evaluate it *via* public investments in education channel.[20]

Starting with the direct effect of PR on $GINI$, we can see that, as referred above, it is statistically significant even considering the entire sample: $\hat{\delta} = -1.8219$ with a *p-value* of 0.0394. However, we emphasize that this significance is explained not by the fact that PR is statistically significant in all income and geo groups, but rather because its effect is very strong in the groups where it is indeed significant. In particular, as reported in columns [2] and [3], we have: $\hat{\theta}_2 = -4.2256$, $\hat{\phi}_4 = -8.8306$ and $\hat{\phi}_7 = -3.4516$ with *p-values* of 0.0130, 0.0000 and 0.0725 respectively. Note that, the negative political rivalry effect is particularly strong in Latin American countries comprised in group geo_4 (and included in group $income_2$): a unit increase in PR represents a decrease in $GINI$ of approximately 8.8 percentage points, keeping other explanatory variables constant. Thus, there is a significant negative political rivalry effect on income inequality, which is especially strong in those countries where inequality levels are considerably higher compared to other regions.

Next, we assess the effect of PR on $GINI$ *via* E, which attenuates income inequality by promoting social mobility and enabling income convergence. Based on results in columns [2] and [3], we calculate the indirect negative estimated effect of political rivalry on income inequality, which amounts to, on average, around 10% and 5% of the total effect for the included geo and income groups respectively. Note that, although this indirect effect is somewhat weaker than that obtained in the previous regressions, this may not translate the real magnitude of the political rivalry impact *via* E for the following reasons. First, the indirect effect is likely to be dampened by the very strong direct effect of political rivalry on income inequality (when political rivalry either dete-

[20]Although, as we have seen in the previous regression, GDP *per capita* is affected by political rivalry and thus may in general be one of the possible channels of transmission of its indirect effects, it is not statistically significant for explaining income inequality. Therefore, it is irrelevant to consider it in the calculation of the indirect effects of political rivalry on income inequality.

riorates general conditions or impedes their improvement through inefficient economic and social policies pursued by the political elite). Second, it is likely to represent only a partial indirect effect of E, since the latter could not be completely removed due to its implicit presence (through human capital accumulation) in other explanatory variables ($log(GDP)$ and $SECTOR$ in particular).[21] Thus, the values of the political rivalry indirect effects, suggested by the results of this regression, may not thoroughly illustrate their true magnitude and, in line with previous regressions, educational investments and human capital accumulation are likely to be important propagation channels of political rivalry effects to key economic indicators.

Table 4.11: Results of regressions (4.3)-*gini*, (4.4)-*gini* and(4.5)-*gini*

Dependent variable: $GINI_i$			
Explanatory variables	***Coefficient estimates***		
	Regression (3)	**Regression (4)**	**Regression (5)**
constant	49.2127*** (4.8502)	47.0653*** (4.7499)	44.3523*** (4.7304)
S_BEN_i	−0.2287*** (−4.8635)	−0.2408*** (−5.2351)	−0.2094*** (−4.8339)
E_i	0.3548** (2.5308)	0.3382** (2.4767)	0.3034** (2.2731)
$log(GDP)_i$	−0.2471 (−2.12443)	−0.0386 (−0.0391)	−0.0559 (−0.0604)
$TRADE_i$	−0.0127 (−0.8926)	−0.0116 (−0.8417)	0.0115 (0.1123)
$SECTOR_i$	−0.1401** (−2.1419)	−0.1048 (−1.6096)	−0.0816 (−1.3228)
PR_i	−1.8219** (−2.1419)	−0.4359 (−0.4316)	0.2646 (0.2859)

[21] Note that the correlation coefficients between E and $log(GDP)$ and $SECTOR$ are of −0.42 and 0.56 respectively.

$PR_i \cdot Geo_4$	-	-	-8.8306^{***} (-4.4992)
$PR_i \cdot Geo_7$	-	-	-3.4516^{*} (-1.8167)
$PR_i \cdot Inc_2$	-	-4.2256^{**} (-2.5317)	-
N	103	103	103
R^2	0.39	0.43	0.50
$F-statistic$	10.2305^{***}	10.1788^{***}	11.8088^{***}
$White\ (\chi^2)$	38.9357^{*}	40.8406	47.1053
$Breusch-Godfrey\ LM\ (\chi^2)$	1.4948	3.5513	2.2554
$Ramsey\ RESET\ (F)$	2.1041	0.6328	0.5173

Notes: see Table 2.

4.4.2 Diagnostic testing and robustness analysis

In this section, we present and discuss the results of several diagnostic tests and robustness analysis performed for all the regressions in Section 4.1. We perform the usual tests for heteroscedasticity ($White$), serial correlation ($Breusch-Godfrey\ LM$) and generic model specification ($Ramsey\ RESET$), the results for which are reported in the Tables 8-11 for each regression respectively.[22] As regards the model specification and heteroscedasticity, no problems have been detected in any of the regressions; serial correlation has been detected in regressions (4.3)-*learn* and 4.4-*learn*.[23] Consequently, in columns [1] and [2] of Table 9, the $t-statistics$ were calculated from autocorrelation consistent standard errors, using the $Newey-West$ procedure.

In order to check for possible multicollinearity, we apply the common procedure of running auxiliary regressions (for regressions (4.3)-e, (4.3)-*learn*, (4.3)-*gdp* and (4.3)-

[22]Following standard procedures, cross-terms where included in the $White$ test, the $Breusch-Godfrey\ LM$ test was conducted with two lags, and the $Ramsey\ RESET$ included one fitted term.

[23]All tests were conducted for a 5% level of significance.

gini), in which each of the explanatory variables (from the respective (4.3)) is regressed on all other explanatory variables. We do this in order to examine the degree of independence of each variable's effect in their original regressions. The R^2 values from the auxiliary regressions are then used to calculate each variable's tolerance level, given by $1 - R^2$. A small tolerance value indicates that the variable under consideration is almost a perfect linear combination of other explanatory variables, and that it should not be included in the original regression. Following Allison (1999), we consider a tolerance level of 0.40 as the lowest bound, below which the degree of multicollinearity is considered to be excessive. This analysis revealed tolerance level below 0.40 (namely, 0.21) only for regression (4.3)-*gini*, when estimating $log(GDP)$ on the other explanatory variables.[24] Based on this result, we remove $log(GDP)$ from regressions (4.3)-*gini*, (4.4)-*gini* and (4.5)-*gini* and we confirm that the change in the estimation results is very slight, that is, all coefficients' estimates remain almost identical and the variables' significance is the same. This is due to the fact that variable $log(GDP)$ is not significant for explaining $GINI$, as we have seen above. Thus, all previously drawn conclusions as to the effects of other explanatory variables on $GINI$ continue to verify.

Next, we check the robustness of our main results by examining how the coefficient estimates of our variables of interest, PR, $(PR \cdot Inc_j)$ and $(PR \cdot Geo_k)$, behave when the regressions' specifications are modified by removing explanatory variables. If the estimates do not change significantly (that is, take the opposite sign, show dramatic variations in magnitude and/or statistical significance), this indicates that the coefficients are robust and can be interpreted as reliable causal effects of political rivalry on the selected economic variables. In particular, we perform the robustness analysis by removing, alternately, one explanatory variable from each regression and checking for the changes in the coefficient estimates of our variables of interest. As regards the

[24]Besides this procedure, we also check for other signs of multicollinearity, such as: correlation coefficients above 0.9 between explanatory variables; very high standard errors and low t-statistics; unexpected changes in coefficient magnitudes or signs; and non-significant coefficients despite a high R^2. These are clearly not present in our regressions.

three-regression series for E, the only significant change occurs when we remove variable $GINI$ from the regression (4.5)-e, which considerably increases the significance of variable $(PR \cdot Geo_4)$ (*p-value* decreases from 0.0983 to 0.0022). This is explained by the high correlation between $GINI$ and $(PR \cdot Geo_4)$ due to the reasons already mentioned in our analysis in Section 4.1. The estimated effect of political rivalry on GDP *per capita* is also robust, as slight changes occur only when removing variables E and DEM. This result for E is not new, as the same operation has already been performed in our previous analysis of the indirect effects of political rivalry on GDP *per capita* (see Section 4.1). As for DEM, dropping it from regressions (4.3)-gdp and (4.4)-gdp increased the significance of the variables PR and $(PR \cdot Inc_2)$ for a 10% and 5% level of significance respectively, which suggests that political rivalry may influence GDP *per capita* also through its relation with a country's specific form of government. As regards the remaining regressions for E and $log(GDP)$, as well as all the regressions for $LEARN$ and $GINI$, the coefficients' estimates of PR, $(PR \cdot Inc_j)$ and $(PR \cdot Geo_k)$ are robust to structural changes, as no significant variations in these estimates have been detected when dropping variables. In this way, the robustness analysis results further validate and support the key conclusions of this chapter.

4.5 Concluding remarks

In this chapter we intended to empirically test the main theoretical conclusions of the previous chapter regarding the impact of political rivalry on selected economic variables. In particular, based on empirical data for a large number of countries, we analysed how political rivalry may influence educational investments, individual learning choice, GDP *per capita* and income inequality. Given that, to our knowledge, there are no previous empirical data on political rivalry, we have first constructed a composite political rivalry indicator, comprising the elements of institutional quality and exclusive pecuniary benefits from natural resources, which we consider crucial for determining the degree of rivalry between the political elite and other social groups. A preliminary analysis of this new political rivalry indicator revealed a high level of heterogeneity by income and geographical location. In particular, we find that higher-income countries have much lower levels of political rivalry, mainly due to their high institutional quality. On the contrary, exclusive natural resources rents are responsible for increasing the level of political rivalry in countries from Eastern Europe, Central Asia, Middle East and North Africa.

Regarding the main findings of this chapter, our empirical analysis clearly suggests that, for certain income and geo groups, political rivalry has indeed a negative effect on the considered economic variables. In particular, as regards public investments in education and individual learning choice, political rivalry effects are significant in lower income countries, and, among these, their magnitude increases with the decrease in the development level. Regarding GDP *per capita*, our results suggest that even small differences in the degree of political rivalry imply considerable asymmetries in *per capita* income. This is particularly relevant for low income countries. As for the impact of political rivalry on income inequality, our findings indicate that it is globally significant even before sample disaggregation by income and geographical location. However, this is explained not by a statistically significant effect of political rivalry for all groups of countries, but rather by the fact that its impact is very strong in the groups where it is indeed significant. Again, this effect is particularly strong in countries with higher inequality levels. The results of our robustness analysis further support these conclusions, given that structural changes cause no significant variations in the coefficients' estimates for political rivalry.

The analysis performed also reveals the presence of the so-called indirect effects of political rivalry, particularly strong when transmitted *via* public investments in education, accounting for about one third of the total effect. Although we would expect similar mechanisms to work in higher-income countries as well, albeit on a smaller scale, this is not confirmed by the data. It may occur because the relationship between political rivalry and the selected economic variables may in fact be weaker in higher-income countries; also, the mechanisms that link the two variables and are relevant for higher-income countries may be more complex than those considered in our study. Thus, processes explaining the relationship between political rivalry and the selected economic variables for different income levels, as well as other mechanisms of transmission, should be further explored in future research.

Appendix

Table 4.12: List of countries by income level

$income_1$	PR	$income_2$	PR	$income_3$	PR	$income_4$	PR
Andorra	1.37	Algeria	-1.40	Albania	-0.49	Afghanistan	-1.71
Aruba	1.17	American Samoa	0.39	Armenia	-0.27	Bangladesh	-1.01
Australia	1.67	Angola	-2.57	Belize	-0.23	Benin	-0.55
Austria	1.77	Antigua and Barbuda	0.75	Bhutan	-0.18	Burkina Faso	-0.47
Bahamas, The	1.16	Argentina	-0.47	Bolivia	-0.93	Burundi	-1.56
Bahrain	-0.12	Azerbaijan	-2.02	Cameroon	-1.12	Cambodia	-0.87
Barbados	1.23	Belarus	-1.10	Cape Verde	0.12	Central African Republic	-1.37
Belgium	1.46	Bosnia and Herzegovina	-0.54	Congo, Rep.	-1.70	Chad	-1.81
Bermuda	1.26	Botswana	0.62	Côte d'Ivoir	-1.02	Comoros	-1.44
Brunei Darussalam	-0.44	Brazil	-0.06	Djibouti	-0.77	Congo, Dem. Rep.	-1.64
Canada	1.72	Bulgaria	0.06	Egypt, Arab Rep.	-0.85	Equatorial Guinea	-1.49
Cayman Islands	1.32	Chile	1.37	El Salvador	-0.50	Eritreia	-2.65
Croatia	0.19	China	-0.55	Fiji	-0.59	Ethiopia	-0.86
Cyprus	1.24	Colombia	-0.17	Georgia	-1.46	Gambia, The	-0.53
Czech Republik	0.78	Costa Rica	0.43	Gabon	-0.61	Guinea	-0.98
Denmark	2.13	Cuba	-0.56	Ghana	-0.12	Guinea-Bissau	-1.17

Estonia	0.99	Dominica	0.55	Guatemala	-0.46	Haiti	-1.47
Finland	2.09	Dominican Republic	-0.46	Guyana	-0.70	Kenya	-0.60
France	1.32	Ecuador	-0.84	Honduras	-0.80	Korea, Dem. Rep.	-1.96
Germany	1.60	Grenada	0.40	India	-0.29	Kyrgyz Republic	-0.66
Greece	0.60	Iran, Islamic Rep.	-0.96	Indonesia	-0.51	Liberia	-1.32
Greenland	1.03	Jamaica	0.00	Iraq	-1.77	Madagascar	-0.39
Guam	0.50	Jordan	0.13	Kiribati	-1.28	Malawi	-0.58
Hong Kong SAR, China	1.74	Kazakhstan	-0.66	Kosovo	-0.36	Mali	-0.91
Hungary	0.76	Latvia	0.40	Lao PDR	-2.19	Mauritania	-0.43
Iceland	1.80	Lebanon	-0.58	Lesotho	-0.35	Mozambique	-0.49
Ireland	0.72	Libya	-1.21	Marshall Islands	-0.97	Myanmar	-1.88
Israel	-0.93	Lithuania	-0.55	Micronesia, Fed. Sts.	-0.62	Nepal	-0.71
Italy	0.60	Macedonia, FYR	-0.25	Moldova	-0.51	Niger	-1.66
Japan	1.15	Malaysia	0.56	Mongolia	-0.68	Rwanda	-0.50
Korea, Rep.	0.70	Maldives	-0.13	Morocco	-0.15	Sierra Leone	-1.09
Kuwait	0.31	Mauritius	0.01	Nicaragua	-0.68	Somalia	-2.18
Liechtenstein	1.12	Mexico	0.09	Nigeria	-1.01	Tajikistan	-1.23
Luxembourg	1.84	Montenegro	-0.49	Pakistan	-0.70	Tanzania	-0.58
Macao SAR, China	0.78	Namibia	0.22	Papua New Guinea	-0.84	Togo	-1.00
Malta	1.03	Palau	-0.64	Paraguay	-1.02	Uganda	-0.60
Netherlands	1.91	Panama	-0.85	Philippines	-0.26	Zimbabwe	-1.46
New Zealand	1.90	Peru	-0.11	Samoa	0.02		
Norway	0.70	Romania	-0.17	São Tomé and Principe	-0.67		
Oman	0.31	Russian Federation	-0.60	Senegal	-0.26		
Poland	0.57	Serbia	-0.60	Solomon Islands	-1.04		
Portugal	1.09	Seychelles	-0.04	South Sudan	-1.73		
Puerto Rico	-0.16	South Africa	0.49	Sri Lanka	-0.18		
Qatar	0.47	St. Lucia	0.58	Sudan	-1.62		
Saudi Arabia	-0.17	St. Vincent and the Grenadines	0.52	Swaziland	-0.57		
Singapore	2.09	Suriname	-0.45	Syrian Arab Republic	-1.53		
Slovak Republic	0.66	Thailand	0.08	Timor-Leste	-1.13		
Slovenia	0.65	Tunisia	0.12	Tonga	-1.61		

Spain	1.23	Turkey	0.02	Ukraine	-0.83		
St. Kitts and Nevis	0.50	Turkmenistan	-1.57	Uzbekistan	-2.63		
Sweden	1.91	Tuvalu	-0.38	Vanuatu	-0.40		
Switzerland	1.91	Uruguay	0.63	Vietnam	-0.78		
Trinidad and Tobago	0.16	Venezuela, RB	-1.74	West Bank and Gaza	-0.88		
United Arab Emirates	0.22			Yemen, Rep.	-1.58		
United Kingdom	1.76			Zambia	-0.96		
United States	1.54						
Virgin Islands (U.S.)	0.91						

Table 4.14: List of countries by geographical location

geo_1	geo_2	geo_3	geo_4	geo_5	geo_6	geo_7
American Samoa	Brunei Darussalam	Albania	Antigua and Barbuda	Algeria	Afghanistan	Angola
Andorra	Cambodia	Armenia	Argentina	Bahrain	Bangladesh	Benin
Australia	China	Azerbaijan	Aruba	Djibouti	Bhutan	Botswana
Austria	Fiji	Belarus	Bahamas, The	Egypt, Arab Rep.	India	Burkina Faso
Belgium	Guam	Bosnia and Herzegovina	Barbados	Iran, Islamic Rep.	Maldives	Burundi
Canada	Hong Kong SAR, China	Bulgaria	Bermuda	Iraq	Nepal	Cameroon
Cyprus	Indonesia	Croatia	Belize	Israel	Pakistan	Cape Verde
Denmark	Japan	Czech Republic	Bolivia	Jordan	Sri Lanka	Central African Republic
Finland	Kiribati	Estonia	Brazil	Kuwait		Chad
France	Korea	Georgia	Cayman Islands	Lebanon		Comoros
Germany	Korea, Dem. Rep.	Hungary	Chile	Libya		Congo, Dem. Rep.
Greece	Lao PDR	Kazakhstan	Colombia	Morocco		Congo, Rep.

Greenland	Macao SAR, China	Kosovo	Costa Rica	Oman		Côte d'Ivoire
Iceland	Malaysia	Kyrgyz Republic	Dominica	Qatar		Equatorial Guinea
Ireland	Marshall Islands	Latvia	Dominican Republic	Saudi Arabia		Eritrea
Italy	Micronesia, Fed. Sts.	Lithuania	Ecuador	Syrian Arab Republic		Ethiopia
Lichtenstein	Mongolia	Macedonia, FYR	El Salvador	Tunisia		Gabon
Luxembourg	Myanmar	Moldova	Grenada	United Arab Emirates		Gambia, The
Malta	Palau	Montenegro	Guatemala	West Bank and Gaza		Ghana
Netherlands	Papua New Guinea	Poland	Guyana	Yemen, Rep.		Guinea
New Zealand	Philippines	Romania	Haiti			Guinea-Bissau
Norway	Singapore	Russian Federation	Honduras			Kenya
Portugal	Samoa	Serbia	Jamaica			Lesotho
Saudi Arabia	Solomon Islands	Slovak Republic	Mexico			Liberia
Spain	Thailand	Slovenia	Nicaragua			Madagasccar
Sweden	Timor-Leste	Tajikistan	Panama			Malawi
Switzerland	Tonga	Turkey	Paraguay			Mali
United Kingdom	Tuvalu	Turkmenistan	Peru			Mauritania
United States	Vanuatu	Ukraine	Puerto Rico			Mauritius
Virgin Islands (U.S.)	Vietnam	Uzbekistan	St. Kitts and Nevis			Mozambique
			St. Lucia			Namibia
			St. Vincent and the Grenadines			Niger
			Suriname			Nigeria
			Trinidad and Tobago			Rwanda
			Uruguay			São Tomé and Principe
			Venzuela, RB			Senegal
						Seychelles
						Sierra Leone
						Somalia

						South Africa
						South Sudan
						Sudan
						Swaziland
						Tanzania
						Togo
						Uganda
						Zambia
						Zimbabwe

Table 4.16: Variables description

Variable	***Designation***	***Description***
DEM	dummy for democracy	Voice and accountability indicator (Worldbank Governance Indicators): reflects perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.
E	public investments in education	Pupil-teacher ratio (secondary): number of pupils enrolled in secondary school divided by the number of secondary school teachers.
EPB	exclusive pecuniary benefits	Total natural resources rents (% of GDP): the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents.
$GINI$	income inequality	Gini Index: the extent to which the distribution of income or consumption expenditure among individuals or households within an economy deviates from a perfectly equal distribution (a Gini Index of 0 represents perfect equality, while an index of 100 implies perfect inequality).
$GRAD$	grades	Progression to secondary school (% of total) divided by progression through secondary (% of total enrollment): Progression to secondary - number of new entrants to the first grade of secondary education (general programmes only) in a given year, expressed as a percentage of the number of pupils enrolled in the final grade of primary education in the previous year; Progression through secondary - 100% minus the percentage of repeaters in secondary (all grades), *i.e.* the number of students enrolled in the same grade as in the previous year, as a percentage of all students enrolled in secondary school.
HCA	human capital accumulation	Ratio of labour force with tertiary education (% of total) to the sum of labour force with secondary and labour force with primary education (% of total). Labor force with tertiary / secondary / primary education is the proportion of labor force that has a tertiary / secondary / primary education, as a percentage of the total labor force.
H_TECH	high-technology exports *per capita*	High-technology exports (% of manufactured exports) divided by the number of population. High-technology exports: products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery.
IQ	institutional quality	Simple average of three Worldbank Governance Indicators: Governance effectiveness - reflects perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. Regulatory quality - reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. Control of corruption - reflects perceptions of the extent to which

Chapter 5

Directed technological change with costly investment and complementarities, skill premium and the industrial structure

5.1 Overview

This chapter begins the second part of this thesis, where the topics of economic growth and income inequality are investigated by analysing structural transformations in the composition of employment, aggregate production, and wage structure, underlying balanced growth in modern economies. In particular, we develop an extended directed technological change model with R&D driven growth, complementarities between intermediate goods in production, and internal costly investment, in order to study the behaviour of the growth rate, technological-knowledge bias, skill premium and industrial structure.

Our baseline closed economy model builds on the original framework of Acemoglu and Zilibotti (2001) extended by the introduction of physical capital and: (*i*) vertical differentiation following Aghion and Howitt (1992), (*ii*) Hayashi's (1982) internal investment costs in both physical capital and R&D and (*iii*) complementarities between intermediate goods used in the production of final goods, as in Evans *et al.* (1998). In particular, the model assumes that final goods are produced through a combination of labour and quality-adjusted complementary intermediate goods and that two distinct production technologies, skilled and unskilled, are available. Then, to produce each final good, firms can employ either skilled labour and skilled-specific intermediate goods or unskilled labour and unskilled-specific intermediate goods.

The perfectly competitive final goods can then be used in consumption, production of intermediate goods or R&D. On their turn, intermediate-good firms produce under monopolistic competition, using physical capital and choosing between investing into either vertical or horizontal R&D. That is, we model aggregate economic growth as occurring both along an extensive (horizontal R&D) and an intensive (vertical R&D) margin, *i.e.* both through expanding variety and increasing quality of intermediate goods. We then relate horizontal R&D to measures of industrial structure and show that vertical R&D is the ultimate engine of growth. The adopted Schumpeterian approach on temporary monopoly position generating higher profits for the currently innovating firm, enables us to endogenize economic processes designated as the causes of modern economic development and recurring structural change (*e.g.* Howitt, 1999; François and Lloyd-Ellis, 2009). Also, given that a larger number of product lines (horizontal innovation) puts pressure on economy's resources due to the existence of positive fixed and recurrent operating costs, while greater productivity of existing product lines (vertical innovation) does not, we believe that using the two dimensions of technology (*e.g.*, as in Howitt, 1999; Segerstrom, 2000; Peretto and Connolly, 2007) allows us to attain a more comprehensive reflection of the endogenous economic growth and industrial concentration mechanisms.

