ESSAYS ON ECONOMIC INTEGRATION

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Essays on Economic Integration

(Essays over economische integratie)

Thesis

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Haris Munandar
Rotterdam, September 2006

Contents

Chapter 1

Introduction

1.1 Motivation and structure of the thesis

Globalization has become one of the most widely used buzzwords of the late twentieth century and the early twenty-first century. People discuss them with passion, concern and sometimes disappointment. Globalization takes numerous forms, from wider coverage of trade to deeper foreign direct investment and from broader technology dissemination to larger migration of labor. Despite the hype and excitement, globalization from economic point of view simply means economic integration.[1] In this thesis, new results are provided on properties and implications of economic integration concerning distribution of production, relative growth, income inequality and exchange rates dynamics. In this section the relevance of the research is emphasized and the structure of the thesis is described.

1.1.1 The limiting distribution of production

Among the properties of economic integration is the increasingly low barrier of factor mobility (Sachs and Warner, 1995; International Monetary Fund, 2004). A number of economies in many regions have engaged in discussions, agreements and implementation on how to liberalize cross border flow of capital to stimulate economic activities. Across states within U.S. and across countries within E.U. people can now move relatively more easily from one place to another in search of better jobs. However, less attention has been given to the implications of allowing greater mobility of productive factors within an integrated economy. This literature gap is crucial because factor flows become increasingly important and can take the role as a substitute for international trade (Feenstra, 2004).

[1] Bhagwati (2004) and Stiglitz (2006) provide excellent and different views on various aspects of globalization.

Economic integration also generates a trend towards uniformity in technology. Multinationals open up new factories and bring their expertise and production technology from the home country to be disseminated in their subsidiaries abroad. Firms are forced to adopt the most advanced technology available to maximize efficiency or to survive.

In this study the implications of allowing factor mobility within an integrated economy for the distribution of production across members are investigated, assuming increasingly similar production technology utilization. Using the equalization of rates of return as a driving force, it turns out that the crucial elements in the distribution of production is not the formation of 'level' of factors among the economies under investigation, but the construction of 'share' of factors among them. Specifically, such factor mobility among members of an integrated economy implies that each member's share of total integrated economy output will equal its shares of total integrated economy productive factors. This result is termed equal share relationship. Such theoretical construct is closely related to the concept of integrated equilibrium, a description on the resource allocation the world would have if goods and factors were both perfectly mobile (Dixit and Norman, 1980; Helpman and Krugman, 1985; Grossman and Helpman, 1991).

The analysis offers a new perspective on convergence in cross-economy production. Namely, economic integration, and factor mobility in general, will lead to the emergence of the equal-share relationship that imposes constraints on the distribution of production. It is readily applied in a context of provincial or state economies within a country, of country economies within a regional integration institution and within the world itself. More importantly, this analysis sets a constraint on the long-run relative growth performance among the integrated economy members. In particular, since the sum of output shares across integrated economy members are equal to unity, the long-run expected growth rate of output shares must be zero.

This result also addresses Lucas' (1990) question as to why more capital does not flow from rich to poor countries. In this framework, such question should be restated into why the distribution of production across countries is not equal. The analysis suggests that an economy with a low share of human capital will also have a low share of physical capital, and also a low share of output.

1.1.2 Zipf's law for an integrated economy

In the limit, economic integration is represented by a fully integrated economy in which free mobility of goods and factors among members, identical technology adoption, together with harmonization of policies, emerge. While many works have demonstrated the important role of trade and factor mobility as influences on economic growth (Barro