Our decision to introduce the assumption of costly investment is motivated by the argument that directed technological change growth models should consider investments as a decision variable of the firm, implying that firms undergo expenses associated to investments both in capital accumulation and R&D, as part of total capital investments (Benavie *et al.*, 1996; Romer, 1996; Anagnostopoulou, 2008). The addition of this specific element enables us to analyse skill-biased technological development in a more realistic environment of internal capital investment costs, which include R&D expenses.

In order to reflect another relevant feature of modern industrialized economies in our baseline model, we introduce the element of complementarity between intermediate goods in final goods production. This assumption is primarily motivated by the argument that complementarities should be an essential feature in explaining economic growth, business cycles and underdevelopment (Matsuyama, 1995). We incorporate the important idea that an increase in the number of complementary goods leads to an increase in the production of a capital good, and that an increase in the production of a specific intermediate good raises the demand for its complementary intermediate goods. Introducing this specific element into the model contributes to enriching our analysis on the skill-biased technological development and economic growth.

Within the proposed framework, we analyze the effects of internal costly investment and complementarity degree on the economy's steady-state growth rate, technological-knowledge bias, and skill premium. We also examine the same effects on industrial structure, measured by the relative number of intermediate-good firms and the relative production. We find that both elements – costly investment and complementarity – affect the economy's growth rate, the complementarity degree alone influences technological-knowledge bias through the price channel and the relative production through the technological-knowledge bias channel, while neither one of the two elements affects the skill premium and the relative number of intermediate-good firms in equilibrium.

We also examine the impact of an increase in the skilled-labour endowment on the key equilibrium variables of the model and on industrial structure. We perform this analysis due to the increased importance of skilled labour in most developed (and developing) economies, and also because of the key role that this issue has played in the Skill Biased Technological Change ($SBTC$) literature. We find that an increase in the relative labour supply positively affects the economy's growth rate, technological-knowledge bias and industrial structure. Thus, the inherent mechanisms of our model accommodate the empirical evidence for a number of developed countries on a positive correlation between the supply of skilled labour and different measures of concentration in the skill-specific technology sectors. In particular, our model's comparative analysis verifies the empirical data on the relationship between the relative number of firms, relative production and the relative supply of skills, on a sample of European countries for 1995-2007 average, suggesting that the relative number of firms, relative production and the relative production tend to be positively correlated to the relative supply of skills.[1] As regards the skill premium, the relative labour supply variations have no

[1] Given our theoretical framework, the referred empirical data focuses only on skilled and unskilled-technology sectors and leaves out the medium-high and medium-low categories, thus referring to the

explicit impact on its equilibrium value. We show that this is due in particular to our production function characteristics (namely, a constant elasticity of substitution between factors equal to 2) exactly offsetting the initial supply and the market-size and price-channel effects, which leaves the equilibrium skill premium being determined solely by the absolute productivities ratio. Intuitively, if technological development induced by changes in the relative supply of skills, *i.e.* *SBTC*, leads to an increase in the productivity of labour favoured by technological development (in particular skilled labour), this result suggests that the persisting increase in the wage inequality between skilled and unskilled workers observed in several developed countries throughout the past 30 years may have been due to such increases in the productive advantage of skilled workers.

The remainder of this work is organised as follows. After the Introduction, Section 2 sets up the model specifying the role of internal costly investment and complementarity degree, and presents the main results focusing on consumers, final-goods and intermediate-goods sectors, and R&D decisions. In Section 3 the steady-state equilibrium is defined and discussed. Section 4 provides a comparative analysis of the steady-state effects of costly investment, complementarity degree, and relative labour endowment. Conclusions are presented in Section 5. A summing up of the empirical data on the relationship between the relative supply of skills and our measures of industrial structure is provided in the Appendix.

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extreme categories for manufacturing in OECD classification. Also, although our theoretical model considers the production of intermediate and capital goods, the lack of empirical data detailed by type of good determined the use of total production data for each sector. Data source: Eurostat on-line database.

5.2 Model specifications

5.2.1 Consumers

The economy consists of $L + H$ identical and infinitely-lived households and has a zero population growth. Indexed with $a \in [0, 1]$ depending on their ability level, households consume final goods, own firms and supply unskilled or skilled labour, which we denote by L (indexed by $a \leq \overline{a}$) and H (indexed by $a > \overline{a}$) respectively. The amount of both types of labour supplied to the economy is fixed, implying $L + H = 1$, with $L = \int_0^{\overline{a}} L_a da$ and $H = \int_{\overline{a}}^1 H_a da$. All households have identical preferences and in each period t they decide on the division of their income (from wages and interest) between consumption and saving, maximizing lifetime utility:

$$maxU(t) = \int\limits_0^{\infty} e^{-\rho t} \cdot \frac{C_a(t)^{(1-\sigma)} - 1}{1-\sigma} dt$$

subject to their budget constraint:

$$\dot{E}_a(t) = r(t)E_a(t) + W_m(t)m_a(t) - C_a(t)$$

(with $m = L$ if $a \leq \overline{a}$ and $m = H$ if $a > \overline{a}$), and the transversality condition:

$$\lim_{t \to \infty} E_a(t)e^{-\rho t} = 0$$

where σ is the relative risk aversion coefficient,[2] ρ is the subjective discount rate, $C_a(t)$ is the consumption of the representative household a at time t and $\dot{E}_a(t)$ is the change in the asset stock, $E_a(t)$, given by the difference between income from interest and wages, $r(t)E_a(t)$ and $W_m(t)m_a(t)$ respectively, and consumption.

[2]Determining the willingness to shift consumption between periods, a smaller σ indicates that marginal utility is slowly decreasing in $C_a(t)$, implying thus a higher degree of consumption variation over time.

The optimal consumption path (independent from a) is the standard *Euler* equation:

$$\frac{\dot{C_a}(t)}{C_a(t)} = \frac{\dot{C}(t)}{C(t)} = \frac{r(t) - \rho}{\sigma} \tag{5.1}$$

Equation (5.1) implies that in a balanced-growth path (BGP) the interest rate, $r(t)$, must be constant.

5.2.2 Final-Goods Sector

Building on Acemoglu and Zilibotti (2001) and Afonso (2006), we assume that the composite final good, Y, is produced by competitive final-good firms continuously indexed by $n \in [0, 1]$. Firms produce employing a combination of labour and intermediate goods, using one of the two substitute production technologies available. In particular, firms can either use unskilled labour, L, and a continuum of L-specific intermediate goods indexed by $j_L \in [0, A_L(t)]$, or skilled labour, H, and a continuum of H-specific intermediate goods indexed by $j_H \in [0, A_H(t)]$. Thus, each set of intermediate goods only combines with its corresponding type of labour, and each firm produces with one production technology exclusively, which we denote by L- and H-technology respectively. Also, following Evans *et al.* (1998), we assume that intermediate goods enter complementarily the production function, which for a representative firm n is given by:

$$Y(n,t) = ((1-n)lL(n))^{(1-\alpha)} \left(\int_0^{A_L(t)} \lambda^{\gamma k_L(j_L,t)} \cdot x_L(n, j_L, t)^{\gamma} dj_L \right)^{\phi} + (nhH(n))^{(1-\alpha)} \left(\int_0^{A_H(t)} \lambda^{\gamma k_H(j_H,t)} \cdot x_H(n \tag{5.2}$$

where $x_m(n, j_m, t)$ represents the quantity of the intermediate good j_m, $m = L, H$, and variables $H(n)$ and $L(n)$ denote the amount of skilled and unskilled labour used to produce the final good n at time t; variables $A_H(t)$ and $A_L(t)$ represent the measure of variety of H- and L-specific intermediate goods available at time t; $\lambda > 1$ reflects the improvement in the quality of an intermediate good j brought in by successful vertical innovation, and k indicates both the number of quality improvements and the top quality rung at time t; $h > l \geq 1$ reflects the *absolute* productivity advantage of skilled over unskilled labour, while the terms n and $(1-n)$ reflect the *relative* productivity advantage of each labour type, implying that skilled labour is relatively more productive for manufacturing final goods indexed by larger ns and vice versa; and the terms $(1-\alpha)$ and $\alpha = \gamma\phi$ denote the share of labour and intermediate goods in production (the integral terms summing up the contribution of intermediate goods to the final-goods production). The terms n and $(1-n)$ also imply that at each time t there exists an endogenous threshold $\overline{n}$, at which switching from one production technology to another becomes advantageous, and consequently, each final good n is produced with one technology – H or L – exclusively. Parameter $\phi > 1$ reflects our assumption of complementarity between intermediate goods used in production, implying that an increase in the quantity of one intermediate good increases the marginal productivity of the other intermediate goods. Restriction $\alpha = \gamma\phi$ is imposed to ensure constant returns to scale (with $0 < \alpha < 1$).

Normalizing the price of the composite final good n, $P(n,t)$, to 1 in each t such that $exp \int_0^1 \ln P(n) dn = 1$, the economy's aggregate output at time t, $Y(t)$, is given by the integral over the n final goods:

$$Y(t) = \int_0^1 P(n,t) \cdot Y(n,t) dn = exp \int_0^1 \ln Y(n,t) dn \tag{5.3}$$

Operating in a perfect competition environment, each final good firm n seeks to maximize its profits at time t, taking as given the prices of the complementary intermediate goods j and the wages of skilled or unskilled labour employed in production:

$$\max_{x_m(n,j_m,t)} \pi(n,t) = P(n,t) \cdot Y(n,t) - W_L(t)L(n) - W_H(t)H(n) - \int_0^{A_L(t)} p_L(j_L,t) \cdot x_L(n,j_L,t)dj_L - \int_0^{A_H(t)} p_H(j_H,t) \cdot$$

where $Y(n,t)$ is given by (5.2), $p_m(j_m,t)$ denotes the price of the m-type complementary intermediate good j_m, and $W_m(t)$ is the wage paid for each unit of $m-$type labour. Note that, since each final-good firm produces exclusively with one type of technology, profits at each t are maximized with respect to $x_m(n,j_m,t)$. Then, from the first order conditions (FOCs) of each final-producer type's maximization problem, we can derive the inverse demand functions for L- and H-specific intermediate goods used in final goods production:

$$\begin{aligned} p_L(j_L,t) &= P(n,t)\left((1-n)lL(n)\right)^{(1-\alpha)} \alpha\lambda^{\gamma k_L(j_L,t)} x_L(n,j_L,t)^{(\gamma-1)} \left(\int_0^{A_L(t)} \lambda^{\gamma k_L(j_L,t)} \cdot x_L(n,j_L,t)^{\gamma} dj_L\right)^{(\phi-1)} \\ p_H(j_H,t) &= P(n,t)\left(nhH(n)\right)^{(1-\alpha)} \alpha\lambda^{\gamma k_H(j_H,t)} x_H(n,j_H,t)^{(\gamma-1)} \left(\int_0^{A_H(t)} \lambda^{\gamma k_H(j_H,t)} \cdot x_H(n,j_H,t)^{\gamma} dj_H\right)^{(\phi-1)} \end{aligned} \tag{5.4}$$

Solving expressions (5.4) for $\int_0^{A_L(t)} \lambda^{\gamma k_L(j_L,t)} \cdot x_L(n,j_L,t)^{\gamma} dj_L$ and $\int_0^{A_H(t)} \lambda^{\gamma k_H(j_H,t)} \cdot x_H(n,j_H,t)^{\gamma} dj_H$ respectively, and substituting in equation (5.2), the economy's aggregate output can be re-written as:

$$Y(n,t) = \left(\frac{\alpha P(n,t)}{p_m(j_m,t)}\right)^{\frac{\alpha}{1-\alpha}} \cdot \left[(1-n)lL(n) \cdot Q_L(t)^{(\varepsilon+1)} + nhH(n) \cdot Q_H(t)^{(\varepsilon+1)}\right] \tag{5.5}$$

where, as we will further show, $p_L(j_L,t)$ and $p_H(j_H,t)$ are equal,[3] thus allowing us to place it in front of the brackets; the term $\varepsilon \equiv \frac{\phi-1}{1-\alpha}$ in (5.5) is a positive constant reflecting the effect of complementarity degree between intermediate goods on final goods production; and $Q_H(t)$ and $Q_L(t)$ are aggregate quality indexes denoting the

[3]This results from the intermediate-good firms profit maximization problem.

technological-knowledge stock accumulated in t for the H- and L-technology group respectively, being defined by:

$$Q_m(t) \equiv \int_0^{A_m(t)} \left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}} dj_m,\ m = L, H \tag{5.6}$$

5.2.3 Intermediate-Goods Sector and Internal Costly Investment

The intermediate-goods sector fosters the production of specialized intermediate goods and the R&D activity, horizontal and vertical, meaning that intermediate-good firms both produce intermediate goods to supply the final-goods sector and decide on the amount of R&D investments. Operating under monopolistic competition, intermediate-good firms use both physical and R&D capital in their productive activity. That is, the production of intermediate goods requires the use of physical machines corresponding to each type of intermediate goods previously invented through R&D (with one of the same technologies available for the production of final and intermediate goods, *i.e.* H- or L-technology).

Assuming that producing one unit of any intermediate good j takes one unit of physical capital, we define the physical capital stock as the total amount of various types of intermediate goods produced in the economy, $K(t) = K_L(t) + K_H(t)$, with $K_L(t) = \int_0^{A_L(t)} X_L(j_L,t)dj_L$ and $K_H(t) = \int_0^{A_H(t)} X_H(j_H,t)dj_H$, where $X_L(j_L,t) = \int_0^{\bar{n}} x_L(n,j_L,t)dn$ and $X_H(j_H,t) = \int_{\bar{n}}^1 x_H(n,j_H,t)dn$ denote the demand faced by intermediate-good producers (obtained from the expressions (5.4)). Total investment, $\dot{Z}(t)$, in each period t, is given by the sum of investment in physical capital, $\dot{K}(t)$, and investment in vertical, $R_{v,m}(t)$, and horizontal, $R_{h,m}(t)$, R&D:

$$\dot{Z}(t) = \dot{K}(t) + R_{h,L}(t) + R_{h,H}(t) + R_{v,L}(t) + R_{v,H}(t)$$

Following Thompson (2008) we consider that investments (both in physical and R&D capital) involve an internal cost associated to the installation of new capital. Assuming zero capital depreciation, we specify that installing $I(t) = \dot{Z}(t)$ new units of total capital requires spending an amount given by $J(t) = I(t) + \frac{1}{2}\theta\frac{I(t)^2}{Z(t)}$, where $Z(t)$ is the total capital stock at t, $\frac{1}{2}\theta\frac{I(t)^2}{Z(t)}$ represents the Hayashi's (1982) internal installation cost, and θ denotes the adjustment cost parameter.

In every period t, firms choose their investment rate so as to maximize the present discounted value of cash flows, and the current-value Hamiltonian for our optimal control problem is:

$$H(t) = Y(t) - I(t) - \frac{1}{2}\theta\frac{I(t)^2}{Z(t)} + q(t)\left[I(t) - \dot{Z}(t)\right]$$

where $q(t)$ is the market value of capital. As we show later on, the output growth rate, $g \equiv g_Y$, is equal to the investment rate, that is $g = g_Z = \frac{I(t)}{Z(t)}$. Then, from the FOC for an optimum we have:

$$q(t) = 1 + \theta g \tag{5.7}$$

and the transversality condition $\lim_{t\to\infty} \exp(-rt)q(t)Z(t) = 0$.

Expression (5.7) defines the market value of capital, $q(t)$, in a BGP.

In each period t, an intermediate-good firm must decide on the optimal price and production quantity of intermediate good to supply to the final-good producers. Thus, in each t, a monopolistic H- or L-technology intermediate-good producer maximizes its profits taking as given the previously derived inverse demand curves (5.4) for its good:

$$\max_{X_m(j_m,t)} \pi_m(j_m,t) = p_m(j_m,t) \cdot X_m(j_m,t) - rq \cdot X_m(j_m,t), \ m = L, H,$$

where rq (the interest rate times the market value of capital) denotes the production cost of one unit of intermediate good j to supply to the final-good firm n.

As previously mentioned, the FOCs yield $p_L(j_L,t) = p_H(j_H,t) = p$, which leads to the mark-up rule:

$$p = \frac{rq}{\gamma} \tag{5.8}$$

Equation (5.8) implies that the price charged by intermediate-good producers for their differentiated goods is equal for all j and *H(L)*-technology sectors, *i.e.*, it is *sector-invariant*. Moreover, in a BGP when $r(t)$ and $q(t)$ are constant, the mark-up $p = \frac{rq}{\gamma}$ (where γ is a parameter) is both *sector-* and *time-invariant*.

Next, using expressions (5.4) and (5.8), recalling that in any moment in time we have $L = \int_0^{\overline{n}} L(n)dn$ and $H = \int_{\overline{n}}^1 H(n)dn$, and normalizing prices such that:

$$P_L(t)^{\frac{1}{1-\alpha}} \equiv P(n,t)^{\frac{1}{1-\alpha}}(1-n), \quad P_H(t)^{\frac{1}{1-\alpha}} \equiv P(n,t)^{\frac{1}{1-\alpha}} n \ , \tag{5.9}$$

we derive the total quantity that each *H(L)*-technology intermediate-good firm produces and sells, accounting for the threshold final good $\overline{n}$, and resulting profits:

$$X_m(j_m,t) = M\left(\frac{\alpha P_m(t)}{p}\right)^{\frac{1}{1-\alpha}} \left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}} Q_m(t)^{\varepsilon} \tag{5.10}$$

$$\pi_m(t) = \pi_0 M P_m(t)^{\frac{1}{1-\alpha}} \left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}} Q_m(t)^{\varepsilon} \tag{5.11}$$

with $m = L$, H and $M = lL$, hH, and where $\pi_0 \equiv (1-\gamma)\left(\frac{rq}{\gamma}\right)^{-\frac{\alpha}{1-\alpha}} \alpha^{\frac{1}{1-\alpha}}$.

We can now proceed to the economy's R&D sector, where we derive the free-entry and dynamic arbitrage conditions for horizontal and vertical R&D.

5.2.4 R&D Sector

We assume that intermediate-goods sector firms can choose between investing into either vertical or horizontal R&D. By devoting their resources to vertical R&D, intermediate-good firms target qualitative improvements of already existing intermediate-product lines, while in case of horizontal R&D they aim at variety expansion, *i.e.* creating a new product line. We also assume that, contrarily to vertical R&D, when the improved intermediate good will possess the highest quality in the given industry j, in case of horizontal R&D the newly-created product line will be characterized by the *average* quality level in the targeted intermediate-goods industry. We proceed by describing each R&D dimension's key features, and then derive the vertical and horizontal innovation arbitrage conditions, as well as the consistency and the inter-technology arbitrage conditions.

5.2.4.1 Vertical R&D free-entry and dynamic arbitrage conditions

In devoting resources to vertical R&D, each potential entrant seeks to improve the quality of an existent intermediate good. As in standard quality-ladders models, the R&D technology used for developing new designs is common for all intermediate-good firms, there is free entry into vertical R&D, and the innovation arrival rate follows a Poisson process. Each newly developed design is protected by a patent which grants the successful innovator exclusive rights over the use of improved quality. Since vertical R&D is a standard creative destruction process, this Schumpeterian monopoly is temporary. However, temporary exclusive rights over the top-quality intermediate good confer the successful innovator higher profits for the duration of the patent, thus motivating investment in vertical R&D. On its turn, the duration of the patent is determined by the instantaneous vertical-R&D arrival rate, which we denote by $I_m^i(k_m)$ – vertical innovation rate at time t, by firm i, in the intermediate-good industry j_m, when the top quality is at $k_m(j_m, t)$ level. Aggregated across firms in j_m, the instantaneous arrival rate of a new quality improvement is given by:

$$I_m(k_m) = R_{v,m}(k_m) \cdot \frac{1}{\varsigma} \cdot \left(\lambda^{-(k_m+1)}\right)^{\frac{\gamma}{1-\gamma}} \cdot Q_m^{-\varepsilon} \tag{5.12}$$

where $R_{v,m}(k_m)$ denotes resources devoted to vertical R&D in j_m; ς is a constant fixed vertical-R&D cost, assumed equal for both production technologies; and the term $\left(\lambda^{-(k_m+1)}\right)^{\frac{\gamma}{1-\gamma}} \cdot Q_m^{-\varepsilon}$ accounts for the adverse effect resulting from the increasing complexity of quality improvements, implying that research becomes progressively more difficult with each new vertical innovation.[4]

The expected present value of an intermediate-good firm's profits from developing the $k_m + 1$ quality level depends on the expected monopoly profits, given by (5.11), the market real interest rate, $r(t)$, and the duration of the monopoly position determined by the instantaneous arrival rate, $I_m(k_m)$:

$$V_m(k_m+1) = \pi_0 M \left(\lambda^{(k_m+1)}\right)^{\frac{\gamma}{1-\gamma}} \int_t^{\infty} P_m(s)^{\frac{1}{1-\alpha}} \cdot Q_m(s)^{\epsilon} \cdot e^{-\int_t^s [r(v)+I_m(k_m(v))]dv} ds. \tag{5.13}$$

Assuming free-entry into vertical R&D, the dynamic zero-profit condition is:

[4] The assumption of complementarity between intermediate goods further adds to the progressive complexity of new quality improvements, captured by the term $Q_m^{-\varepsilon}$. Note that our complementarity specification implies that incentives for discovering new goods would grow rapidly over time (more complements raise the values of new intermediate goods), thus leading to explosive growth. Therefore, as in Evans *et al.* (1998), $\varepsilon \equiv \frac{\phi-1}{1-\alpha}$ reflects the offsetting effect induced by a higher cost for designing intermediate goods with a higher index, implying that the values for r and g are constant over time, and allowing us to solve the model for a BGP equilibrium.

$$I_m(k_m) \cdot V_m(k_m+1) = R_{v,m}(k_m) \tag{5.14}$$

To derive the vertical R&D arbitrage condition we time-differentiate expression (5.14) with $V_m(k_m+1)$ given by (5.13), bearing in mind Leibnitz's rule, which yields:

$$r(t) + I_m(t) = (1-\gamma)\frac{1}{\varsigma}M\left(\frac{rq}{\gamma}\right)^{-\frac{\alpha}{1-\alpha}}(\alpha P_m(t))^{\frac{1}{1-\alpha}} + \varepsilon\frac{\dot{Q}_m(t)}{Q_m(t)}, \tag{5.15}$$

where the rates of entry are symmetric across industries $I_m(t) = I_m(k_m(j_m,t))$. Expression (5.15) represents the vertical R&D arbitrage condition, from which the optimal vertical innovation rate can be derived.

After solving equation (5.12) for $R_{v,m}(j_m,t) = R_{v,m}(k_m)$ and aggregating across industries j_m, we determine optimal total resources devoted to vertical R&D, $R_{v,m}(t) = \int_0^{A_m(t)} R_{v,m}(j_m,t)\, dj_m$. As the innovation rate is industry independent, then:

$$R_{v,m}(t) = \zeta \cdot \lambda^{\frac{\gamma}{1-\gamma}} \cdot I_m(t) \cdot Q_m(t)^{(\epsilon+1)}. \tag{5.16}$$

5.2.4.2 Horizontal R&D free-entry and dynamic arbitrage conditions

We derive the horizontal R&D free-entry and dynamic arbitrage condition following the same reasoning as in the vertical R&D case. However, as we emphasized in the beginning of this section, contrarily to the vertical R&D case, where each new successful innovation increases the quality of an existent good by $\lambda^{\frac{\gamma}{1-\gamma}}$, a successful horizontal innovation, *i.e.* the newly created intermediate-good line, will possess the *average* quality level of already existing varieties in the m-complementary intermediate-goods sector. Therefore, before we proceed to the derivation of the horizontal R&D arbitrage condition, we need to define the *average industry quality index* and specify the variety expansion cost function.

So far, in our model, we have been working with the m-complementary intermediate-goods sector aggregate quality index, $Q_m(t)$, defined by (5.6). However, recalling that we have $A_m(t)$ m-complementary intermediate-goods sector industries, we can alternatively consider an *average* industry quality index, which may be defined as follows:

$$\overline{z}(t) \equiv \int_0^{A_m(t)} \frac{\left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}}}{A_m(t)} dj_m \equiv \frac{Q_m(t)}{A_m(t)}$$

The average industry quality level, $\overline{z}(t)$, will be considered in the derivation of the free-entry (profits and expected value respectively) and arbitrage conditions for horizontal R&D.

The production function of new varieties of intermediate goods by firm f, exhibiting constant returns to scale at firm level and involving a horizontal innovation cost symmetric across all firms, is of the form:

$$\dot{A}_m^f(t) = \frac{1}{\eta_m(t)} R_{h,m}^f(t)$$

where $\dot{A}_m^f(t)$ denotes the contribution of an individual firm to the total of new intermediate-good varieties that are being created at time t; $R_{h,m}^f$ denotes the resources an intermediate-good firm devotes to creating new product lines, and $\eta_m(t)$ may be interpreted as the horizontal R&D entry cost (in units of final good). Then, aggregating across firms, total resources devoted to horizontal R&D are given by:

$$R_{h,m}(t) = \eta_m(t)\dot{A}_m(t) \tag{5.17}$$

Following Barro and Sala-i-Martin (2004, Ch.4), let the horizontal R&D entry cost, $\eta_m(t)$, be given by $\eta_m(t) = \beta_1 A_m(t)^{\beta_2}$, where $\beta_1 > 0$ and $\beta_2 > 0$ are the fixed-flow cost and elasticity (can be also interpreted as an entry barrier index) parameters respectively. Taking into account the average quality index defined above and following a similar line of reasoning as in the vertical R&D case, the expected present value from investing in variety expansion, $V_m(\overline{z})$, is given by:

$$V_m(\overline{z}) = \pi_0 M \cdot \overline{z}(t) \int_t^{\infty} P_m(s)^{\frac{1}{1-\alpha}} \cdot Q_m(s)^{\epsilon} \cdot e^{-\int_t^s [r(v) - I(\overline{z}(v))]dv} ds$$

Then, analogously to the vertical R&D case, the free-entry condition for horizontal R&D is $\dot{A}_m(t) \cdot V_m(\overline{z}) = \eta_m(t)\dot{A}_m(t)$, which by (5.17) implies $V_m(\overline{z}) = \eta_m(t)$. Time-differentiating the latter yields the horizontal R&D arbitrage condition:

$$r(t) + I(t) = \frac{\bar{\pi}_m(t)}{\eta_m(t)} \tag{5.18}$$

where $\bar{\pi}_m(t) = \pi_0 M P_m(t)^{\frac{1}{1-\alpha}} \bar{z}(t) Q_m(t)^{\varepsilon}$.

5.2.4.3 Consistency and inter-technology arbitrage conditions

Using the above derived vertical and horizontal R&D arbitrage conditions given by equations (5.15) and (5.18) respectively, we can now derive the *consistency* arbitrage condition, by equating the effective rate of return, $r(t)+I(t)$, for both R&D dimensions for $m = L$, H in every t. The consistency arbitrage condition reflects the idea that, in equilibrium, the competitive capital market is equally willing to finance R&D in either variety expansion or quality improvement. Thus, using equations (5.15) and (5.18) and recalling the above expressions for $\bar{\pi}_m(t)$, $\overline{z}(t) \equiv \frac{Q_m(t)}{A_m(t)}$, $\eta_m(t)$ and π_0, the consistency arbitrage condition is:

$$\frac{Q_m(t)^{(\varepsilon+1)}}{\eta_m(t) \cdot A_m(t)} = \frac{1}{\varsigma} + \varepsilon \frac{\dot{Q}_m(t)}{Q_m(t) \cdot \pi_0 M \cdot P_m(t)^{\frac{1}{1-\alpha}}} \tag{5.19}$$

For the case of vertical R&D we can also derive an *inter-technology* arbitrage condition, defining a situation of indifference between innovating in L- or H-technology intermediate-goods sector. We do that by simply equating the effective rate of return for each $m = L$, H in (5.15), which yields:

$$I_H(t) - I_L(t) = \frac{\pi_0}{\varsigma} \left(hHP_H(t)^{\frac{1}{1-\alpha}} - lLP_L(t)^{\frac{1}{1-\alpha}} \right) + \varepsilon \left(\frac{\dot{Q}_H(t)}{Q_H(t)} - \frac{\dot{Q}_L(t)}{Q_L(t)} \right) \tag{5.20}$$

5.3 General equilibrium

In this section we derive the general equilibrium and characterize the interior BGP. We specifically discuss the steady-state values for the economy's equilibrium growth rates, technological-knowledge bias, threshold final good, skill premium and final-good prices.

In a BGP equilibrium we must have that aggregate macroeconomic variables – output, consumption, intermediate goods and resources spent on R&D – all grow at a constant rate: $g_Y = g_C = g_X = g_R = g$. Similarly, in a BGP, aggregate quality indices for both m-type technologies grow at the same constant rate, *i.e.* $g_{Q_L} = g_{Q_H}$.

Consequently, in equilibrium we have:

(i) a constant interest rate, which implies a constant equilibrium rate of successful vertical R&D for both m-type technologies;

(ii) a constant technological-knowledge bias, $\frac{Q_H}{Q_L}$, which on its turn implies constant levels for the threshold final good, $\overline{n}$, final-good prices, P_L and P_H, and skill premium, $W = \frac{W_H}{W_L}$;

(iii) a steady-state linear relationship between aggregate output and aggregate quality index growth rates, and between vertical and horizontal R&D growth rates.

Let us start by deriving the equilibrium values (for a given technological-knowledge bias) for the threshold final good, $\overline{n}$, final-good prices, P_H and P_L, and wages paid to skilled and unskilled labour, W_H and W_L.

Given that the existence of an endogenous threshold reflects the idea that the production of final goods $n \in [0, \overline{n}]$ is more efficient using L-technology, and of final goods $n \in [\overline{n}, 1]$ is more efficient using H-technology, we can rewrite expression (5.5) as:

$$Y(n,t) = \begin{cases} \left(\frac{\alpha P(n,t)}{p}\right)^{\frac{\alpha}{1-\alpha}} (1-n) l L(n) Q_L(t)^{(\varepsilon+1)}, \; for \; n \in [0, \overline{n}] \\ \left(\frac{\alpha P(n,t)}{p}\right)^{\frac{\alpha}{1-\alpha}} n h H(n) Q_H(t)^{(\varepsilon+1)}, \; for \; n \in [\overline{n}, 1] \end{cases} \tag{5.21}$$

By perfect competition assumption, it must be true that for $\overline{n}$ the L- and the H- technology firms must break even. Then, using expression (5.21), rewriting price normalization (5.9), and normalizing labour such that $L(n) = \frac{L}{\overline{n}}$, $H(n) = \frac{H}{1-\overline{n}}$, we can derive the endogenous final-good price ratio as a function of $\overline{n}$, and an endogenous relationship between final-good price ratio, $\frac{P_H}{P_L}$, technological-knowledge bias, $\frac{Q_H}{Q_L}$, and threshold final good, $\overline{n}$:

$$\left(\frac{P_H}{P_L}\right)^{\frac{1}{1-\alpha}} = \frac{\overline{n}}{1-\overline{n}} \tag{5.22}$$

$$\frac{1-\overline{n}}{\overline{n}} = \left(\frac{P_H}{P_L}\right)^{\frac{1}{1-\alpha}} \frac{hH}{lL} \left(\frac{Q_H(t)}{Q_L(t)}\right)^{(\varepsilon+1)} \tag{5.23}$$

Expression (5.22) reflects the idea that in the production of the final good $n = \overline{n}$, in each t both a firm that uses L-technology and a firm that uses H-technology should break even. Combining expressions (5.22) and (5.23), we can endogenously derive the threshold final good $\overline{n}$:

$$\overline{n} = \left[1 + \left(\frac{hH}{lL} \cdot \left(\frac{Q_H(t)}{Q_L(t)}\right)^{(\varepsilon+1)}\right)^{\frac{1}{2}}\right]^{-1} \tag{5.24}$$

In order to obtain the final-good prices, P_L and P_H, we use our expression (5.3) for normalized (following Acemoglu and Zilibotti, 2001) aggregate output, which, combined with price normalization (5.9) and equations (5.22) and (5.24), after some algebra yields:

$$\begin{gathered} P_H = \exp(-(1-\alpha)) \cdot (1-\overline{n})^{-(1-\alpha)} \\ P_L = \exp(-(1-\alpha)) \cdot \overline{n}^{-(1-\alpha)} \end{gathered} \tag{5.25}$$

Finally, assuming that the wage *per* unit of m-type labour equals its marginal product, we use the production function (5.21) aggregated across n (keeping in mind that $\int_0^{\overline{n}(t)} L(n)dn = L$ and $\int_{\overline{n}(t)}^1 H(n)dn = H$ hold at any moment t) to derive the skilled and unskilled labour wages:

$$Y(t) = Y_L(t) + Y_H(t), \text{ where } \begin{cases} Y_H(t) = \left(\frac{\alpha}{p}\right)^{\frac{\alpha}{1-\alpha}} hHP_H^{\frac{1}{1-\alpha}} Q_H(t)^{(\varepsilon+1)} \\ Y_L(t) = \left(\frac{\alpha}{p}\right)^{\frac{\alpha}{1-\alpha}} lLP_L^{\frac{1}{1-\alpha}} Q_L(t)^{(\varepsilon+1)} \end{cases} \tag{5.26}$$

$$\begin{gathered} W_H = \frac{\partial Y_H}{\partial H} = \left(\frac{\alpha}{R}\right)^{\frac{\alpha}{1-\alpha}} hP_H^{\frac{1}{1-\alpha}} Q_H(t)^{(\varepsilon+1)} \\ W_L = \frac{\partial Y_L}{\partial L} = \left(\frac{\alpha}{R}\right)^{\frac{\alpha}{1-\alpha}} lP_L^{\frac{1}{1-\alpha}} Q_L(t)^{(\varepsilon+1)} \end{gathered} \tag{5.27}$$

The skill premium, W, our wage inequality measure, is then given by the ratio of skilled to unskilled labour wages from (5.27):

$$W = \frac{W_H}{W_L} = \frac{h}{l}\left(\frac{P_H}{P_L}\right)^{\frac{1}{1-\alpha}}\left(\frac{Q_H(t)}{Q_L(t)}\right)^{(\varepsilon+1)} \tag{5.28}$$

where $\varepsilon + 1 = \frac{\phi-\alpha}{1-\alpha}$.

Also, using expressions (5.3), (5.21) and (5.24), we can define equilibrium aggregate output (as a function of aggregate technological-knowledge indices) as:

$$Y(t) = \exp^{-1}\left(\frac{\alpha\gamma}{rq}\right)^{\frac{\alpha}{1-\alpha}}\left[\left(lLQ_L(t)^{(\varepsilon+1)}\right)^{\frac{1}{2}} + \left(hHQ_H(t)^{(\varepsilon+1)}\right)^{\frac{1}{2}}\right]^2 \tag{5.29}$$

We have derived the equilibrium values for final-good prices as functions of the threshold final good, which on its turn was derived as a function of the endogenous technological-knowledge bias, while equilibrium skill premium is a function of both price ratio and technological-knowledge bias.

To complete our derivation of the steady-state equilibrium, we now turn to deriving the steady-state technological-knowledge bias, $\left(\frac{Q_H}{Q_L}\right)^*$, which will allow us to fully specify the equilibrium threshold final good, $\overline{n}^*$, final-good prices, P_L^* and P_H^*, and skill premium, W^*.

5.3.1 Equilibrium technological-knowledge bias, $\left(\frac{Q_H}{Q_L}\right)^*$

Recalling our inter-technology arbitrage condition (5.20) and keeping in mind that in steady state we must have $g_{Q_L} = g_{Q_H}$ and $I_L = I_H$, we can derive the equilibrium price ratio as a function of labour endowments and absolute productivity parameters:

$$\left(\frac{P_H}{P_L}\right)^{\frac{1}{1-\alpha}} = \left(\frac{lL}{hH}\right) \tag{5.30}$$

Combining this with expressions (5.22) and (5.24), after some algebra we obtain:

$$\left(\frac{Q_H}{Q_L}\right)^* = \left(\frac{hH}{lL}\right)^{\frac{1-\alpha}{\phi-\alpha}} \tag{5.31}$$

Expression (5.31) defines the equilibrium technological-knowledge bias $\left(\frac{Q_H}{Q_L}\right)^*$ in particular as a function of the relative labour endowment, $\frac{H}{L}$. This is a common result in the *SBTC* literature, reflecting the endogeneity of the *skill*-bias of newly adopted technologies. In fact, recalling expression (5.15) we can see that labour endowments influence the direction of technological-knowledge development through two channels. On the one hand, the market-size channel, acting through $H(L)$, increases the probability of *H(L)*-technology R&D, since an increase in the labour supply broadens the market for the respective technology type. On the other hand, the price channel, acting through P_m, reduces the probability of *H(L)*-technology R&D, given that the structure of labour endowments favours developing technologies that save the relatively scarce type of labour, since the prices for the final goods that they produce will be higher. Expression (5.31) shows that the market-size effect dominates the price-channel effect, since technological-knowledge bias is increasing in the relative skilled-labour supply. Acemoglu (2009, Ch. 15) refers to this result as a *weak equilibrium (relative) bias*, implying that an increase in the relative supply of a factor – in our case the relative supply of H – always induces technological-knowledge change that is biased in favour of this factor. Additionally, as expression (5.31) shows, in equilibrium $\left(\frac{Q_H}{Q_L}\right)^*$ is directly affected by the complementarity degree, ϕ. This result will be analyzed in more detail in our discussion on steady-state effects.

Using equation (5.31) we can now complete the derivation of equilibrium threshold final good, final-good prices and skill premium, previously calculated for a given technological-knowledge bias.

5.3.2 Steady-state equilibrium threshold final good, final-good prices, and skill premium

The steady-state equilibrium value for the threshold final good $\overline{n}$ is derived by substituting (5.31) in (5.24), which gives us:

$$\overline{n}^* = \left[1 + \left(\frac{hH}{lL}\right)\right]^{-1} \tag{5.32}$$

From expression (5.32), the equilibrium threshold final good, $\overline{n}$, is decreasing in the relative labour endowment, and consequently it is decreasing in the technological-knowledge bias. Once again, this result is consistent with the *SBTC* literature. Namely, when technological knowledge is skill-biased (there is a large relative supply of H), the fraction of industries using H-technology is large and so $\overline{n}$ is small.

Next, we can complete the derivation of the equilibrium final-good prices, P_L and P_H, by substituting (5.32) in equations (5.25), which yields:

$$\begin{aligned} P_H^* &= \exp^{(\alpha-1)} \cdot \left[1 + \left(\tfrac{lL}{hH}\right)\right]^{-(\alpha-1)} \\ P_L^* &= \exp^{(\alpha-1)} \cdot \left[1 + \left(\tfrac{hH}{lL}\right)\right]^{-(\alpha-1)} \end{aligned} \tag{5.33}$$

Here again, the result we obtain regarding prices is consistent with the *SBTC* literature – when technological knowledge is skill-biased, $\overline{n}^*$ is small and equations (5.33) verify the relation $P_L^* > P_H^*$. As we have previously mentioned, this is what the price-channel effect supposes.

Using equation (5.30) in (5.28), our expression for skill premium becomes:

$$W = \frac{L}{H}\left(\frac{Q_H(t)}{Q_L(t)}\right)^{(\varepsilon+1)} \tag{5.34}$$

Expression (5.34) illustrates the two mechanisms through which changes in relative labour endowments influence the skill premium in equilibrium. Initially, an increase in the supply of the H factor reduces the skill premium, which is consistent with the basic producer theory, *i.e.* increasing supply reduces prices. This immediate effect is followed by a change in the opposite direction induced through the technological-knowledge bias (as mentioned above, technological-knowledge bias increases as a result of a higher supply of H, because the market-size effect dominates the price-channel effect). If the technological-knowledge bias effect on W outweighs the initial supply effect, then, as is the case in most $SBTC$ models, a positive cumulative effect on W is verified. Acemoglu (2009, Ch.15) refers to this result as the *strong equilibrium (relative) bias*, implying that a greater relative supply of a factor causes sufficiently strong technological-knowledge change as to make the resulting relative price of this (more abundant) factor increase. In equilibrium however, this result does not verify in our model. In particular, substituting the above derived expressions (5.31) in (5.34) we get:

$$W^* = \frac{L}{H}\left(\frac{hH}{lL}\right) = \frac{h}{l} \tag{5.35}$$

Thus, our steady-state skill premium, W^*, does not depend on relative labour endowments, $\frac{H}{L}$, because the two above referred mechanisms exactly offset each other. Following Acemoglu (2009, Ch.15), we attribute this result to the effect of elasticity of substitution between technologies in the production function. More specifically, in the absence of state dependence, an elasticity of substitution higher than 2 is required to ensure an overall positive effect on W.[5] Recalling our expression (5.29), we can see that

[5] State dependence implies that, to achieve sustained growth, factors allocated to R&D need to become more and more productive over time, because of spillovers from past research (the path of

this condition is not verified in our case, since our aggregate output is characterized by constant elasticity of substitution between H- and L- technologies equal to 2. Although appearing in line with the existing empirical evidence (as referred by Acemoglu (2009, Ch.15), in the context of substitution between skilled and unskilled workers an elasticity of substitution close to 2 is most probable), this specific feature of our aggregate output function implies that the market-size effect can not create sufficiently powerful technological-knowledge change as to induce an increase in the relative marginal product, and thus in the relative price, of the factor that has become more abundant. Consequently, the *strong equilibrium (relative) bias* is not verified in our case.

As expression (5.35) shows, in our case the steady-state skill premium is determined solely by the productivity advantage ratio of skilled to unskilled labour, $\frac{h}{l}$. Although the role of $\frac{h}{l}$ is fairly intuitive, since workers' productivity has a direct positive impact on wages and consequently on the skill premium, the result that it is the only determinant of equilibrium skill premium deserves a more thorough investigation.

5.3.3 Equilibrium growth rate

Here, we derive the BGP growth rates for aggregate output and vertical and horizontal R&D. The equilibrium growth rate of aggregate output can be derived log-differentiating expression (5.26) for each m-technology, which gives us:

$$g = (1 + \varepsilon) g_{Q_m} \tag{5.36}$$

Also, from our consistency arbitrage condition (5.19), a balanced-path relationship

past innovations affects the relative costs of different types of innovations). According to Acemoglu (2009, Ch.15), an elasticity of substitution greater than 2 is not always crucial for obtaining the strong equilibrium (relative) bias. Provided a directed technological change model with knowledge spillovers and state dependence, the result of upward-sloping relative demand curves requires that the elasticity of substitution be higher than a certain threshold (determined by the state dependece parameter).

between vertical and horizontal R&D growth rates can be defined, keeping in mind that in a BGP the right-hand side of expression (5.19) is constant. Log-differentiating equation (5.19) yields: $g_{A_m} = \frac{(1+\varepsilon)}{(1+\beta_2)} g_{Q_m}$, implying that variety expansion is sustained by endogenous technological-knowledge accumulation. In particular, expected higher profits from increased intermediate-good quality generated by vertical R&D make it attractive for intermediate-good firms to invest in variety expansion, despite the negative spillovers in horizontal entry (entry cost increases with the number of newly created product lines). Thus, regarding our view that economic growth proceeds both along an intensive and an extensive margin, the derived balanced-path relationship between vertical and horizontal R&D growth rates together with equation (5.36), imply that vertical innovation drives economic growth, in the sense that it sustains both variety expansion and aggregate output growth.

Next, using expressions (5.6), assuming $Q_m(t)$ deterministic and recalling the above defined average industry quality level, we can also define the aggregate quality index growth rate as: $g_{Q_m} = I_m(\lambda^{\frac{\gamma}{1-\gamma}} - 1) + g_{A_m}$, which is positive if $I_m > 0$ (with I_m derived from (5.15)). Then, using the above defined relations we can now complete the derivation of the economy's equilibrium aggregate quality index, g_{Q_m}, and output growth rates, g. In particular, keeping in mind that both r and q are functions of g,[6] we obtain the following implicit expressions for the optimal growth rates g_{Q_m} and g:

$$g_{Q_m} = \psi \left(\lambda^{\frac{\gamma}{1-\gamma}} - 1\right) \left(\frac{(1-\gamma)}{\varsigma} M \left(\frac{rq}{\gamma}\right)^{-\frac{\alpha}{1-\alpha}} (\alpha P_m)^{\frac{1}{1-\alpha}} - r \right) \tag{5.37}$$

$$g = (1+\varepsilon)\, \psi \left(\lambda^{\frac{\gamma}{1-\gamma}} - 1\right) \left(\frac{(1-\gamma)}{\varsigma} M \left(\frac{rq}{\gamma}\right)^{-\frac{\alpha}{1-\alpha}} (\alpha P_m)^{\frac{1}{1-\alpha}} - r \right) \tag{5.38}$$

where $\psi \equiv \frac{\beta_2+1}{\beta_2 - \varepsilon - \varepsilon(\beta_2+1)(\lambda^{\frac{\gamma}{1-\gamma}} - 1)}$, and both r and q are functions of g: $r = g\sigma + \rho$ and $q = 1 + \theta g$.

[6] Recalling our consumption and investment optimization problems for the equilibrium interest rate and market capital values as functions of equilibrium growth rate, given by (5.1) and (5.7) respectively.

Regarding equations (5.37) and (5.38), it is important to emphasize the following. Given that, apart from the production of intermediate goods further supplied to the final-good firms, intermediate-good producers also decide on the amount of R&D expenditures, if equation (5.37) verified $g_{Q_m} < 0$, intermediate-good firms would have no incentives to invest in vertical R&D. Consequently, there would be no quality improvements of intermediate goods over time, *i.e.* g_{Q_m} would be zero, which by equation (5.36) would lead to $g = 0$. Therefore, equations (5.37) and (5.38) are assumed to verify $g_{Q_m} \geq 0$ and (by consequence) $g \geq 0$ respectively.[7]

Following from the above discussion on the equilibrium growth rate and recalling equations (5.19), (5.16) and (5.17), we can see that in BGP Y_m, $R_{v,m}$ and $R_{h,m}$ all grow with $Q_m^{\epsilon+1}$. Then, from the aggregate resource constraint, $Y = C + \dot{K}_L + \dot{K}_H + R_{v,L} + R_{v,H} + R_{h,L} + R_{h,H}$, it can be shown that in BGP C and $\dot{K}_m$ also grow with $Q_m^{\epsilon+1}$. Thus, the physical and R&D capital stocks that result from $\dot{K}_m$, $R_{v,m}$ and $R_{h,m}$ must also grow with $Q_m^{\epsilon+1}$, and hence the total capital stock Z, which is a linear combination of physical and R&D capital. It follows from here that $g_Z = g_Y$, as considered in our derivations in Subsection 2.3 above.

5.3.4 Industrial structure

In this section we derive two measures of industrial structure, differentiating between the relative number of intermediate-good firms (aggregate variety index ratio) and the quality-adjusted relative production.

Recalling that, in alternative to vertical R&D, intermediate-good firms can also invest in horizontal R&D, *i.e.* creation of new product lines in each m-type sector,

[7] As regards the vertical R&D optimal growth rate, it is easy to see that replacing in equation (5.37) M and P_m for each m-type technology (with P_m given by equation (5.33)), in steady state aggregate quality indices for both m-type technologies grow at the same constant rate, *i.e.* $g_{Q_L} = g_{Q_H}$.

we associate the latter to industrial structure and correspondingly define it by the aggregate variety index ratio, $\frac{A_H}{A_L}$, and the quality-adjusted relative production, $\frac{\tilde{X_H}}{X_L}$.[8]

The aggregate variety index ratio can be endogenously derived from the consistency arbitrage condition (5.19) and accounting for our horizontal R&D cost function specification:

$$\left(\frac{A_H}{A_L}\right) = \left(\frac{Q_H}{Q_L}\right)^{\frac{\varepsilon+1}{(\beta_2+1)}} \left(\frac{\varsigma^{-1} + \varepsilon g_{Q_H} \left(\pi^0 hH\right)^{-1} P_H^{-\frac{1}{1-\alpha}}}{\varsigma^{-1} + \varepsilon g_{Q_L} \left(\pi^0 lL\right)^{-1} P_L^{-\frac{1}{1-\alpha}}}\right)^{-\frac{1}{(\beta_2+1)}} \tag{5.39}$$

Recalling the derived expression for steady-state final-good prices, and the fact that in steady state aggregate quality indexes for both m-type technologies grow at the same constant rate, the component with exponent $-\frac{1}{(\beta_2+1)}$ becomes equal to 1. Thus, the aggregate variety index ratio is determined by the technological-knowledge bias, adjusted by the elasticity parameter β_2 from the horizontal R&D cost function. Then, taking into account equation (5.31), the above derived expression for the steady-state aggregate variety index ratio becomes:

$$\left(\frac{A_H}{A_L}\right)^* = \left(\frac{hH}{lL}\right)^{\frac{1}{(\beta_2+1)}} \tag{5.40}$$

Next, aggregating expression (5.10) and using (5.31), we can define the equilibrium relative production:

$$\left(\frac{X_H}{X_L}\right)^* = \frac{hH}{lL} \tag{5.41}$$

However, since the empirical motivation we refer regarding the industrial structure uses production data presented on a quality-adjusted basis,[9] we find it useful to also compute the equilibrium relative production, $\frac{X_H}{X_L}$, in quality-adjusted terms. For this,

[8] Note that in the sense that the endogenous threshold final good, $\overline{n}$, determines when the switch from one technology to another becomes advantageous, it can be also regarded as an alternative measure of final goods production structure.

[9] See, for example, Eurostat, 2001)

following Gil *et al.* (2012), we define the proxy $\widetilde{X}_m \equiv X_m \cdot (Q_m/A_m)^{\frac{1-\gamma}{\gamma}}$ for X_m, which, bearing in mind expressions (5.31), (5.40) and (5.41), allows us to derive the following quality-adjusted measure of relative production:

$$\left(\frac{\tilde{X}_H}{X_L}\right)^* = \left(\frac{X_H}{X_L}\right)^* \cdot \left[\frac{\left(\frac{Q_H}{Q_L}\right)^*}{\left(\frac{A_H}{A_L}\right)^*}\right]^{\frac{1-\gamma}{\gamma}} = \left(\frac{hH}{lL}\right)^{1+\left(\frac{1-\alpha}{\alpha}-\frac{\phi-\alpha}{\alpha(\beta_2+1)}\right)} \tag{5.42}$$

Thus, similarly to the aggregate variety index ratio, the quality-adjusted measure of relative production is determined by the technological-knowledge bias, adjusted by the complementarity parameter, ϕ, the horizontal R&D elasticity parameter, β_2, and the production function elasticity parameter, α.

5.4 Steady-state effects: comparative analysis

In this section we analyze the steady-state effects on equilibrium aggregate output growth rate, g, technological-knowledge bias, $\left(\frac{Q_H}{Q_L}\right)^*$, skill premium, W^*, and our industrial structure measures, $\left(\frac{A_H}{A_L}\right)^*$ and $\frac{\tilde{X}_H}{X_L}$. In particular, we assess the impact of an increase in the complementarity degree, ϕ, internal investment costs, θ, and skilled-labour supply, H.

5.4.1 Steady-state effects on equilibrium growth rate, g

One of the basic assumptions of our model is the feature of complementarity between intermediate goods in production, reflecting the idea that having more of one type of good raises the marginal productivity of the others. Let us see what happens to the economy's equilibrium growth rate if the degree of complementarity intensifies.

In order to assess the effects of an increase in the complementarity degree parameter, ϕ, we use the Implicit Function Theorem to derive $\frac{\partial g}{\partial \phi} = -\frac{\frac{\partial F}{\partial \phi}}{\frac{\partial F}{\partial g}}$. Recalling that $\psi \equiv \frac{\beta_2+1}{\beta_2-\varepsilon-\varepsilon(\beta_2+1)(\lambda^{\frac{\gamma}{1-\gamma}}-1)}$ and $\varepsilon \equiv \frac{\phi-1}{1-\alpha}$ and defining:

$$F(\cdot) \equiv g - \psi\left(1+\varepsilon\right)\left(\lambda^{\frac{\gamma}{1-\gamma}}-1\right)\left((1-\gamma)M\left(\frac{rq}{\gamma}\right)^{-\frac{\alpha}{1-\alpha}}\left(\alpha P_m\right)^{\frac{1}{1-\alpha}}\frac{1}{\varsigma}-r(t)\right)=0,$$

then, taking the corresponding partial derivatives we have:

$$\begin{aligned}\frac{\partial F}{\partial g} = {} & 1+\psi\left(1+\varepsilon\right)\left(\lambda^{\frac{\gamma}{1-\gamma}}-1\right)\frac{\alpha}{1-\alpha} \\ & \cdot\left[(1-\gamma)M\gamma^{\frac{\alpha}{1-\alpha}}\left(\alpha P_m\right)^{\frac{1}{1-\alpha}}\frac{1}{\varsigma}\left(rq\right)^{-\frac{1}{1-\alpha}}\left(\sigma q+\theta r\right)+\sigma\frac{1-\alpha}{\alpha}\right]>0\end{aligned}$$

In $\frac{\partial F}{\partial \phi}$ the derivative of the relevant product, $\left[\psi\left(1+\varepsilon\right)\right]'_{\phi}$, is positive and plugged in the initial expression yields:

$$\begin{aligned}\frac{\partial F}{\partial \phi} = {} & -\left[\frac{\psi}{1-\alpha}\left(\frac{1+(\beta_2+1)(\lambda^{\frac{\gamma}{1-\gamma}}-1)}{\beta_2-\varepsilon-\varepsilon(\beta_2+1)(\lambda^{\frac{\gamma}{1-\gamma}}-1)}\right)\right]\cdot \\ & \cdot\left(\lambda^{\frac{\gamma}{1-\gamma}}-1\right)\left(\frac{(1-\gamma)}{\varsigma}M\left(\frac{rq}{\gamma}\right)^{-\frac{\alpha}{1-\alpha}}\left(\alpha P_m\right)^{\frac{1}{1-\alpha}}-r(t)\right)<0\end{aligned}$$

Thus, we have $\frac{\frac{\partial F}{\partial \phi}}{\frac{\partial F}{\partial g}} = \frac{-}{+} < 0$, and by $\frac{\partial g}{\partial \phi} = -\frac{\frac{\partial F}{\partial \phi}}{\frac{\partial F}{\partial g}}$ it follows that $\frac{\partial g}{\partial \phi} > 0$. We can therefore conclude that an increase in the degree of complementarity between intermediate goods in production positively affects the economy's equilibrium growth rate. The intuition behind this result is fairly simple. When intermediate goods used in production are complements, an increased quantity of some goods raises the marginal productivity of the others.[10] This implies that, at constant prices, the quantity demanded goes up, production increases and output grows faster than it would otherwise. Thus, as we have shown, an increase in the complementarity degree induces an increase in the economy's aggregate output growth rate.

[10]In this sense, the effect of complementarities between intermediate goods in production is equivalent to increasing returns.

Analogously to the previous case, we take the partial derivatives of $F(\cdot)$ to determine the sign of $\frac{\partial g}{\partial \theta} = -\frac{\frac{\partial F}{\partial \theta}}{\frac{\partial F}{\partial g}}$:

$$\frac{\partial F}{\partial \theta} = \psi\left(1+\varepsilon\right)\left(\lambda^{\frac{\gamma}{1-\gamma}}-1\right)\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{(1-\gamma)}{\varsigma}Mr^{-\frac{\alpha}{1-\alpha}}\gamma^{\frac{\alpha}{1-\alpha}}\left(\alpha P_m\right)^{\frac{1}{1-\alpha}}\right)\left(1+\theta g\right)^{-\frac{1}{1-\alpha}}g > 0$$

Recalling that $\frac{\partial F}{\partial g} > 0$, we have $\frac{\frac{\partial F}{\partial \theta}}{\frac{\partial F}{\partial g}} = \frac{+}{+} > 0$, and by $\frac{\partial g}{\partial \theta} = -\frac{\frac{\partial F}{\partial \theta}}{\frac{\partial F}{\partial g}}$ it follows that $\frac{\partial g}{\partial \theta} < 0$. Thus, we can conclude that aggregate output growth is negatively affected by internal investment costs, an increase in which decreases the economy's equilibrium growth rate. The explanation for this result steams directly from the internal investment costs theory. In particular, accounting for capital installation costs in their optimization problem, firms control their rate of investment (not the capital stock) in each t. Consequently, when internal investment costs increase, *i.e.* installing new capital becomes more expensive, firms will tend to reduce investment. This will reduce production of intermediate goods, leading to a slowdown in the economy's aggregate output growth.

Here again, we apply the Implicit Function Theorem to calculate $\frac{\partial g}{\partial H} = -\frac{\frac{\partial F}{\partial H}}{\frac{\partial F}{\partial g}}$:

$$\frac{\partial F}{\partial H} = -\psi\left(1+\varepsilon\right)\left(\lambda^{\frac{\gamma}{1-\gamma}}-1\right)\frac{(1-\gamma)}{\varsigma}\alpha^{\frac{1}{1-\alpha}}h\left(\frac{rq}{\gamma}\right)^{-\frac{\alpha}{1-\alpha}}\exp^{-1} < 0$$

Again, recalling that $\frac{\partial F}{\partial g} > 0$, we have $\frac{\frac{\partial F}{\partial H}}{\frac{\partial F}{\partial g}} = \frac{-}{+} < 0$ and by $\frac{\partial g}{\partial H} = -\frac{\frac{\partial F}{\partial H}}{\frac{\partial F}{\partial g}}$ it follows that $\frac{\partial g}{\partial H} > 0$. Thus, an increase in the skilled-labour supply has a positive effect on output growth rate in steady state due to the market-size channel: an increase in H raises the steady-state vertical innovation probability, thus accelerating the rate of technological-knowledge progress and growth.

5.4.2 Steady-state effects on equilibrium technological-knowledge bias, $\left(\frac{Q_H}{Q_L}\right)^*$.

As regards technological-knowledge bias, we analyze the effects of complementarity and relative labour supply variations; the effects of costly investment can not be directly assessed.

Recalling expression (5.31), the effect of complementarity degree on equilibrium technological-knowledge bias can be directly assessed. In particular, taking the derivative of $\frac{Q_H}{Q_L}$ with respect to ϕ we have:

$$\left[\left(\frac{Q_H}{Q_L}\right)^*\right] = \left[\left(\frac{hH}{lL}\right)^{\frac{1-\alpha}{\phi-\alpha}}\right]'_{\phi} = \left(\frac{hH}{lL}\right)^{\frac{1-\alpha}{\phi-\alpha}} \ln\left(\frac{hH}{lL}\right)\left(-\frac{1-\alpha}{(\phi-\alpha)^2}\right) < 0$$

Thus, an increase in the degree of complementarity between intermediate goods in production reduces technological-knowledge bias. We emphasize that this result is due to a specific economic mechanism that relates the threshold final good and the technological-knowledge bias through the price-channel effect. In particular, recalling our expression (5.24), which defines the threshold final good as a decreasing function of technological-knowledge bias, and also recalling that $\varepsilon \equiv \frac{\phi-1}{1-\alpha}$, we can see that an increase in the complementarity degree ϕ increases ε, which on its turn increases the negative effect of $\frac{Q_H}{Q_L}$ on the threshold final good $\overline{n}$. As previously noted, a lower threshold value implies that there are more final goods produced with H-technology. Once they become more abundant, their market price, P_H, decreases. This reduces final-good firms' economic motivation for their production, and results in a lower demand for the corresponding type of labour, *i.e.* skilled labour. Consequently, the dimensions of skill-biased technological change are reduces, and so is the technological-knowledge bias. In sum, variations in the complementarity degree influence $\overline{n}$, which in turn affects technological-knowledge bias *via* the price-channel effect.

As it can be seen from expression (5.31), equilibrium technological-knowledge bias does not depend on the internal investment costs parameter, θ, for the same reason that we will refer for the equilibrium skill premium, in Section 4.3.

As the *SBTC* literature predicts, an increase in the skilled-labour supply has a positive effect on technological-knowledge bias, also verified in our case:

$$\left[\left(\frac{Q_H}{Q_L}\right)^*\right] = \left[\left(\frac{hH}{lL}\right)^{\frac{1-\alpha}{\phi-\alpha}}\right]'_H = \left(\frac{1-\alpha}{\phi-\alpha}\right)\frac{h}{lL}\left(\frac{hH}{lL}\right)^{\frac{1-\phi}{\phi-\alpha}} > 0$$

That is, increasing the supply of skilled workers induces technological-knowledge change biased in favour of skilled labour, as it was shown in our discussion on general equilibrium.

5.4.3 Steady-state effects on equilibrium skill premium, W^*

Recalling our expression (5.35), we can see that neither complementarities nor investment costs have a direct effect on W^*. In particular, the costly investment parameter, θ, does not explicitly enter our equilibrium skill premium equation, which is due to its implicit equitable effects on both available technologies, and consequently on the derived skilled and unskilled labour prices, thus canceling out in the relative factor price calculation. As regards the effect of an increase in the skilled-labour supply, it has no impact on equilibrium skill premium because of the offsetting of the initial supply, price-channel effect and market-size effect, as already discussed in Section 3.2. For the same reason, the complementarity degree parameter, ϕ, does not affect the skill premium in equilibrium.

5.4.4 Steady-state effects on equilibrium industrial structure measures, $\left(\frac{A_H}{A_L}\right)^*$and $\frac{\tilde{X_H}}{X_L}$

As expression (5.40) illustrates, complementarities and costly investment do not affect the steady-state aggregate variety index ratio $\left(\frac{A_H}{A_L}\right)^*$ for the same reasons as referred for the case of equilibrium skill premium. In particular, due to its implicit equitable effects on both available technologies, the effect of internal investment costs cancels out, as does the effect of complementarities induced through the aggregate quality index growth rates for each m-type technology, g_{Q_H} and g_{Q_L} (see equations (5.37), (5.39) and (5.40)).

However, from expression (5.42) we can see that the quality-adjusted relative production, $\frac{\tilde{X_H}}{X_L}$, is negatively affected in equilibrium by the complementarity parameter ϕ:

$$\left[\frac{\tilde{X_H}}{X_L}\right]'_{\phi} = \left[\left(\frac{hH}{lL}\right)^{1+\left(\frac{1-\alpha}{\alpha}-\frac{\phi-\alpha}{\alpha(\beta_2+1)}\right)}\right]'_{\phi} = \left(\frac{hH}{lL}\right)^{1+\left(\frac{1-\alpha}{\alpha}-\frac{\phi-\alpha}{\alpha(\beta_2+1)}\right)} \ln\left(\frac{hH}{lL}\right)\left(-\frac{1}{(\beta_2+1)}\right) < 0$$

As we have seen above, an increase in the complementarities' parameter reduces the technological-knowledge bias. Since this bias directly determines our measure of industrial structure of the intermediate-good firms' relative production, variations in the complementarity degree are immediately transmitted to the equilibrium quality-adjusted relative production.

Taking the partial derivative of $\left(\frac{A_H}{A_L}\right)^*$ and $\frac{\tilde{X_H}}{X_L}$ with respect to H we have:

$$\frac{\partial\left(\frac{A_H}{A_L}\right)^*}{\partial H} = \frac{1}{(\beta_2+1)} \left(\frac{hH}{lL}\right)^{-\frac{\beta_2}{(\beta_2+1)}} \frac{h}{lL} > 0$$

and

$$\frac{\partial\left(\frac{\tilde{X_H}}{X_L}\right)}{\partial H} = \left(1 + \left(\frac{1-\alpha}{\alpha} - \frac{\phi-\alpha}{\alpha(\beta_2+1)}\right)\right) \left(\frac{hH}{lL}\right)^{\left(\frac{1-\alpha}{\alpha} - \frac{\phi-\alpha}{\alpha(\beta_2+1)}\right)} \frac{h}{lL} > 0$$

Thus, in consistency with empirical data, an increase in the skilled-labour supply biases industrial concentration in favour of the H-technology sector.

5.5 Concluding remarks

In this chapter, we have developed an extended directed technological change model and studied the growth rate, technological-knowledge bias, industrial structure and skill-premium behaviour in a framework of R&D driven growth, complementarities between intermediate goods in production, and internal investment costs. We have found that equilibrium output growth rate is affected both by complementarities and internal investment costs. We have also found that the complementarity degree directly influences technological-knowledge bias and the quality-adjusted relative production in equilibrium, and defined the underlying mechanism; and we have determined that neither of the two elements have a direct impact on steady-state skill premium and aggregate variety index ratio. We have also shown that while in the proposed framework the Acemoglu's (2009) *weak equilibrium (relative) bias* is verified, *i.e.* technological-knowledge is biased in favour of the more abundant skilled labour, the *strong equilibrium (relative) bias* is not verified because the resulting technological-knowledge change is not strong enough as to induce an increase in the skill premium. This is particularly due to our model's aggregate production function with a constant elasticity of substitution equal to 2, implying that labour endowments do not influence the steady-state skill premium, which is determined solely by the absolute productivities of skilled and unskilled labour.

We have also performed an analysis of the steady-state effects of an increase in complementarity degree, internal investment costs and skilled-labour supply on our model's key variables. As regards the steady-state effects on growth rate, we have found that it is positively influenced by both complementarities and skilled-labour endowments, and negatively by internal investment costs. Also, we verified that the positive correlation of the relative supply of skilled labour to our measures of industrial structure is consistent with related empirical evidence. We have also found that while in line with the $SBTC$ literature an increase in skilled-labour supply has a positive effect on equilibrium technological-knowledge bias, an increase in the complementarity degree reduces it *via* the price channel, and neither of these two parameters influence the skill premium, because the initial supply, price-channel and market-size effect exactly offset each other. On its turn, an increase in internal investment costs affects neither the technological-knowledge bias nor the skill premium, due to its implicit equitable effects on both available technologies.

Finally, we believe that there are several topics that would be interesting to consider for future research. Our model generates a number of results that call for empirical confirmation, namely, those referred in our steady-state analysis. Furthermore, the result that equilibrium skill premium depends solely on the productivity advantage of skilled over unskilled labour deserves a more thorough investigation. In particular, given that, having a direct impact on workers productivity, skills both increase the capacity to innovate and apply new ideas, and stimulate technological development, it is plausible that the absolute productivity advantages of skilled and unskilled workers are related to technological-knowledge bias and labour supply. Therefore, a challenging task would be to endogenize the productivity parameters in the framework of a $SBTC$ model.

Appendix

Figure 5.1: The relative number of firms, relative production, and the relative supply of skills (in a sample of European countries, 1995-2007 average)

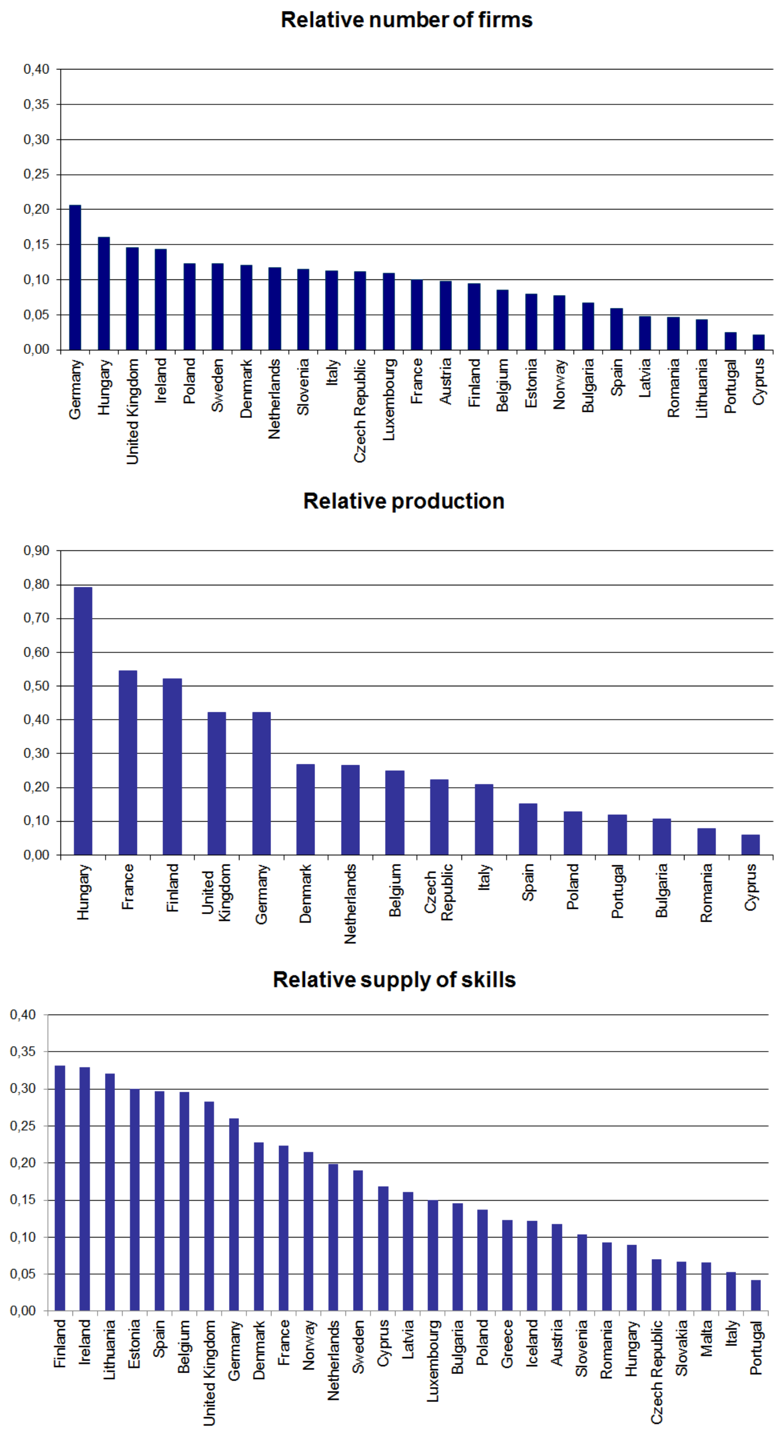
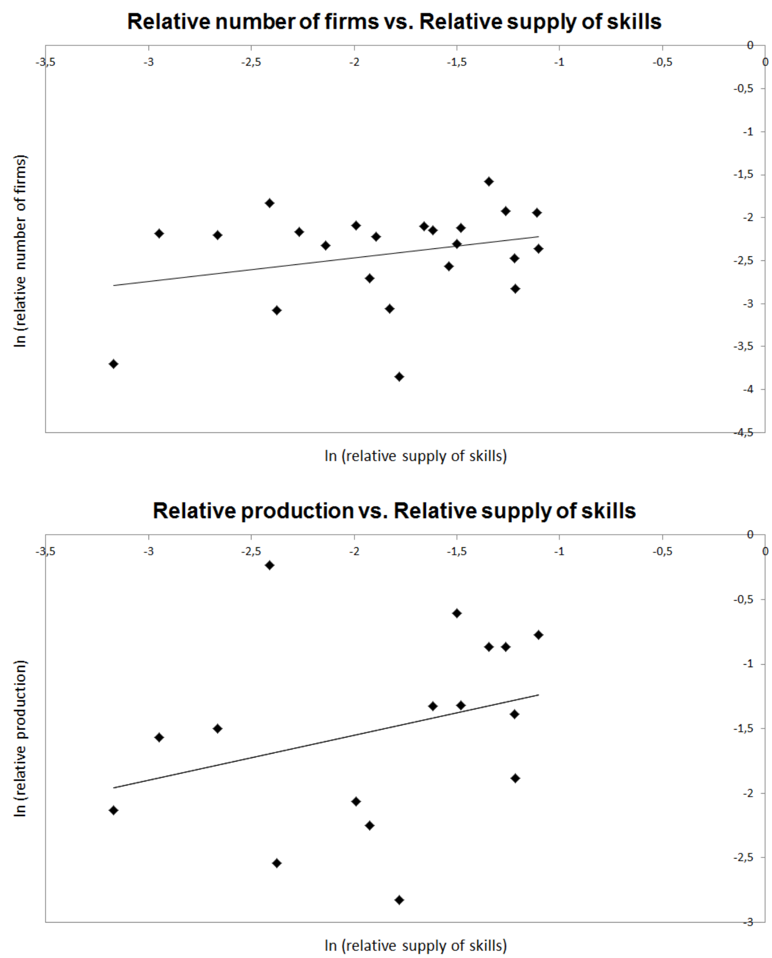


Figure 5.2: The relative number of firms and the relative production *versus* the relative supply of skills: cross-country correlations (in a sample of European countries, 1995-2007 average)



Chapter 6

Technology structure and skill structure: costly investment and complementarity effects quantification

6.1 Overview

This chapter represents an extension to the model developed in the Chapter 5, having the objective of identifying and quantifying the long-run link between the technology structure and the skill structure, by considering an explicit role for the (potential) gross complementarity arising between technological goods. By including internal investment costs, the analysis in this chapter also tackles the long-run relationship between the Tobin-q and the technology characteristics of the firms, such as the degree of complementarity between technological goods, through the impact of the latter on the long-run economic growth rate.

The importance of analysing the relationship between the technology structure and the skill structure under costly investment and complementarity effects is suggested by a number of empirical facts. From the existent literature, we retain that: *(i)* there is an impact of the technology structure, measured by either the number of firms or by production in high- *vis-à-vis* low-tech manufacturing sectors, on industrial performance (Pilat *et al.*, 2006) and on the skill premium (Cozzi and Impullitti, 2010); *(ii)* gross complementarities between technological goods are a relevant feature in explaining industrial growth (*e.g.*, Matsuyama, 1995; Ciccone and Matsuyama, 1996); *(iii)* there is a positive relationship between the Tobin-q and the R&D and technology characteristics of the firms (*e.g.*, Chan *et al.*, 1990; Connolly and Hirschey, 2005). Moreover, by gathering data for a number of European countries between 1995 and 2007,[1] we find that there is a positive relationship between the technology structure (regarding both the number of firms and production in high- *vis-à-vis* low-tech manufacturing sectors) and both the skill premium and the skill structure (the latter being measured as the ratio of high- to low-skilled manufacturing workers). In particular, we infer from this evidence that the skill structure featuring a higher proportion of high-skilled workers is

[1] The Appendix provides further details on the data.

associated with technological change directed towards the high-tech sectors, given the observed positive elasticity of the technology structure regarding the skill structure.

In the light of these facts, in this chapter we develop an extended directed technological change model of endogenous growth, integrating a number of key elements. Firstly, the model incorporates endogenous directed technical change, such that final-goods production uses either low- or high-skilled labour with labour-specific intermediate goods, while R&D can be directed to either the low- or the high-skilled labour complementary technology; hence, the intermediate goods are the technological goods in the model, and "sector" denotes a group of firms producing the same type of labour-complementary intermediate goods. Since the data shows that the high-tech sectors are more intensive in high-skilled labour than the low-tech sectors,[2] we consider the high- and low-skilled labour-complementary intermediate-good sectors in the model as the theoretical counterpart of the high- and low-tech sectors (*e.g.*, Cozzi and Impullitti, 2010). This directed technical change setup allows us to have an endogenous high- *versus* low-tech technological bias.

We also consider simultaneously vertical and horizontal R&D. Under our R&D specification, the choice between vertical (increase of product quality) and horizontal innovation (creation of new products and industries) is related to the allocation of R&D expenditures, which are fully endogenous. Therefore, we endogenise the rate of growth along both the vertical and the horizontal direction, and thereby the number of industries/firms in each sector.[3] Given the distinct nature of vertical and horizontal innovation (immaterial *versus* physical) and the consequent asymmetry in terms of R&D complexity costs, this framework then makes economic growth and firm dy-

[2]According to the data for the average of the European Union (27 countries), 30.9% of the employment in the high-tech manufacturing sectors is high-skilled ("college graduates"), against 12.1% of the employment in the low-tech manufacturing sectors (see the Appendix for more details on the data).

[3]An alternative approach in the literature assumes that the allocation of resources between vertical and horizontal R&D implies a division of labour between the two types of R&D. Since the total labour level is determined exogenously, the rate of growth along the horizontal direction is exogenous, *i.e.*, the BGP flow of new products and industries occurs at the same rate as (or is proportional to) population growth.

namics closely related: vertical R&D is the ultimate growth engine, while horizontal R&D builds an explicit link between aggregate and technology-structure variables (the number of firms and production in high- and in low-tech sectors).

Finally, the model features two additional assumptions: *(i)* we allow for an interaction between the quantity of one intermediate good and the marginal productivity of the other intermediate goods, such that gross substitutability or gross complementarity may arise between the intermediate goods used in the production of final goods; *(ii)* we include Hayashi's (1982) internal investment costs (*e.g.*, Benavie *et al.*, 1996; Thompson, 2008). Therefore, the model establishes a relationship between the technology structure and the skill structure regulated by the degree of gross substitutability/complementarity between technological goods (*i.e.*, intermediate goods), together with a relationship between the Tobin-q and the technology characteristics of the firms.

By solving the model for the balanced-growth path (BGP), we uncover the analytical mechanism that explains the cross-country behaviour of the technological structure. Two types of effects exist: the market-size effect, through which a higher proportion of high-skilled workers induces technological change directed towards the high-tech sectors, and the skill-premium effect, reflecting the absolute productivity advantage of high-skilled workers. However, the interaction between the quantity of one technological good and the marginal productivity of the other technological goods plays a crucial role here. In particular, goods must be either gross substitutes or gross complements with the degree of complementarity *below* a certain threshold such that the elasticity of the technology structure with respect to the skill structure is positive, as observed in the cross-country data. That is, the increased incentives for allocating resources to R&D activities that come from gross complementarity must not be too large to offset the technological-knowledge bias channel. It is noteworthy that no upper limit seems to arise in related models featuring complementarities (*e.g.*, Evans *et al.*, 1998; Jones and Williams, 2000; Thompson, 2008).

Next, we take our model to the data and quantitatively associate the empirical facts on the technology structure and the skill structure to the degree of gross substitutability/complementarity between technological goods. In particular, we are interested in checking whether the case of gross complementarity, which features as a key assumption in a significant strand of the theoretical literature that studies poverty traps, growth and business cycles (*e.g.*, Matsuyama, 1995; Ciccone and Matsuyama, 1996; Evans *et al.*, 1998), has empirical support. Based on the analytical BGP relationships derived in the model and on the cross-country data for the technology structure and the skill structure, we compute indirect estimates of the value of the parameter that regulates the degree of gross substitutability/complementarity. Our results show that this parameter has a confidence interval between 1.08 and 1.78. Since the estimates are, in any case, larger than unity, our identification and estimation exercise suggests that there is gross complementarity between technological goods, thus backing up the complementarity assumption appearing in the referred theoretical literature. However, our empirical results also suggest that the values that the literature tends to use to calibrate the complementarity parameter are apparently too high.[4] Additionally, our estimations show that the elasticity regulating the horizontal-R&D complexity costs exceeds the one in the vertical-R&D case by between 22 and 130 percent, in line with what should be expected having in mind the distinct nature of the two types of R&D.

We are also interested in the long-run relationship between the Tobin-q and both the degree of complementarity between technology goods and the complexity effect pertaining to horizontal R&D, through the impact of the last two factors on the long-run economic growth rate. To obtain quantitative results, we calibrate the model bearing in mind the previous estimation exercise. Our results confirm the strong relationship between the Tobin-q and the R&D and technology characteristics of the firms that has been frequently reported by the empirical literature (*e.g.*, Chan *et al.*, 1990; Hall, 1999;

[4] For instance, Evans *et al.* (1998) and Thompson (2008) use a value of 4.

Connolly and Hirschey, 2005). Nevertheless, our estimation and calibration exercise also suggests that it is important to distinguish between the technological determinants of the long-run market value of capital and explicitly consider their interaction, since it may significantly dampen or enhance the impact on the Tobin-q.

The remainder of this work is organised as follows. Section 2 presents a dynamic general-equilibrium model of directed technological change with vertical and horizontal R&D, internal costly investment and gross substitutability/complementarity between the intermediate goods. In Sections 3 and 4, we derive the general equilibrium and analyse the BGP properties. In Section 5, we take the model to the data and quantitatively associate the empirical facts on the technology structure and the skill structure to the degree of gross substitutability/complementarity, and also quantify the long-run relationship between the Tobin-q and the technology characteristics of the firms. Concluding remarks are presented in Section 6.

6.2 Model specifications

We introduce biased technical change in a closed-economy dynamic general-equilibrium setup. The economy consists of a competitive sector that produces a final good that can be used in consumption, production of intermediate goods and R&D. There are also two intermediate-good sectors, each having a large number of firms which operate in a monopolistic competitive framework. Also, there are both vertical and horizontal R&D activities. If an innovation is successful, an incumbent is replaced by a new entrant in a given existing intermediate-good industry, or a monopolist emerges in a new intermediate-good industry, within a particular sector. Then successful R&D introduces, through creative destruction and variety expansion, both internal and external industry-wide limits to market power and generates endogenous economic growth.

Thus, the model is an extension of Acemoglu and Zilibotti (2001), augmented with vertical R&D, as introduced in Afonso (2006). Moreover, with the purpose of introducing internal costly investment, we assume that final-good producers incur a Hayashi's (1982) investment cost when accumulating total capital, which is composed by physical capital and technological-knowledge capital (*i.e.*, capital accumulated through R&D). We also allow for an interaction between the quantity of one intermediate good and the marginal productivity of the other intermediate goods, such that gross complementarities may arise between the intermediate goods used in the production of final goods, as in, *e.g.*, Evans *et al.* (1998) and Jones and Williams (2000). We will refer to intermediate goods also as technological goods, in the sense that they are the ones that embody successful R&D results.

The economy is populated by a fixed number of infinitely-lived households who maximise lifetime utility, which depends on consumption, bearing in mind the income (wages) generated by the supply of one of two types of labour to final-good firms – low-skilled, L, and high-skilled labour, H – and by the ownership of firms (interest).

6.2.1 Consumption side

The economy consists of a fixed number of identical and infinitely-lived households and has a zero population growth. Indexed with $a \in [0,1]$ depending on their ability level, households consume final goods, own firms (equity) and inelastically supply low-skilled, L_a (if $a \leq \overline{a}$), or high-skilled labour, H_a (if $a > \overline{a}$) to final-good firms. Thus, total labour supply, $L + H$, is exogenous and constant, with $L = \int_0^{\overline{a}} L_a da$ and $H = \int_{\overline{a}}^1 H_a da$. All households have identical preferences and perfect foresight of technological change over time, choosing the time path of final-good consumption so as to maximise discounted lifetime utility:

$$U(t) = \int_0^\infty e^{-\rho t} \cdot \frac{C_a(t)^{(1-\sigma)} - 1}{1-\sigma} dt,$$

subject to the flow budget constraint:

$$\dot{B}_a(t) = r(t)B_a(t) + W_m(t) \cdot m_a(t) - C_a(t) \tag{6.1}$$

(with $m = L$ if $a \leq \overline{a}$ and $m = H$ if $a > \overline{a}$), where $\sigma > 0$ is the relative risk aversion coefficient, $0 < \rho < 1$ is the subjective discount rate, $r(t)$ is the market real interest rate, $W_m(t)$ is the real wage, $C_a(t)$ is the consumption of the representative household a and B_a denotes the household's real equity holdings. The initial level of wealth, $B_a(0)$, is given and the non-Ponzi games condition $lim_{t\to\infty} e^{-\int_0^t r(s)ds} B_a(t) \geq 0$ is imposed.

The optimal consumption path is given by the standard Euler equation:

$$\frac{\dot{C_a(t)}}{C_a(t)} = \frac{\dot{C(t)}}{C(t)} = \frac{r(t) - \rho}{\sigma}, \tag{6.2}$$

which is independent from a, and the transversality condition is $\lim_{t\to\infty} B_a(t)e^{-\rho t} = 0$. Along the balanced-growth path (BGP), with $\dot{C}/C$ constant , r will also be constant.

6.2.2 Production side

The composite final-good, Y, is produced by competitive final-good firms continuously indexed by $n \in [0, 1]$, such that $Y(t) = \int_0^1 P(n,t)Y(n,t)dn$, where $P(n,t)$ and $Y(n,t)$ are the relative price and the quantity of the final good produced by firm n. Firms produce employing a combination of labour and intermediate goods, using one of the two substitute production technologies available. In particular, firms can either use low-skilled labour, L, and a continuum of L-specific intermediate goods indexed by

$j_L \in [0, A_L(t)]$, or high-skilled labour, H, and a continuum of H-specific intermediate goods indexed by $j_H \in [0, A_H(t)]$. Thus, each set of intermediate goods only combines with its corresponding type of labour, and each firm produces with one production technology exclusively, which we denote by L- and H-technology respectively. The production function for a representative firm n is given by:

$$\begin{aligned} Y(n,t) = \;& ((1-n)\cdot l \cdot L(n))^{(1-\alpha)} \cdot \left(\int_0^{A_L(t)} \lambda^{\gamma k_L(j_L,t)} \cdot x_L(n,j_L,t)^{\gamma} dj_L\right)^{\phi} + \\ & + (n \cdot h \cdot H(n))^{(1-\alpha)} \cdot \left(\int_0^{A_H(t)} \lambda^{\gamma k_H(j_H,t)} \cdot x_H(n,j_H,t)^{\gamma} dj_H\right)^{\phi}, \end{aligned} \tag{6.3}$$

where: $x_m(n, j_m, t)$ represents the quantity of the intermediate good j_m, $m = L, H$, and variables $H(n)$ and $L(n)$ denote the amount of high- and low-skilled labour used to produce the final good n at time t; variables $A_H(t)$ and $A_L(t)$ represent the measure of variety of H- and L-specific intermediate goods available at time t; $\lambda > 1$ reflects the improvement in the quality of an intermediate good j brought in by vertical innovation, and k indicates both the number of quality improvements and the top quality rung at time t; $h > l \geq 1$ reflects the *absolute* productivity advantage of high- over low-skilled labour, while terms n and $(1-n)$ reflect the *relative* productivity advantage of each labour type, implying that high-skilled labour is relatively more productive for manufacturing final goods indexed by larger ns and *vice versa*; terms $(1-\alpha)$ and α, with $0 < \alpha < 1$, denote the share of labour and intermediate goods in production; and ϕ regulates the relationship between the quantity of one intermediate good and the marginal productivity of the other intermediate goods in the production function. We impose $\gamma = \alpha/\phi$ to ensure constant returns to scale, whereas $\phi > \alpha$ is required to guarantee that the model generates positive endogenous growth, as we will show below. If $\phi > 1$, then there is gross complementarity between intermediate goods used in production, in the sense that an increase in the quantity of one intermediate good increases the marginal productivity of the other intermediate goods. The terms

n and $(1-n)$ imply that at each time t there exists an endogenous threshold $\overline{n}$, at which switching from one production technology to another becomes advantageous, and consequently, each final good n is produced with one technology $-$ H or L $-$ exclusively.

Operating in a perfect competition environment, each final-good firm n seeks to maximise its profits at time t, taking as given $P(n,t)$, the prices of the intermediate goods j_m, $p_m(j_m,t)$, and the wages of high- or low-skilled labour employed in production, $W_m(t)$, $m = L, H$,:

$$\begin{aligned} \max_{x_m(n,j_m,t)} \quad & P(n,t) \cdot Y(n,t) - W_L(t) \cdot L(n) - W_H(t) \cdot H(n) - \\ & - \textstyle\int_0^{A_L(t)} p_L(j_L,t) \cdot x_L(n,j_L,t) dj_L - \int_0^{A_H(t)} p_H(j_H,t) \cdot x_H(n,j_H,t) dj_H . \end{aligned}$$

Note that, since each final-good firm produces exclusively with one type of technology, profits at each t are maximized with respect to $x_m(n,j_m,t)$. Then, from the first-order conditions of each final-producer type's maximization problem, we can derive the inverse demand functions for L- and H-specific intermediate goods used in final goods production:

$$\begin{aligned} p_L(j_L,t) &= P(n,t) \cdot ((1-n) \cdot l \cdot L(n))^{(1-\alpha)} \cdot \alpha \cdot \lambda^{\gamma k_L(j_L,t)} \cdot x_L(n,j_L,t)^{(\gamma-1)} \cdot \Big(\textstyle\int_0^{A_L(t)} \lambda^{\gamma k_L(j_L,t)} \cdot x_L(n,j_L,t) \\ p_H(j_H,t) &= P(n,t) \cdot (n \cdot h \cdot H(n))^{(1-\alpha)} \cdot \alpha \cdot \lambda^{\gamma k_H(j_H,t)} \cdot x_H(n,j_H,t)^{(\gamma-1)} \cdot \Big(\textstyle\int_0^{A_H(t)} \lambda^{\gamma k_H(j_H,t)} \cdot x_H(n,j_H,t)^{\gamma} \end{aligned} \tag{6.4}$$

Solving (6.4) for $\int_0^{A_L(t)} \lambda^{\gamma k_L(j_L,t)} \cdot x_L(n,j_L,t)^{\gamma} dj_L$ and $\int_0^{A_H(t)} \lambda^{\gamma k_H(j_H,t)} \cdot x_H(n,j_H,t)^{\gamma} dj_H$ respectively, and substituting in equation (6.3), final-good output for firm n can be re-written as:

$$Y(n,t) = \left(\frac{\alpha \cdot P(n,t)}{p_m(j_m,t)}\right)^{\frac{\alpha}{1-\alpha}} \cdot \left[(1-n)\cdot l \cdot L(n) \cdot Q_L(t)^{(\varepsilon+1)} + n \cdot h \cdot H(n) \cdot Q_H(t)^{(\varepsilon+1)}\right] \tag{6.5}$$

where, as we will further show, $p_L(j_L,t)$ and $p_H(j_H,t)$ are equal, thus allowing us to place it in front of the brackets, and $Q_H(t)$ and $Q_L(t)$ are aggregate quality indices denoting the technological-knowledge stock at t for the H- and L-technology group respectively, being defined by:

$$Q_m(t) \equiv \int_0^{A_m(t)} \left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}} dj_m,\ m = L, H. \tag{6.6}$$

The term $\varepsilon \equiv (\phi - 1)/(1-\alpha)$ in (6.5) is a constant reflecting the interaction between the quantity of one intermediate good and the marginal productivity of the other intermediate goods in the final-good production function.

Final-good producers are end-users of the stock of technological knowledge and of physical capital, in as much as these stocks are embodied in the intermediate goods. Indeed, in line with Romer (1990) and others, the production of one unit of each intermediate good j_m takes one unit of physical capital, *i.e.*, $X_m(j_m,t) = K_m(j_m,t)$, $m = L, H$, where $X_L(j_L,t) = \int_0^{\bar{n}} x_L(n,j_L,t)dn$ and $X_H(j_H,t) = \int_{\bar{n}}^1 x_H(n,j_H,t)dn$, with $x_m(n,j_m,t)$ computed from (6.4). Thus, the aggregate physical capital stock is the total quantity of the various types of intermediate goods, $K(t) = K_L(t) + K_H(t)$, with $K_L(t) = \int_0^{A_L(t)} X_L(j_L,t)dj_L$ and $K_H(t) = \int_0^{A_H(t)} X_H(j_H,t)dj_H$. On the other hand, the production of intermediate goods also requires the use of designs (blueprints), where the source of new designs (new varieties or higher quality goods) are R&D activities, as detailed below. The technological-knowledge stock, (6.6), summarises the cumulative effect of R&D activities over time.

Following Thompson (2008), we assume that final-good producers incur a Hayashi's (1982) investment cost when accumulating total capital, which is composed by physical capital and technological knowledge (*i.e.*, capital accumulated through R&D). Total investment, $\dot{Z}(t)$, is then given by the sum of investment in physical capital, $\dot{K}(t)$, and investment in vertical, $R_{v,m}(t)$, and horizontal, $R_{h,m}(t)$, R&D:

$$\dot{Z}(t) = \dot{K}(t) + R_{h,L}(t) + R_{h,H}(t) + R_{v,L}(t) + R_{v,H}(t) \tag{6.7}$$

Assuming zero capital depreciation, installing $\mathcal{I}(t) = \dot{Z}(t)$ new units of total capital requires spending an amount $J(t) = \mathcal{I}(t) + \frac{1}{2}\theta\frac{\mathcal{I}(t)^2}{Z(t)}$, where $Z(t)$ is the total capital stock at t, $\frac{1}{2}\theta\frac{\mathcal{I}(t)^2}{Z(t)}$ represents the Hayashi's internal installation cost, and θ denotes the adjustment-cost parameter. In every period t, final-good firms choose their investment rate so as to maximize the present discounted value of cash-flows. The current-value Hamiltonian for the optimal control problem is:

$$H(t) = Y(t) - \mathcal{I}(t) - \frac{1}{2}\cdot\theta\cdot\frac{\mathcal{I}(t)^2}{Z(t)} + q(t)\cdot\Big(\mathcal{I}(t) - \dot{Z}(t)\Big)$$

where $q(t)$ is the market value of total capital. The corresponding transversality condition is $\lim_{t\to\infty} e^{-\int_0^t r(s)ds}\cdot q(t)\cdot Z(t) = 0$, where the market interest rate, $r(s)$, equals the cost of capital. At this point, we anticipate the result, to be shown later on, that the economic growth rate, $g \equiv g_Y$, is equal to the investment rate along the BGP, *i.e.*, $g = g_Z = \mathcal{I}(t)/Z(t)$. Then, from the first-order conditions, we have the long-run market value of capital:

$$q = 1 + \theta g \tag{6.8}$$

This ratio is known as Tobin's (1969) marginal q. With Hayashi's investment cost function, marginal q equals Tobin's average q, the ratio of the market value of the firm to the replacement cost of its total capital stock. This equivalence is important because although it is marginal q that is relevant to investment, only average q is observable.

Intermediate-good m-technology sector consists of a continuum $A_m(t)$ of industries. There is monopolistic competition if we consider the whole sector: the monopolist in industry $j_m \in [0, A_m(t)]$ fixes the price $p_m(j_m, t)$ but faces an isoelastic demand curve, (6.4). Intermediate good j is produced with a cost function $r(t)K(j,t) = r(t)X(j,t)$. Along the BGP, the cost of capital will also be constant, *i.e.*, $r(t) = r$. Profit in j_m is thus $\pi_m(j_m, t) = (p_m(j_m, t) - rq) \cdot X_m(j_m, t)$, where rq denotes the production cost of one unit of the intermediate good j. Depending on whether drastic or non-drastic innovations (*e.g.*, Li, 2001; Barro and Sala-i-Martin, 2004) are the case, the profit maximising price is a markup over marginal cost, such that:[5]

$$p_L(j_L, t) = p_H(j_H, t) \equiv p = \frac{rq}{\chi}, \text{ where } \chi = \begin{cases} \gamma & \text{for } \lambda \geq \frac{1}{\gamma} \text{ (drastic innovation)} \\ \frac{1}{\lambda} & \text{for } \lambda < \frac{1}{\gamma} \text{ (non-drastic innovation)} \end{cases} \tag{6.9}$$

Equation (6.9) implies that the price charged by intermediate-good producers for their differentiated goods is equal for all j and *H(L)*-technology sectors, *i.e.*, it is *sector-invariant*. Moreover, on the BGP, where r and q will be constant, the markup is both

[5]Firms producing different quality goods in industry j_m are engaged in Bertrand price competition. This assumption makes sure that only varieties of the lowest quality-adjusted price are kept in the market. Then, if $p_m(k_m)/\lambda < rq$, where $p_m(k_m)$ is the price of the top quality and $p_m(k_m - 1) = rq$ due to Bertrand competition, lower grades are unable to provide any effective competition, and the top-quality producer can charge the unconstrained monopoly price. In this case, since the demand function (6.4) has a price elasticity of $-1/(1-\gamma)$, a top-quality firm sets $p_m(k_m) = rq/\gamma$, which implies that $\lambda > \frac{1}{\gamma}$, *i.e.*, innovations are said to be "drastic". In contrast, if $\frac{1}{\gamma} > \lambda$, innovations are "non-drastic" and the producer of the leading-edge good has to engage in a limit-pricing strategy in order to drive his competitors out of the market, *i.e.*, he/she charges $p_m(k_m) = \lambda rq$. When final-good firms are indifferent between the top and second-highest goods on the quality ladder (*i.e.*, if $\frac{1}{\gamma} = \lambda$), they are assumed to purchase the top quality.

sector- and *time-invariant.*

Next, using expressions (6.4) and (6.9), recalling that in any moment in time we have $L = \int_0^{\overline{n}} L(n)dn$ and $H = \int_{\overline{n}}^1 H(n)dn$, and normalising prices such that:

$$P_L(t)^{\frac{1}{1-\alpha}} \equiv P(n,t)^{\frac{1}{1-\alpha}} \cdot (1-n), \quad P_H(t)^{\frac{1}{1-\alpha}} \equiv P(n,t)^{\frac{1}{1-\alpha}} \cdot n \ , \tag{6.10}$$

we derive the total quantity that each *H(L)*-technology intermediate-good firm produces and sells, accounting for the threshold final good $\overline{n}$, and resulting profits:

$$X_m(j_m,t) = M \cdot (\alpha \cdot P_m(t))^{\frac{1}{1-\alpha}} \cdot \left(\frac{rq}{\chi}\right)^{\frac{-1}{1-\alpha}} \cdot \left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}} \cdot Q_m(t)^{\varepsilon}, \ m = L, H \tag{6.11}$$

$$\pi_m(t) = \pi_0 \cdot M \cdot P_m(t)^{\frac{1}{1-\alpha}} \cdot \left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}} \cdot Q_m(t)^{\varepsilon}, \ m = L, H \tag{6.12}$$

with $M = lL, hH$, and $\pi_0 \equiv (1-\gamma)\,(rq/\chi)^{-\frac{\alpha}{1-\alpha}}\,\alpha^{\frac{1}{1-\alpha}}$.

Given that the existence of an endogenous threshold reflects the idea that the production of final goods $n \in [0, \overline{n}]$ is more efficient using L-technology, and of final goods $n \in [\overline{n}, 1]$ is more efficient using H-technology, we can rewrite equation (6.5) as:

$$Y(n,t) = \begin{cases} \left(\frac{\alpha\chi}{rq} \cdot P(n,t)\right)^{\frac{\alpha}{1-\alpha}} \cdot (1-n) \cdot l \cdot L(n) \cdot Q_L(t)^{(\varepsilon+1)}, \ for\ n \in [0, \overline{n}] \\ \left(\frac{\alpha\chi}{rq} \cdot P(n,t)\right)^{\frac{\alpha}{1-\alpha}} \cdot n \cdot h \cdot H(n) \cdot Q_H(t)^{(\varepsilon+1)}, \ for\ n \in [\overline{n}, 1] \end{cases} \tag{6.13}$$

With competitive final-good producers, L- and the H-technology firms must break even at $\overline{n}$. Then, using (6.13), rewriting price normalisation (6.10), and normalising labour such that $L(n) = \frac{L}{\overline{n}}, \ H(n) = \frac{H}{1-\overline{n}}$, it can be shown that the endogenous final-good price ratio as a function of $\overline{n}$ is:[6]

$$\left(\frac{P_H}{P_L}\right)^{\frac{1}{1-\alpha}} = \frac{\overline{n}}{1-\overline{n}}, \tag{6.14}$$

where

$$\overline{n} = \left[1 + \left(\frac{h}{l}\frac{H}{L} \cdot \left(\frac{Q_H(t)}{Q_L(t)}\right)^{(\varepsilon+1)}\right)^{\frac{1}{2}}\right]^{-1} \tag{6.15}$$

and

$$\begin{aligned} P_H &== P(n,t) \cdot n^{1-\alpha} = e^{-(1-\alpha)} \cdot (1-\overline{n})^{-(1-\alpha)} \\ P_L &= P(n,t) \cdot (1-n)^{1-\alpha} = e^{-(1-\alpha)} \cdot \overline{n}^{-(1-\alpha)} \end{aligned} \tag{6.16}$$

Assuming that the wage *per* unit of m-type labour equals its marginal product, we use the production function (6.13) aggregated across n (bearing in mind that $\int_0^{\overline{n}(t)} L(n)dn = L$ and $\int_{\overline{n}(t)}^1 H(n)dn = H$ hold at every t) to derive the high- and low-skilled labour wages:

$$Y(t) = Y_L(t) + Y_H(t), \text{ where } \begin{cases} Y_H(t) = \left(\frac{\alpha\chi}{rq}\right)^{\frac{\alpha}{1-\alpha}} \cdot h \cdot H \cdot P_H^{\frac{1}{1-\alpha}} \cdot Q_H(t)^{(\varepsilon+1)} \\ Y_L(t) = \left(\frac{\alpha\chi}{rq}\right)^{\frac{\alpha}{1-\alpha}} \cdot l \cdot L \cdot P_L^{\frac{1}{1-\alpha}} \cdot Q_L(t)^{(\varepsilon+1)} \end{cases} \tag{6.17}$$

$$\begin{aligned} W_H = \frac{\partial Y_H}{\partial H} &= \left(\frac{\alpha\chi}{rq}\right)^{\frac{\alpha}{1-\alpha}} \cdot h \cdot P_H^{\frac{1}{1-\alpha}} \cdot Q_H(t)^{(\varepsilon+1)} \\ W_L = \frac{\partial Y_L}{\partial L} &= \left(\frac{\alpha\chi}{rq}\right)^{\frac{\alpha}{1-\alpha}} \cdot l \cdot P_L^{\frac{1}{1-\alpha}} \cdot Q_L(t)^{(\varepsilon+1)} \end{aligned} \tag{6.18}$$

The skill premium, W_H/W_L, is then given by the ratio of high- and low-skilled labour wages from (6.18):

[6]See Acemoglu and Zilibotti, 2001

$$\frac{W_H}{W_L} = \frac{h}{l} \left(\frac{P_H}{P_L}\right)^{\frac{1}{1-\alpha}} \left(\frac{Q_H(t)}{Q_L(t)}\right)^{(\varepsilon+1)} \tag{6.19}$$

Finally, using (6.13) and (6.15), we can define equilibrium aggregate output as:

$$Y(t) = \frac{1}{e} \cdot \left(\frac{\alpha\chi}{rq}\right)^{\frac{\alpha}{1-\alpha}} \cdot \left[\left(l \cdot L \cdot Q_L(t)^{(\varepsilon+1)}\right)^{\frac{1}{2}} + \left(h \cdot H \cdot Q_H(t)^{(\varepsilon+1)}\right)^{\frac{1}{2}}\right]^2 \tag{6.20}$$

From (6.20), it is clear that the dynamics of technological knowledge will drive economic growth provided that $\epsilon + 1 = (\phi - \alpha)/(1-\alpha) > 0$. This is true if the condition $\phi > \alpha$ is satisfied. Moreover, if there is gross complementarity between intermediate goods, *i.e.*, $\phi > 1$, then $\epsilon + 1 > 1$, which implies that the effect of technological knowledge growth on economic growth is more than proportional.

6.2.3 R&D

We assume that R&D firms can choose between either vertical or horizontal innovation. By devoting their resources to vertical R&D, firms target qualitative improvements of already existing intermediate-good varieties, while in the case of horizontal R&D they aim at variety expansion, *i.e.* at creating a new variety. Each new design (a new variety or a higher quality good) is granted a patent and thus a successful innovator retains exclusive rights over the use of his/her good. We also assume, to simplify the analysis, that both vertical and horizontal R&D are performed by (potential) entrants, and that successful R&D leads to the set-up of a new firm in either an existing or in a new industry (as in, *e.g.*, Howitt, 1999; Strulik, 2007; Gil *et al.*, 2012). There is perfect competition among entrants and free entry in the R&D businesses.

Vertical R&D is a standard creative destruction process, with the innovation arrival rate following a Poisson process. By improving on the current top quality level $k_m(j_m,t)$, a successful vertical R&D firm earns monopoly profits from selling the leading-edge input of $k_m(j_m,t)+1$ quality to final-good firms. However, temporary exclusive rights over the top-quality intermediate good confer the successful innovator higher profits only for the duration of the patent, which is determined by the instantaneous vertical-innovation arrival rate, $I_m^i(j_m,t)$ – vertical innovation rate at time t, by potential entrant i in industry j_m. The rate $I_m^i\,(j_m,t)$ is independently distributed across firms, across industries and over time, and depends on the flow of resources $R_{v,m}^i\,(j_m,t)$ committed by entrants at time t. As in, *e.g.*, Barro and Sala-i-Martin (2004, ch. 7), $I_m^i\,(j_m,t)$ features constant returns in R&D expenditures, $I_m^i(j_m,t)=R_{v,m}^i(j_m,t)/\Phi_m(j_m,t)$. The cost $\Phi_m\,(j_m,t)$ is assumed to be symmetric within sector m, such that:

$$\Phi_m\,(j_m,t)=\zeta\cdot\left(\lambda^{[k_m(j_m,t)+1]}\right)^{\frac{\gamma}{1-\gamma}}\cdot Q_m(t)^{\varepsilon},\;\; m\in\{L,H\}\,, \tag{6.21}$$

where ζ is a constant fixed vertical-R&D cost, assumed equal for both sectors m; and the term $\left(\lambda^{[k_m(j_m,t)+1]}\right)^{\frac{\gamma}{1-\gamma}}\cdot Q_m(t)^{\varepsilon}$ accounts for the adverse effect resulting from the increasing complexity of quality improvements, implying that research becomes progressively more difficult with each new vertical innovation.[7] Aggregated across firms i in j_m, the instantaneous arrival rate of a new quality improvement is given by:

$$I_m(j_m,t)=R_{v,m}(j_m,t)\cdot\frac{1}{\zeta}\cdot\left(\lambda^{-[k_m(j_m,t)+1]}\right)^{\frac{\gamma}{1-\gamma}}\cdot Q_m(t)^{-\varepsilon},\;m=L,H, \tag{6.22}$$

[7] The assumption of complementarity between intermediate goods further adds to the progressive complexity of new quality improvements, captured by the term Q_m^{ε}. Note that our complementarity specification implies that incentives for discovering new goods would grow rapidly over time (more complements raise the values of new intermediate goods), thus leading to explosive growth. Therefore, as in Evans *et al.* (1998), $\varepsilon\equiv\frac{\phi-1}{1-\alpha}$ reflects the offsetting effect induced by a higher cost of designing intermediate goods with a higher index, implying that the values for r and g are constant over time, and allowing us to solve the model for a BGP equilibrium.

As the terminal date of each monopoly arrives as a Poisson process with frequency $I_m(j_m, t)$ *per* (infinitesimal) increment of time, the present value of a monopolist's profits is a random variable. Let $V_m(j_m, t)$ and $V_m^+(j_m, t)$ denote the expected value of an incumbent with current quality level $k_m(j_m, t)$ and $k_m(j_m, t) + 1$, respectively.[8] By focusing on the BGP, we take into account that, as will be shown later, P_m, r and I are constant over time. We then have $V_m(j_m, t) = \pi_0 \cdot M \cdot \left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}} \cdot P_m^{\frac{1}{1-\alpha}} \cdot \int_t^{\infty} Q_m(s)^{\varepsilon} \cdot e^{-(r+I_m(j_m))s} ds$, where $\pi_0 \cdot M \cdot \left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}} \cdot P_m^{\frac{1}{1-\alpha}} = \pi_m(j_m, t) \cdot Q_m(t)^{-\varepsilon}$, given by (6.12), are constant in-between innovations; hence, we can further write:

$$V_m(j_m, t) = \frac{\pi_m(j_m, t)}{r + I_m(j_m) - \varepsilon \cdot \frac{\dot{Q}_m}{Q_m}}, \; m = L, H, \tag{6.23}$$

where $\dot{Q}_m / Q_m$ is also constant on BGP. On the other hand, free-entry prevails in vertical R&D such that the condition $I_m(j_m, t) \cdot V_m^+(j_m, t) = R_{v,m}(j_m, t)$ holds, which implies:

$$V_m^+(j_m, t) = \Phi_m(j_m, t) = \zeta \cdot \left(\lambda^{[k_m(j_m,t)+1]}\right)^{\frac{\gamma}{1-\gamma}} \cdot Q_m(t)^{-\varepsilon}, \; m = L, H. \tag{6.24}$$

By substituting (6.23) into (6.24) and using (6.12) to simplify, we get the no-arbitrage condition facing a vertical innovator:

$$r + I_m = (1 - \gamma) \cdot \frac{M}{\zeta} \cdot \left(\frac{rq}{\chi}\right)^{-\frac{\alpha}{1-\alpha}} \cdot (\alpha P_m)^{\frac{1}{1-\alpha}} + \varepsilon \frac{\dot{Q}_m}{Q_m}, \; m = L, H, \tag{6.25}$$

where the rates of entry are symmetric across industries $I_m = I_m(j_m)$.

After solving equation (6.22) for $R_{v,m}(j_m, t)$ and aggregating across industries j_m, we determine the optimal total resources devoted to vertical R&D, $R_{v,m}(t) =$

[8] Entrants behave as risk neutral agents, and, thus, only care about the expected value of the firm, since $V_m(j_m, t)$ is the perfectly diversified stock-market valuation of the current incumbent in industry j.

$\int_0^{A_m(t)} R_{v,m}\left(j_m,t\right)dj_m$. As the innovation rate is industry independent, then:

$$R_{v,m}(t) = \zeta \cdot \lambda^{\frac{\gamma}{1-\gamma}} \cdot I_m \cdot Q_m(t)^{(\varepsilon+1)},\ m = L, H. \tag{6.26}$$

Variety expansion arises from (horizontal) R&D aimed at creating a new intermediate good. We derive the horizontal R&D arbitrage condition following the same reasoning as in the vertical R&D case. However, contrarily to the vertical R&D case, where each new successful innovation increases the quality of an existent good by $\lambda^{\frac{\gamma}{1-\gamma}}$, each horizontal innovation results in a new intermediate good with a quality level drawn randomly from the distribution of existing varieties (*e.g.*, Howitt, 1999). Thus, the expected quality level of the horizontal innovator is:

$$\overline{z}_m(t) \equiv \int\limits_0^{A_m(t)} \frac{\left(\lambda^{k_m(j_m,t)}\right)^{\frac{\gamma}{1-\gamma}}}{A_m(t)} dj_m \equiv \frac{Q_m(t)}{A_m(t)},\ m = L, H. \tag{6.27}$$

The production function of new varieties of intermediate goods, exhibiting constant returns to scale at firm level and involving a horizontal innovation cost symmetric across firms, is $\dot{A}^f_m(t)/A^f_m(t) = R^f_{h,m}(t)/\eta_m(t)$, where $\dot{A}^f_m$ denotes the contribution of R&D firm f to the total of new m-complementary intermediate-good varieties that are being created at time t at a cost of η_m units of the final good, and $R^f_{h,m}$ denotes the resources a firm devotes to creating new product lines. Then, aggregating across firms f, total resources devoted to horizontal R&D are given by:

$$R_{h,m}(t) = \eta_m(t) \cdot \frac{\dot{A}_m(t)}{A_m(t)},\ m = L, H. \tag{6.28}$$

We assume that the cost of setting up a new variety is:

$$\eta_m(t) = \beta_1 \cdot A_m(t)^{\beta_2+1}, \tag{6.29}$$

where $\beta_1 > 0$ is a constant fixed (flow) cost and $\beta_2 > \varepsilon$. The latter condition, jointly with $\phi > \alpha$, guarantees that $\varepsilon > -1$ and hence $\beta_2 + 1 > 0$.[9] Thus, similarly to vertical R&D, horizontal entry cost function η_m incorporates an R&D complexity effect that arises through the dependence of η_m on A_m (*e.g.*, Evans *et al.*, 1998; and Barro and Sala-i-Martin, 2004, ch. 6), implying that the larger the number of existing varieties, the costlier it is to introduce new ones.

Taking into account the expected quality level (6.27) and following a similar line of reasoning as in the vertical R&D case, the expected value of a monopolist is $V_m(t) = \pi_0 \cdot M \cdot \overline{z}_m(t) \cdot P_m^{\frac{1}{1-\alpha}} \cdot \int_t^\infty Q_m(s)^\varepsilon \cdot e^{-[r+I_m(\overline{z}_m(s))]s} ds$, where $\pi_0 \cdot M \cdot \overline{z}_m(t) \cdot P_m^{\frac{1}{1-\alpha}} = \bar{\pi}_m(t) \cdot Q_m(t)^{-\varepsilon}$. The free-entry condition, $\dot{A}_m(t) \cdot V_m(t) = R_{h,m}(t)$, by (6.28) simplifies to:

$$V_m(t) = \frac{\eta_m(t)}{A_m(t)}, \; m = L, H. \tag{6.30}$$

Then, time-differentiating (6.30) yields the horizontal R&D no-arbitrage condition:

$$r + I_m = \frac{\bar{\pi}_m(t)}{\eta_m(t)/A_m(t)} + \varepsilon \frac{\dot{Q}_m}{Q_m}, \; m = L, H. \tag{6.31}$$

Using the above derived vertical and horizontal R&D arbitrage conditions given by equations (6.25) and (6.31) respectively, we can now derive the *intra-sector* arbitrage condition, by equating the effective rate of return, $r + I_m$, $m = L$, H, for both R&D types. The *intra-sector* no-arbitrage condition reflects the idea that, in equilibrium, the

[9]It will be shown later that the condition $\beta_2 > \epsilon$ is required for positive economic growth to exist with simultaneous vertical and horizontal R&D along the BGP.

competitive capital market is equally willing to finance vertical and horizontal R&D in each sector m. Thus, using equations (6.25) and (6.31), the intra-sector no-arbitrage condition is:

$$\zeta \cdot Q_m(t)^{\varepsilon} \cdot \frac{Q_m(t)}{A_m(t)} = \frac{\eta_m(t)}{A_m(t)} = \beta_1 A_m^{\beta_2}(t), \; m = L, H. \tag{6.32}$$

The *intra-sector* no-arbitrage conditions, within the H- and L-technology R&D sectors, equate the average cost of horizontal R&D, η_m/A_m, to the average cost of vertical R&D, $\zeta Q_m^{\varepsilon} \bar{z}_m$.

We must also derive an *inter-sector* no-arbitrage condition, defining a situation of indifference between, *e.g.*, vertical innovating in L- or H-technology R&D sector. Thus, by equating the effective rate of return for each $m = L$, H in (6.25), we get:

$$I_H - I_L = \frac{\pi_0}{\zeta}\left(h \cdot H \cdot P_H^{\frac{1}{1-\alpha}} - l \cdot L \cdot P_L^{\frac{1}{1-\alpha}}\right) \tag{6.33}$$

6.3 The general-equilibrium BGP

In this section, we derive and characterise the general-equilibrium interior BGP.

The aggregate financial wealth held by households is composed by the equity of intermediate-good producers $B(t) = B_L(t) + B_H(t)$, where $B_m(t) = K_m(t) + \int_0^{A_m(t)} V_m(j_m, t) dj_m$, $m = L, H$. Equivalently, from the no-arbitrage condition between vertical and horizontal entry, we have $B(t) = K_L(t) + K_H(t) + \eta_L(t) \cdot A_L(t) + \eta_H(t) \cdot A_H(t)$. Taking time derivatives and comparing with (6.1), the aggregate flow budget constraint is equivalent to the final-good market equilibrium condition:

$$Y(t) = C(t) + \dot{Z}(t) \tag{6.34}$$

The dynamic general equilibrium is defined by the paths of allocations and price distributions $(\{X_m(j_m,t),p_m(j_m,t)\},j_m\in[0,A_m(t)])_{t\geq 0}$ and of the number of firms, quality indices and vertical-innovation rates $(\{\,A_m(t),Q_m(t),I_m(t)\}\,)_{t\geq 0}$ for sectors $m=L,H$, and by the aggregate paths $(\mathcal{I}(t),C(t),q(t),r(t))_{t\geq 0}$, such that: *(i)* final-good firms, intermediate-good firms and consumers solve their problems; *(ii)* free-entry and no-arbitrage conditions are met; and *(iii)* markets clear. Total supplies of high- and low-skilled labour are exogenous.

Along the general-equilibrium BGP, the aggregate resource constraint (6.34) is satisfied with Y, C and $\dot{Z}$ growing at the same constant rate, $g_Y=g_C=g_{\dot{Z}}$. Since a constant $g_{\dot{Z}}$ implies $g_{\dot{Z}}=g_Z$, then $g_Y=g_Z$, as considered in our derivations in Subsection 2.2 above. By considering (6.20) and by time-differentiating (6.32), we show that a general-equilibrium BGP exists only if the following conditions hold among the asymptotic growth rates, which are all constant:

(i) the growth rates of the quality indices are equal, $g_{Q_L}=g_{Q_H}$, and are monotonously related to the endogenous growth rate of the economy, $g_Y=g=(1+\varepsilon)g_{Q_m}$, $m=L,H$;

(ii) the growth rates of the number of varieties are equal, $g_{A_L}=g_{A_H}$;

(iii) the vertical-innovation rates and the final-good price indices are trendless, $g_{I_L}=g_{I_H}=g_{P_L}=g_{P_H}=0$;

(iv) the growth rates of the quality indices and of the number of varieties are monotonously related as $g_{Q_L}/g_{A_L}=g_{Q_H}/g_{A_H}=(1+\beta_2)/(1+\varepsilon)$. Then $g_{A_H}=g_{A_L}=g/(1+\beta_2)$;

(v) the market interest rate and the market value of total capital are trendless, $g_r=g_q=0$.

The transversality conditions hold if $g > 0$. Thus, it is clear from *(i)* and *(iv)* that variety expansion is sustained by endogenous technological-knowledge accumulation. In particular, expected higher profits from increased intermediate-good quality generated by vertical R&D make it attractive for intermediate-good firms to invest in variety expansion, despite the negative spillovers in horizontal entry (entry cost increases with the number of newly created varieties). Thus, vertical innovation drives economic growth, in the sense that it sustains both variety expansion and aggregate output growth.

The necessary condition *(i)* implies that the trendless levels for the vertical-innovation rates verify $I_L = I_H = I$, along the BGP. Introducing this in equation (6.33) we derive:

$$\left(\frac{P_H}{P_L}\right)^* = \left(\frac{l}{h}\frac{L}{H}\right)^{1-\alpha} \tag{6.35}$$

where $*$ denotes BGP values.

Combining this with expressions (6.14) and (6.15), after some algebra we obtain:

$$\left(\frac{Q_H}{Q_L}\right)^* = \left(\frac{h}{l}\frac{H}{L}\right)^{\frac{1-\alpha}{\phi-\alpha}} \tag{6.36}$$

Equation (6.36) defines the long-run technological-knowledge bias $(Q_H/Q_L)^*$ as a function of the relative supply of skills, H/L. This is a common result in the Skill Biased Technological Change (*SBTC*) literature, reflecting the endogeneity of the skill-bias of newly adopted technologies. In fact, recalling expression (6.25) we can see that the skill structure influences the direction of technological-knowledge development through two channels. On the one hand, the market-size channel, acting through $H(L)$, increases the innovation rate of *H(L)*-technology R&D, since an increase in the labour supply broadens the market for the respective technology type. On the other hand, the price channel, acting through P_m, reduces the innovation rate of *H(L)*-technology R&D, *i.e.*, this channel favours developing technologies that complement the relatively scarce type of labour, since the prices for the final goods that they produce will be higher. Expression (6.36) shows that the market-size effect dominates the price-channel effect, since the technological-knowledge bias is increasing in the relative supply of skills. Additionally, as (6.36) shows, $(Q_H/Q_L)^*$ is directly affected by the degree of gross substitutability/complementarity, ϕ. This result will be analysed in more detail below.

Using equation (6.35) in (6.19), the expression for the skill premium becomes:

$$\frac{W_H}{W_L} = \frac{L}{H}\left(\frac{Q_H(t)}{Q_L(t)}\right)^{(\varepsilon+1)} \tag{6.37}$$

Equation (6.37) illustrates the two mechanisms through which changes in the relative supply of skills influence the skill premium in equilibrium. Initially, an increase in the supply of the H factor reduces the skill premium, which is consistent with the basic producer theory, *i.e.* increasing supply reduces prices. This immediate effect is then followed by a change in the opposite direction induced through the technological-knowledge bias. By substituting (6.36) in (6.37), we get:

$$\left(\frac{W_H}{W_L}\right)^* = \frac{L}{H}\left(\frac{h}{l}\frac{H}{L}\right) = \frac{h}{l} \tag{6.38}$$

Thus, the long-run skill premium does not depend on the relative supply of skills, H/L, because the two above referred to mechanisms exactly offset each other. As noted by Acemoglu and Zilibotti (2001), this results from the fact that the aggregate production function is characterized by a constant elasticity of substitution between H- and L- technologies equal to 2 (see (6.20)). As emphasised by Acemoglu (2009, Ch.15), in the context of substitution between high- and low-skilled workers an elasticity of substitution close to 2 seems to be the most probable according to the empirical evidence. As (6.38) shows, the long-run skill premium is determined solely by the productivity advantage ratio of high- to low-skilled labour, h/l (*e.g.*, Acemoglu and Zilibotti, 2001).

If we assume that the number of industries, A_m, is large enough to treat Q_m as time-differentiable and non-stochastic, we can time-differentiate (6.6) to get $\dot{Q}_m$. Then, if $\beta_2 > \varepsilon$, we can derive another relationship between the growth rate of the quality indices and of the number of varieties,

$$g_{Q_m}(t) = I_m(t) \cdot (\lambda^{\frac{\gamma}{1-\gamma}} - 1) + g_{A_m}(t),\ m = L, H. \tag{6.39}$$

By applying (6.39) to the BGP, and by combining it with the BGP condition $g^*_{A_m} = (1+\varepsilon)/(1+\beta_2)g^*_{Q_m}$, we find that the constraint $\beta_2 > \varepsilon$ is required for (6.39) to be well defined, *i.e.*, for positive BGP economic growth to exist with both positive $g^*_{A_m}$ and I^*_m. Under this condition, the economic growth rate, $g^* = (1+\varepsilon)g^*_{Q_m}$, is proportional to the growth rate of intermediate-good quality plus the growth rate of the number of varieties, in line with the well-known view that industrial growth proceeds both along an intensive and an extensive margin. Note also that, since $\varepsilon \equiv (\phi - 1) / (1 - \alpha)$, that condition is equivalent to $\phi < \beta_2 \cdot (1-\alpha) + 1$. This upper limit on the parameter that regulates gross substitutability/complementarity, ϕ, is necessary because of the roundabout effect linking horizontal and vertical R&D: given the distinct nature of vertical and horizontal innovation (immaterial *versus* physical) and the consequent asymmetry in terms of R&D complexity costs (see (6.21) and (6.29)), vertical innovation sustains variety expansion, which, in turn, expands the technological-knowledge stock, thereby increasing the amount of resources available for both types of R&D. Such a constraint on ϕ does not arise in, *e.g.*, Evans *et al.* (1998), Thompson (2008), where only horizontal R&D exists, whereas in Jones and Williams (2000) vertical innovation is just a spillover of horizontal R&D activities.

Using the relations presented above, we complete the derivation of the growth rate of the aggregate quality indices, g_{Q_m}, and the economic growth rate, g for the BGP. We obtain the following implicit equations for g_{Q_m} and g:

$$g^*_{Q_m} = \psi\left(\Omega - r^*\right), \tag{6.40}$$

$$g^* = (1+\varepsilon)\,\psi\left(\Omega - r^*\right), \tag{6.41}$$

where

$$\Omega \equiv \frac{1-\gamma}{\zeta} M \left(\frac{r^* q^*}{\chi}\right)^{-\frac{\alpha}{1-\alpha}} \left(\alpha P^*_m\right)^{\frac{1}{1-\alpha}}, \tag{6.42}$$

$$\psi \equiv \frac{(1+\beta_2)\left(\lambda^{\frac{\gamma}{1-\gamma}} - 1\right)}{\beta_2 - \varepsilon - \varepsilon(\beta_2+1)(\lambda^{\frac{\gamma}{1-\gamma}} - 1)}, \tag{6.43}$$

and both r^* and q^* are functions of g^*, by (6.2) and (6.8), respectively.[10]

Next, we analyse the BGP effects on the long-run economic growth rate of shifts in the technological parameters ϕ, θ and β_2.

In order to assess the effects of an increase in the degree of gross substitutability/complementarity, ϕ, we use the Implicit Function Theorem to derive $\frac{\partial g}{\partial \phi} = -\frac{\partial F}{\partial \phi} / \frac{\partial F}{\partial g}$.

[10] Despite the non-linearity of (6.41), there are no multiple general-equilibria interior BGP. To see this, observe that (6.41) is negatively sloped in the first quadrant of the space (g, r, q), while (6.2) and (6.8) are always non-negatively sloped.

Recalling expressions (6.43), (6.42) and that $\varepsilon \equiv (\phi - 1) / (1 - \alpha)$, and defining $F(\cdot) \equiv g - \psi(1+\varepsilon)(\Omega - r) = 0$, we first compute $\frac{\partial F}{\partial g}$, evaluated at the BGP:

$$\begin{aligned}\frac{\partial F}{\partial g} = \quad & 1 + \psi(1+\varepsilon)\left(\tfrac{\alpha}{1-\alpha}\right)(g\sigma + \rho)^{-\frac{1}{1-\alpha}} \cdot \\ & \cdot \left[(1-\gamma)M\chi^{\frac{\alpha}{1-\alpha}}(\alpha P_m)^{\frac{1}{1-\alpha}}\tfrac{1}{\zeta}(rq)^{-\frac{1}{1-\alpha}}(\sigma q + \theta r) + \sigma\left(\tfrac{1-\alpha}{\alpha}\right)\right] > 0\end{aligned} \tag{6.44}$$

Then we find that $\frac{\partial F}{\partial \phi}$, also evaluated at the BGP, is:

$$\frac{\partial F}{\partial \phi} = -\frac{\psi^2}{1-\alpha}\left(\frac{1+(\beta_2+1)(\lambda^{\frac{\gamma}{1-\gamma}}-1)}{(\beta_2+1)\left(\lambda^{\frac{\gamma}{1-\gamma}}-1\right)}\right) \cdot (\Omega - r) < 0 \tag{6.45}$$

Consequently, we have $\frac{\partial F}{\partial \phi} / \frac{\partial F}{\partial g} < 0$, and thus $\frac{\partial g}{\partial \phi} > 0$, *i.e.*, an increase in ϕ – a reduction in the degree of gross substitutability or an increase in the degree of gross complementarity between technological goods – positively affects the long-run economic growth rate. The intuition behind this result is fairly simple. When technological goods used in production are gross complements, an increased quantity of some goods raises the marginal productivity of the others.[11] This implies that, at constant prices, the quantity demanded goes up, production increases and output grows faster than it would otherwise.

We now assess the effects of an increase in the horizontal R&D complexity-cost parameter, β_2, by deriving $\frac{\partial g}{\partial \beta_2} = -\frac{\partial F}{\partial \beta_2} / \frac{\partial F}{\partial g}$. Since $\frac{\partial F}{\partial \beta_2}$, evaluated at the BGP, is:

$$\frac{\partial F}{\partial \beta_2} = -\left(-\frac{1+\varepsilon}{\left[\beta_2 - \varepsilon - \varepsilon(\beta_2+1)(\lambda^{\frac{\gamma}{1-\gamma}}-1)\right]^2}\right) \cdot (1+\varepsilon) \cdot \left(\lambda^{\frac{\gamma}{1-\gamma}} - 1\right) \cdot (\Omega - r) > 0 \tag{6.46}$$

it follows that $\frac{\partial F}{\partial \beta_2} / \frac{\partial F}{\partial g} > 0$, and thus $\frac{\partial g}{\partial \beta_2} < 0$, *i.e.*, an increase in the horizontal R&D complexity-cost parameter, β_2, negatively affects the the long-run economic growth rate.

[11] In this sense, the effect of complementarities between technological goods in production is equivalent to increasing returns.

The intuition behind this result is the following. Recalling our horizontal R&D entry cost function, $\eta_m(t)$, we can see that entry costs are higher as a result of an increase in β_2 (see Section 6.2.3), which makes investments in the creation of new product lines less attractive for the intermediate-good firms. And given that the economic growth rate increases with the aggregate quality index growth rate, which on its turn is positively influenced by the variety expansion growth rate, the negative effect on g is verified.

Finally, in order to analyse the impact of changes in the adjustment-cost parameter, θ, we determine the sign of $\frac{\partial g}{\partial \theta} = -\frac{\partial F}{\partial \theta} / \frac{\partial F}{\partial g}$. Since $\frac{\partial F}{\partial \theta}$, evaluated at the BGP, is:

$$\frac{\partial F}{\partial \theta} = \psi (1+\varepsilon) \left(\frac{\alpha}{1-\alpha} \right) \left(\frac{(1-\gamma)}{\zeta} M r^{-\frac{\alpha}{1-\alpha}} \chi^{\frac{\alpha}{1-\alpha}} (\alpha P_m)^{\frac{1}{1-\alpha}} \right) (1+\theta g)^{-\frac{1}{1-\alpha}} g > 0 \tag{6.47}$$

then $\frac{\partial F}{\partial \theta} / \frac{\partial F}{\partial g} > 0$ and thus $\frac{\partial g}{\partial \theta} < 0$, *i.e.*, the long-run economic growth rate is negatively affected by the internal investment costs. The explanation for this result steams directly from the internal investment costs theory. In particular, accounting for capital installation costs in their optimisation problem, firms control their rate of investment (not the capital stock) at each t. Consequently, when internal investment costs increase, *i.e.* installing new capital becomes more expensive, firms will tend to reduce investment. This will slowdown the accumulation of technological knowledge, leading to a reduction in the economic growth rate.

6.4 Long-run technology structure

In order to take our model to the data and, in particular, to quantitatively associate the empirical facts on the technology structure and the skill structure to the complexity costs and the complementarity between technological goods (*i.e.*, the intermediate goods), a task to carry out in Section 6.5, we need to consider convenient measures of the technology-structure variables.

The long-run technology structure of our model is characterised by the technological-knowledge bias,$(Q_H/Q_L)^*$, the relative intermediate-good production $(X_H/X_L)^*$, and the relative number of firms $(A_H/A_L)^*$ (*i.e.*, H- *vis-à-vis* L-technology sector). In equation (6.36), we show that the technological-knowledge bias is a function of the skill structure, which is characterised by the relative supply of skills, H/L. The same can be proved as regards relative production and the relative number of firms. From the no-arbitrage condition (6.32) and taking into account equation (6.36), we derive the relative number of firms:

$$\left(\frac{A_H}{A_L}\right)^* = \left(\frac{h}{l}\frac{H}{L}\right)^{D_0} = \left(\frac{W_H}{W_L}\right)^{D_0} \cdot \left(\frac{H}{L}\right)^{D_0}, \tag{6.48}$$

where:

$$D_0 \equiv \frac{1}{\beta_2 + 1}. \tag{6.49}$$

From the expressions for X_L and X_H (obtained by aggregating (6.11)) and (6.36), we get:

$$\left(\frac{X_H}{X_L}\right)^* = \frac{h}{l}\frac{H}{L} = \frac{W_H}{W_L} \cdot \frac{H}{L}. \tag{6.50}$$

However, since we wish to confront our theoretical results with the data on production for a number of countries and the data is presented on a quality-adjusted base by the national statistics offices (see, *e.g.*, Eurostat, 2001), we find it convenient to compute production also in quality-adjusted terms. Reiterating the steps as in Section 6.2.2, we find total intermediate-good quality-adjusted production to be $\mathfrak{X}_m = \int_0^{A_m} \int_0^{\bar{n}} \lambda^{k_m(j_m)} \cdot X_m(n, j_m) dn dj_m = M \cdot (\alpha \cdot P_L(t))^{\frac{1}{1-\alpha}} \cdot (r \cdot q/\chi)^{\frac{-1}{1-\alpha}} \mathcal{Q}_m \cdot Q_m^{\epsilon}$, $m = L, H$, where $\mathcal{Q}_m = \int_0^{A_m} \lambda^{k_m(j_m)\frac{1}{1-\gamma}} dj_m$. Although we cannot find an explicit algebraic expression for the BGP value of $\mathcal{Q}_m$, as shown in Gil *et al*. (2012b), we can build an adequate proxy for

$\mathcal{Q}_m$, $\widehat{\mathcal{Q}}_m = Q_m^{\frac{1}{\gamma}} \cdot A_m^{-\left(\frac{1-\gamma}{\gamma}\right)}$. Accordingly, we define the proxy $\widehat{\mathfrak{X}}_m = X_m \cdot (Q_m/A_m)^{\frac{1-\gamma}{\gamma}}$ for $\mathfrak{X}_m$. Thus, bearing in mind (6.36), (6.48) and (6.50), we consider the following quality-adjusted measure of relative production:

$$\left(\frac{\widehat{\mathfrak{X}}_H}{\widehat{\mathfrak{X}}_L}\right)^* = \left(\frac{X_H}{X_L}\right)^* \cdot \left[\frac{\left(\frac{Q_H}{Q_L}\right)^*}{\left(\frac{A_H}{A_L}\right)^*}\right]^{\frac{1-\gamma}{\gamma}} = \left(\frac{h}{l}\frac{H}{L}\right)^{D_1} = \left(\frac{W_H}{W_L}\right)^{D_1} \cdot \left(\frac{H}{L}\right)^{D_1}, \qquad (6.51)$$

where:

$$D_1 \equiv 1 + \left(\frac{1-\alpha}{\phi-\alpha} - \frac{1}{\beta_2+1}\right) \cdot \left(\frac{\phi-\alpha}{\alpha}\right) \qquad (6.52)$$

In the above equations, we used the fact that, on the BGP, the skill premium relates one-to-one to the absolute productivity advantage of high- over low-skilled labour h/l (see (6.38)), in order to replace the latter with W_H/W_L. Thus, we see that, according to the model, two types of effects determine the cross-country behaviour of the technology structure depicted by Figure 6.2 in the Appendix: the market-size effect, through which a higher proportion of high-skilled workers is associated with technological change directed towards the high-tech sectors and the skill-premium effect, reflecting the absolute productivity advantage of high-skilled workers.

Anticipating the empirical results detailed in Section 6.5, we focus on the conditions under which: *(i)* the elasticities D_0 and D_1 are positive and *(ii)* $D_0 < D_1$. As already shown in Section 6.2.3, given the constraints $\phi > \alpha$ and $\beta_2 > \varepsilon$, $\varepsilon \equiv (\phi-1)/(1-\alpha)$, we have $\beta_2 > -1$ and thus $D_0 > 0$. On the other hand, the constraint $\beta_2 > \varepsilon \Leftrightarrow \phi < \beta_2 \cdot (1-\alpha) + 1$ is sufficient for both $D_1 > 0$ and $D_0 < D_1$ to be satisfied (the former inequality is equivalent to $\phi < \beta_2 + 1 + \alpha$ and the latter to $\phi < \beta_2 + 1$). Thus, when the degree of gross substitutability/complementarity, ϕ, is compatible with BGP economic growth both along an intensive and an extensive margin (see Section 6.3), it also implies a positive elasticity of both technology-structure variables – the relative number of firms and relative production – with respect to the skill structure and the skill premium, as observed in the data. Moreover, an elasticity of relative production larger than that of the relative number of firms reflects the fact that the vertical-innovation mechanism ultimately commands the horizontal entry dynamics, meaning that a BGP with increasingly costly horizontal R&D occurs only because entrants expect the incumbency value to grow, propelled by quality-enhancing R&D. This mechanism generates a roundabout effect that amplifies the impact of the market-size channel on relative (quality-adjusted) production, when compared to the impact on the relative number of firms.

6.5 Estimation and calibration

We now turn to a quantitative assessment of the model and investigate how important our analytical mechanism may be in accounting for the cross-country pattern in the distribution of firms and production between high- and low-tech sectors. Although it should be clear that our mechanism does not account for all the variation in the technology structure across countries, we abstract from all other potential sources of variation. Thus, this exercise provides an upper bound on how much of the referred to cross-country differences can be explained by the variation in the skill structure. Then, given the estimated effect of the skill structure on the technology structure, we establish the implicit estimate of the horizontal R&D complexity-cost parameter, β_2, and thereby of the degree of complementarity between technological goods, ϕ.

In particular, we are interested in checking whether the case of $\phi > 1$, which features as a key assumption in the theoretical literature that studies poverty traps, growth and business cycles based on the mechanism of gross complementarity in technological goods (*e.g.*, Matsuyama, 1995; Ciccone and Matsuyama, 1996; Evans *et al.*, 1998), has empirical support, by using recent cross-country data on the technology structure (*i.e.*, relative production and the relative number of firms) and the skill structure (*i.e.*, the relative supply of skills).[12] Recall, from Section 6.2, that the only assumption on ϕ imposed by our theoretical model is $\phi > \alpha$, with $0 < \alpha < 1$, such that either gross substitutability ($\phi < 1$) or gross complementarity ($\phi > 1$) may arise *a priori*.

We adopt the following strategy. First, we consider equations (6.48) and (6.51) to get:

$$\ln A_H/A_L = D_0 \ln (H/L) + D_0 \ln (W_H/W_L) \tag{6.53}$$

$$\ln \widehat{\mathfrak{X}}_H/\widehat{\mathfrak{X}}_L = D_1 \ln (H/L) + D_1 \ln (W_H/W_L) \tag{6.54}$$

Then, based on (6.53) and (6.54), we run the regressions:

$$\ln A_H/A_L = S_0 + D_{01} \ln (H/L) + D_{02} \ln (W_H/W_L) + e_0 \tag{6.55}$$

$$\ln \widehat{\mathfrak{X}}_H/\widehat{\mathfrak{X}}_L = S_1 + D_{11} \ln (H/L) + D_{12} \ln (W_H/W_L) + e_1 \tag{6.56}$$

where e_i, $i = 0, 1$, are the error terms, to get the estimates $\hat{D}_{01}$, $\hat{D}_{02}$, $\hat{D}_{11}$, and $\hat{D}_{12}$.[13] Table 6.1 reports the OLS estimates of the coefficients in regressions (6.55) and (6.56), which are run on the cross-section data in the Appendix. Bearing in mind that, in light of the theoretical model, $D_{01} = D_{02} = D_0$ and $D_{11} = D_{12} = D_1$, we overlap the confidence intervals for D_{i1} and D_{i2}, $i = 0, 1$, in order to get a single confidence interval for the elasticities D_i. This is depicted by Table 6.2.

[12] See the Appendix for more details on the data.

[13] The log-log relationships arising from our BGP results for the relative number of firms and for relative production (equations (6.53) and (6.54)) have no intercept, in contrast to the regression equations (6.55) and (6.56). We can easily modify our model in order to have a non-zero intercept in (6.53) and (6.54), by considering heterogeneous flow fixed costs of R&D across L- and H-technology sectors in (6.22) and (6.28), such that $\zeta_H \neq \zeta_L$ and $\beta_{1H} \neq \beta_{1L}$.

Dependent variable	ln Relative number of firms	ln Relative production
Constant	-1.890	-0.908
(s.e.); (p-value)	(0.489); (0.001)	(0.442); (0.061)
ln Relative supply of skills	0.506	0.832
(s.e.); (p-value)	(0.312);(0.120)	(0.280); (0.011)
ln Skill premium	0.766	1.717
(s.e.); (p-value)	(0.332); (0.032)	(0.842); (0.062)
Observations	23	16
R^2	0.144	0.291

Table 6.1: OLS regressions of the technology-structure variables (relative production and the relative number of firms) on the relative supply of skills and the skill premium, in logs, run on cross-country data. Standard errors (s.e.) are heteroscedasticity consistent.

	$i = 0$	$i = 1$
Confidence interval for D_{i1}	0.506 ± 0.312	0.832 ± 0.280
Confidence interval for D_{i2}	0.766 ± 0.332	1.717 ± 0.842
Confidence interval (juxtaposed) for D_i	$[0.434; 0.818]$	$[0.875; 1.112]$

Table 6.2: Two-standard-error confidence intervals for the slope coefficients in the regression equations (6.55) and (6.56), based on the results in Table 6.1.

[Table 1 goes about here]

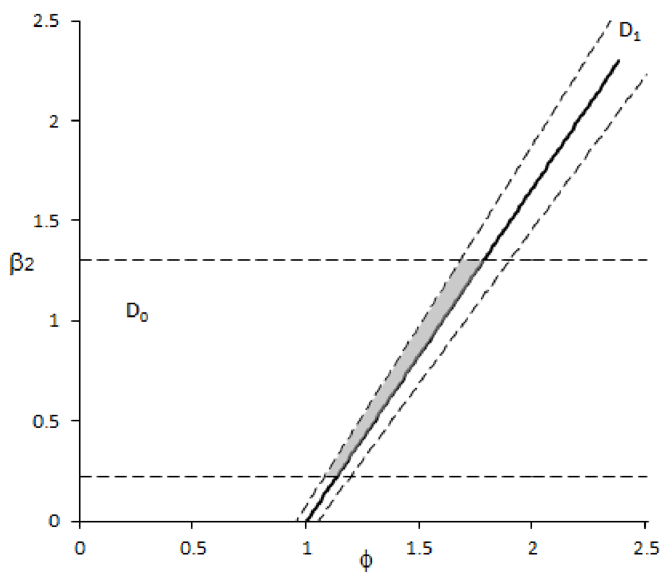
[Table 2 goes about here]

As D_0 is a function of β_2 and D_1 is a function of (α, ϕ, β_2), we let $\alpha = 0.4$, as usual in the literature, and then use the confidence intervals for D_0 and D_1 to get the implicit confidence intervals for (ϕ, β_2). Figure 4.4.1 juxtaposes the confidence intervals for ϕ and β_2, together with the subset of values in space (ϕ, β_2) that results from the constraint $\beta_2 > \varepsilon$, $\varepsilon \equiv (\phi - 1) / (1 - \alpha)$. Our calculations show values for β_2 between 0.22 and 1.30 and for ϕ between 1.08 and 1.78.[14] The fact that we get a

[14]Notice that, even though the goodness of fit of the regressions in Table 6.1 might most likely increase if we added explanatory variables, the approach followed herein reflects the fact that the log-log linear relationships between the technology-structure variables, the skill premium and the relative supply of skills have an exact analytical counterpart in terms of the BGP equilibrium of the model, as already shown. We take advantage of this fact to pursue an identification and estimation strategy for the key technology parameters using the empirical results on the technology-structure variables presented in Table 6.1.

confidence interval with positive values for β_2 indicates that the elasticity regulating the horizontal-R&D complexity costs is larger than the one in the vertical-R&D case (*i.e.*, $1+\beta_2 > 1$), in line with what should be expected bearing in mind the distinct nature of the two types of R&D. On the other hand, since our estimates of ϕ are larger than unity, our identification and estimation exercise suggests that there is gross complementarity between technological goods in production, thus supporting the key complementarity assumption appearing in the theoretical literature mentioned earlier. However, it is also noteworthy that, according to our exercise, calibrated values of ϕ as high as 4, as found in the literature (*e.g.*, Evans *et al.*, 1998; Thompson, 2008), seem to lack empirical support – Figure 4.4.1 makes clear that this observation is true irrespective of the constraint $\beta_2 > \varepsilon \Leftrightarrow \phi < \beta_2 \cdot (1-\alpha) + 1$.

Figure 6.1: Confidence intervals for the parameters ϕ and β_2



Confidence intervals for ϕ and β_2 implicit in the confidence intervals for the elasticities D_i, $i = 0, 1$ in Table 6.2 (dashed lines). The bold line depicts the boundary in space (ϕ, β_2) imposed by the constraint $\beta_2 > \varepsilon$, $\varepsilon \equiv (\phi - 1) / (1 - \alpha)$. $\alpha = 0.4$.

Finally, something may be said about our estimates of the markup, since, recalling (6.9) and that $\gamma = \alpha/\phi$ is imposed to ensure constant returns to scale, we are able to compute γ at the expense of ϕ. Thus, if we consider the drastic-innovation case in our model, such that the markup is $1/\chi = 1/\gamma$, the implicit confidence interval for the markup is $[2.70; 4.45]$. Confronting with the cross-section studies that are known to have robust direct estimates for the markup, we find that our (indirect) estimates are too high (*e.g.*, Nurrbin, 1993; and Basu and Fernald, 2002, indicate values within the interval $[1.016; 1.837]$). However, since those studies do not distinguish between drastic and non-drastic innovations, one may conjecture that the gap between the interval we computed, $[2.70; 4.45]$, and the one found by the empirical literature, $[1.016; 1.837]$, is a consequence of the quite small share of drastic innovations in the total number of innovations.[15]

Alternatively, if we consider the case of non-drastic innovations in our model, then the markup is given by $1/\chi = \lambda < 1/\gamma$, where now $1/\gamma \in [2.70; 4.45]$ defines the interval of critical values for the size of the quality jump, λ, that is implicit in our cross-country data.

We are also interested in the long-run relationship between the Tobin-q and both the degree of complementarity between technology goods, ϕ, and the complexity effect pertaining to horizontal R&D, β_2, through the impact of the last two factors on the long-run economic growth rate. We focus on the extreme values of the confidence intervals for ϕ and β_2 depicted by Figure 4.4.1, such that four scenarios are analysed corresponding to four different pairs (ϕ, β_2). Table 6.3 summarises the results.

To obtain quantitative results, we calibrate the model with the following values for the remaining parameters and exogenous values: $\rho = 0.02$, $\sigma = 1.5$, $\alpha = 0.4$, $\theta = 1$, $\beta_1 = 1$, $\zeta = 2.8$, $\lambda = 1.4$, $h/l = 1.7$ and $H/L = 0.18$. The values for ρ, σ and α are set

[15] If we take the mid-point of those two intervals and also consider that the average markup for non-drastic innovations varies between say 1 and 1.3, then the share of drastic innovations will vary between 4.82 and 15.53 percent.

β_2	ϕ	g^*	q^*	r^*	$\mathcal{E}^q_{\beta_2}$	$\mathcal{E}^q_{\phi}$
0.22	1.08	0.0311	1.0311	0.0666	-0.28	2.80
	1.13	0.0354	1.0354	0.0731	-0.38	3.34
1.30	1.68	0.0334	1.0334	0.0701	-1.20	1.64
	1.78	0.0391	1.0391	0.0787	-1.72	2.11
Simple average						
0.76	1.42	0.0348	1.0348	0.0721	-0.89	2.47

Table 6.3: Calibration results. $\rho = 0.02$, $\sigma = 1.5$, $\alpha = 0.4$, $\theta = 1$, $\beta_1 = 1$, $\zeta = 2.8$, $\lambda = 1.4$, $h/l = 1.7$ and $H/L = 0.18$.

in line with the standard literature (see, *e.g.*, Barro and Sala-i-Martin, 2004), while the values for H/L and h/l correspond to the average value of, respectively, the relative supply of skills and the skill premium in our cross-country data (see the Appendix). To reconcile the empirical literature on the markup with our estimates of the degree of complementarity, we consider the case of non-drastic innovations, the one that seems to be more common in practice, such that the markup is given by $1/\chi = \lambda < 1/\gamma$; then, bearing in mind the average estimate of the markup in Nurrbin (1993) and Basu and Fernald (2002), we let $\lambda = 1.4$. Finally, the values of the parameters θ, β_1 and ζ are chosen in order to calibrate the BGP aggregate growth rate, g^*, around 3.4 percent/year on average across scenarios (see Table 6.3), which corresponds to the average growth rate of the cross-country sample in the Appendix. Then, the implied average value for the real interest rate, r^*, is 7.2 percent, in line with the empirical value for the long-run average real return on the stock market, and which should be taken as the equilibrium rate of return to R&D, as argued by Jones and Williams (2000).

[Table 3 goes about here]

By using equations (6.44)-(6.46) and (6.8), our calibration results show that the elasticity of the Tobin-q with respect to ϕ, $\mathcal{E}^q_{\phi}$, takes values between 1.64 and 3.34, and with respect to β_2, $\mathcal{E}^q_{\beta_2}$, takes values between -0.28 and -1.72, as depicted by Table 6.3. It is noteworthy that $\mathcal{E}^q_{\phi}$ is always greater than unity, meaning that a shift in the degree of gross complementarity between technological goods, ϕ, has a more than proportional effect on the long-run market value of capital (*i.e.*, there is an elastic relationship). In turn, a change in the complexity effect pertaining to horizontal R&D, β_2, which may also be interpreted as a measure of the barriers to entry through R&D activities, also induces a more than proportional (negative) effect on the long-run market value of capital, but only if the complementarity degree is large enough.

A strong positive relationship between the Tobin-q and the R&D and technology characteristics of the firms has been frequently reported by the empirical literature (*e.g.*, Chan *et al.*, 1990; Hall, 1999; Connolly and Hirschey, 2005). This result is apparently supported by our estimation and calibration exercise, which, however, also suggests that it is important to distinguish between the technological determinants of the long-run market value of capital and explicitly analyse their interaction.

6.6 Concluding remarks

Building on the endogenous growth model of directed technical change with simultaneous vertical and horizontal R&D, internal costly investment and gross substitutability/complementarity between technological goods, this chapter aimed at identifying and quantifying the long-run link between: *(i)* the technology structure and the skill structure, by considering an explicit role for the degree of complementarity between technological goods; *(ii)* the Tobin-q and the technology characteristics of the firms through the impact of the latter on the long-run economic growth rate.

Using the model's solution for the BGP equilibrium, we show that it entails an analytical mechanism that is consistent with the observed cross-country pattern in the technology structure. Then, based on the analytical BGP relationships derived and on the cross-country data for the technology structure and the skill structure, we compute indirect estimates of the value of the parameters that regulate the degree of gross substitutability/complementarity and the complexity costs pertaining to horizontal R&D. In particular, our identification and estimation exercise suggests that there is gross complementarity between technological goods, thus supporting the key complementarity assumption appearing in the theoretical literature. Furthermore, a strong relationship between the Tobin-q and the R&D and technology characteristics of the firms is obtained, in line with the related empirical literature.

Finally, we believe that the study of the transitional dynamics should be pursued in future work. The qualitative characterisation of the local dynamics properties might allow one to find to what extent variations in a country's initial conditions lead to non-monotonic time paths of the technology structure and the economic growth rate towards the BGP in face of a shock in the skill structure, as observed in the 80s and 90s in a number of developed countries. This will also allow us to accommodate the fact that the time-span of the available data is relatively short and hence may entail transitional dynamics effects.

Appendix B

In this appendix, we present the cross-country data with respect to the technology structure, measured by the number of firms and by production in high- *vis-à-vis* low-tech manufacturing sectors, by considering the OECD (Organisation for Economic Co-operation and Development) high-tech low-tech classification (see Hatzichronoglou, 1997).[16] We will call these ratios the relative number of firms and relative production, respectively. We also collected data on the skill structure, *i.e.*, the ratio of high- to low-skilled workers or the relative supply of skills, measured as the ratio of college to non-college graduates among persons employed in manufacturing, and the skill premium, measured as the mean annual earnings of the college graduates employed in manufacturing *vis-à-vis* the mean annual earnings of the non-college graduates. "College graduates" refers to those who have completed tertiary education (corresponding to the International Standard Classification of Education [ISCED] levels 5 and 6), while "non-college graduates" refers to those who have completed higher-secondary education or less (ISCED levels from 0 to 4).

The data concerns the 1995-2007 average and covers 25, 16 and 29 European countries regarding, respectively, the number of firms, production,[17] and the supply of skills (educational attainment), whereas the data for the mean annual earnings respects to 2002 and covers 28 European countries. The source is the Eurostat on-line database on Science, Technology and Innovation – tables "Economic statistics on high-tech industries and knowledge-intensive services at the national level" and "Annual data on

[16]High-tech industries are, *e.g.*, aerospace, computers and office machinery, electronics and communications, and pharmaceuticals, while the low-tech sector comprises, *e.g.*, petroleum refining, ferrous metals, paper and printing, textiles and clothing, wood and furniture, and food and beverages.

[17]According to our theoretical model, we should restrict our analysis to the production of intermediate and capital goods. However, we were not able to find data according to the OECD classification of high- and low-tech sectors detailed by type of good and thus focused on total production in each sector.

employment in technology and knowledge-intensive sectors at the national level, by level of education" (available at `http://epp.eurostat.ec.europa.eu`).[18] At the aggregate level, we gathered data on the *per capita* real GDP growth rates for the same period, also from the same Eurostat on-line database.

Figure 6.2 depicts the data by country. We notice that, in all countries in the sample: *(i)* the relative number of firms and relative production are below unity; *(ii)* the relative supply of skills is below unity; and *(iii)* the skill premium is above unity.

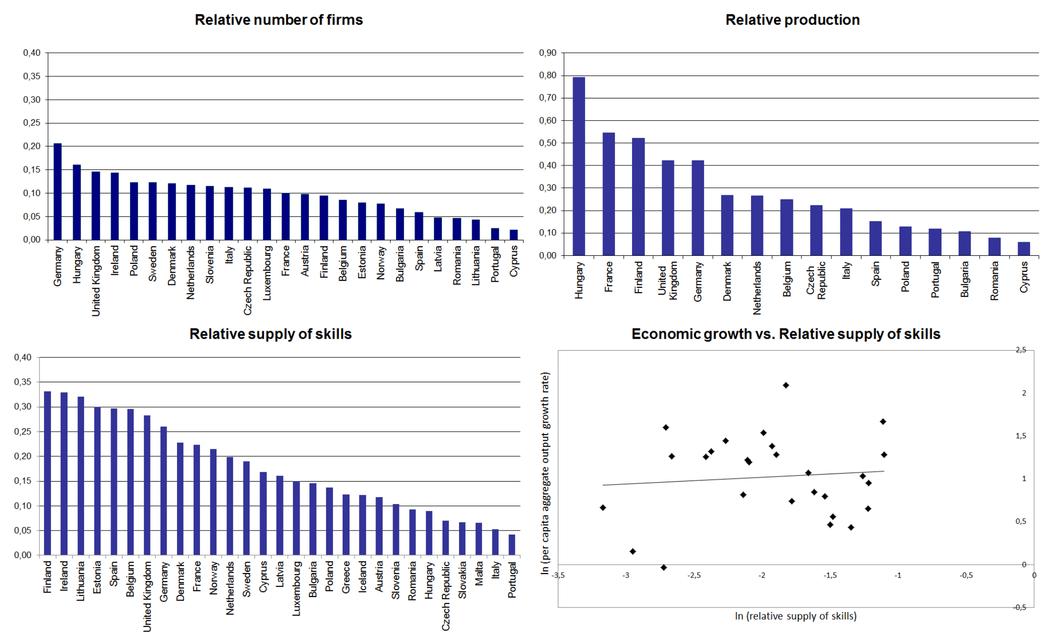


Figure 6.2: The technology-structure variables (the relative number of firms and relative production), the relative supply of skills and the skill premium, in a sample of European countries, 1995-2007 average (except for the skill premium, whose data is from 2002).

[18] Data with respect to output (Gross Value Added) is also available from the on-line OECD STAN Indicators Database (link at `http://stats.oecd.org`). According to the latter, the patterns depicted by Figure 6.2 are also verified for the non-European countries belonging to the OECD, namely the US, Canada, Mexico, Australia, Korea and Japan.

Chapter 7

Conclusions

This Chapter summarizes the main conclusions of our analysis on economic growth and income inequality conducted in this thesis, and also presents some possible venues for future research on the subject.

The first part of this thesis, comprising Chapters 2, 3 and 4, was dedicated to exploring the issues of economic growth and income inequality focusing on the role of the institutional factor and the impact of political rivalry. This analysis was performed using different methodologies, such as critical literature survey, theoretical modeling and empirical study.

In particular, in Chapter 2, based on a comparative critical assessment of an extensive literature covering both political economy and economic growth fields, we have studied how the quality of the institutional factor may influence the efficiency of redistribution policy specifically associated with human capital accumulation. In the decision to accumulate production factors in general and human capital in particular, we have attributed a crucial role to control-rights institutions, which we have defined as a combination of specific policy mechanisms and a hierarchical representation of power. We have also argued that the quality of these institutions is the decisive factor in the final outcome, in the sense that efficient growth-enhancing institutions should not only imply that appropriate public good investments will be undertaken to support aggregate productivity, increase human factor accumulation and stimulate growth, but also provide sufficient security of control rights for individuals, thus avoiding expropriation in the form of *ex-post* redistributive distortions. We have seen that efficient redistribution creates positive externalities by enabling investment in human capital accumulation, and is therefore essentially different from inefficient redistribution, which creates negative externalities by lowering factor endowments and decreasing aggregate productivity. Positive redistribution policy effects may be secured when tax-revenues are appropriately allocated to stimulate investment in human capital accumulation in the form of public tax-financed education, increasing productivity and improving aggregate economic performance. We have then defined a political-economic equilibrium as a combination of a medium strong state, reliable control-rights institutions and efficient redistribution aimed at human capital accumulation. This equilibrium can be distorted by political rivalry affecting the elite's commitment to efficient, growth-enhancing policies. We concluded that qualitative changes in control-rights institutions could either help the convergence or induce the divergence from the defined political-economic equilibrium. As a final point, we specified that a challenging task would be to develop an analytical model incorporating the institutional impact mechanisms suggested in this chapter, which was in fact accomplished in our work included in the next chapter.

In Chapter 3 we proposed an overlapping generations model combining elements of new political economy and endogenous economic growth. Our research was directed towards first, studying the effects of political rivalry on the evolution of human capital accumulation and income inequality and, second, examining how different political incentives may affect the resulting endogenously derived policies and economic allocations. We have found that different political incentives have distinct effects on the resulting policies and economic allocations. In particular, when there is a decoupling between economic and political power, goals pursued by the elite, instead of economic efficiency considerations, determine the policy choice. In this case, the elite's incentive to remain in power for the next period generates political rivalry. This political rivalry induces excessive taxation, which leads to an inefficient redistribution policy and reduces public education investments. Consequently, human capital accumulation and the associated positive growth effects are distorted, and inequality is deepened. On the contrary, when the incentives of the elite refer to elementary revenue extraction, it is in their interest to have increasing human capital accumulation and a highly productive middle-class, as this enables collecting higher output-tax and additional elite exclusive revenues. This determines the elite to choose non-distortionary fiscal policies with an optimal tax rate that does not generate political economy effects, i.e. inequality is not deepened and both human capital accumulation and economic growth are not hampered. Consequently, the resulting public education investments policy generates positive effects by motivating individual learning choice, increasing human capital accumulation, wages and final output, and also fighting inequality. Under such conditions public education investments can be in fact used as a social mobility promoter (most importantly as regards vertical and inter-generational social mobility), enabling income convergence and overcoming inequality. We have also shown that the public education investments and parental income parameters play an essential role in determining the next generation's human capital accumulation, thus having relevant public policy implications especially under conditions of political rivalry. In particular, we have found that when excessive importance is attributed to parental income, negative impacts on individual learning choice and future human capital accumulation can be caused even by small increases of the tax rate above a certain level. A greater role of parental income also implies that human capital accumulation for families with lower parental income is more limited and a more uneven income distribution is more propense to deepening income inequality over time. On the contrary, when parental income is less important than a worker's individual preferences regarding education, the availability of a publicly provided education offers a high potential for social mobility even for workers coming from a less favorable background. These results and conclusions provide an interesting perspective and motivation for empirical testing, which we next performed in Chapter 4.

In particular, in Chapter 4, we conducted an empirical testing of our main conclusions in the previous two chapters, regarding the impact of political rivalry on selected economic variables. Based on empirical data for a large number of countries, we analysed how political rivalry may influence educational investments, individual learning choice, GDP *per capita* and income inequality. Given that, to our knowledge, there are no previous empirical data on political rivalry, one of the key outcomes of our empirical study was the construction and preliminary analysis of the composite political rivalry indicator. Regarding this, we have found that higher-income countries have much lower levels of political rivalry, mainly due to their high institutional quality. On the contrary, exclusive natural resources rents are responsible for increasing the level of political rivalry in countries with relatively higher natural resources endowments, such as Eastern Europe, Central Asia, Middle East and North Africa. Regarding the main findings of this chapter, our empirical analysis clearly suggests that, for certain groups of countries, political rivalry has indeed a negative effect on the considered economic variables. In particular, as regards public investments in education and individual learning choice, political rivalry effects are significant in lower income countries, and their magnitude increases with the decrease in the development level. Regarding GDP *per capita*, our results suggest that even small differences in the degree of political rivalry imply considerable asymmetries in *per capita* income. This is particularly relevant for low income countries. As for the impact of political rivalry on income inequality, our findings indicate that it is globally significant even before sample disaggregation by income and geographical location. However, this is explained not by a statistically significant effect of political rivalry for all groups of countries, but rather by the fact that its impact is very strong in the groups where it is indeed significant, particularly in countries with higher inequality levels. The analysis performed also reveals the presence of the so-called indirect effects of political rivalry, particularly strong when transmitted *via* public investments in education, accounting for about one third of the total effect. Although we would expect similar mechanisms to work in higher-income countries as well, albeit on a smaller scale, this is not confirmed by the data. It may occur because the relationship between political rivalry and the selected economic variables may in fact be weaker in higher-income countries; also, the mechanisms that link the two variables and are relevant for higher-income countries may be more complex than those considered in our study. Thus, processes explaining the relationship between political rivalry and the selected economic variables for different income levels, as well as other mechanisms of transmission, should be further explored in future research.

In the second part of the thesis, Chapters 5 and 6, we employed an extended directed technological change framework in order to analyse the distributional effects of endogenous technological progress in the context of modern economies. We then examined which production factors (and industrial sectors) embrace newly developed and adopted technologies, and which do not, using theoretical modeling and empirical estimation and calibration exercises.

In Chapter 5, we studied economic growth rate, technological-knowledge bias, industrial structure and skill-premium behaviour in a framework of an extended directed technological change model with R&D driven growth, complementarities between intermediate goods in production, and internal investment costs. We have found that equilibrium output growth rate is affected both by complementarities and internal investment costs. We have also found that the complementarity degree directly influences technological-knowledge bias and industrial structure in equilibrium, and defined the underlying mechanism; and we have determined that neither of the two elements have a direct impact on steady-state skill premium and aggregate variety index ratio. We have shown that while, in the proposed framework, the Acemoglu's (2009) weak equilibrium (relative) bias is verified, *i.e.* technological knowledge is biased in favour of the more abundant skilled labour, the strong equilibrium (relative) bias is not verified because the technological-knowledge change resulting from an increase in the skilled labour relative supply is not strong enough as to induce an increase in the skill premium, which in steady-state is determined solely by the absolute productivities of skilled and unskilled labour. This may imply that the persisting increase in wage inequality observed in several developed countries over the last decades may have been due to increases in productivity advantages of skilled workers favoured by technological development. We also verified that the positive correlation of the relative supply of skilled labour to our measures of industrial structure is consistent with related empirical evidence.

Chapter 6 represents an extension of the model developed in Chapter 5. Our main objective was to identify and quantify the long-run link between, on the one hand, the technology structure and the skill structure, by considering an explicit role for the degree of complementarity between technological goods, and, on the other hand, the Tobin-q and the technology characteristics of the firms through the impact of the latter on the long-run economic growth rate. By solving the model for the balanced growth path equilibrium, we show that it entails an analytical mechanism that is consistent with the observed cross-country pattern in the technology structure. Then, based on the analytical equilibrium relationships derived in the model and on the cross-country data for the technology structure and the skill structure, we compute indirect estimates of the value of the parameters that regulate the degree of gross substitutability/complementarity and the complexity costs pertaining to horizontal R&D. In particular, our identification and estimation exercise suggests that there is gross complementarity between technological goods, thus supporting the key complementarity assumption appearing in the theoretical literature. Furthermore, a strong relationship between the Tobin-q and the R&D and technology characteristics of the firms is obtained, in line with the related empirical literature.

Finally, we also identify several potential topics for future work. Considering our analysis approach in the first part of the thesis, the more recent Probabilistic Voting Theorem, in alternative to the largely employed Median Voter Theorem, could be applied in order to deepen the understanding of mechanisms linking political institutions, inequality and redistribution policies (including publicly provided education) with a direct effect on economic growth. Given that mechanisms of efficient redistribution associated with human capital accumulation go closely in hand with issues of inequality and its role for economic growth, another possible venue of future research could be emphasizing the specific impact of inequality on such redistribution. Similarly, a more formalized future research could address the question of whether different equilibrium solutions are possible in a new political economy setting. Also, since parameters defining the importance of public investments in human capital, parental income and individual learning preferences are crucial for some of the results obtained in the theoretical model developed in this part, another future challenge could be to endogenize them, considering their determining factors and taking into account how they can be influenced by public policy. Furthermore, the skill biased technological change theory can provide a new approach to analysing the political rivalry effects on inequality and human capital accumulation through the composition of the labour force, when, depending on political distortions, economic growth can be biased towards a specific sector. In close relation to the conclusions drawn from our analysis both in the first and the second part of the thesis, another research possibility could be to consider the growth rate of aggregate labour-augmenting productivity, as an endogenous variable interacting with human capital accumulation, income inequality and economic growth.

Our extended directed technological change model also generates a number of results, referred in our steady-state analysis, that call for empirical confirmation. For example, the result that equilibrium skill premium depends solely on the productivity advantage of skilled over unskilled labour particularly deserves a more thorough investigation. Given that, having a direct impact on workers productivity, skills both increase the capacity to innovate and apply new ideas, and stimulate technological development, it is plausible that the absolute productivity advantages of skilled and unskilled workers are related to technological-knowledge bias and labour supply. Therefore, a challenging task would be to endogenize the productivity parameters in the framework of a *SBTC* model. As for our estimation and calibration exercise in the last chapter, a relatively short time-span of the available data may entail transitional dynamics effects, the study of which should be pursued in future work. The qualitative characterisation of the local dynamics properties may allow finding to what extent variations in a country's initial conditions lead to non-monotonic time paths of the technology structure and the economic growth rate towards the balanced growth path in face of a shock in the skill structure, as observed in the 1980s and 1990s in a number of developed countries.

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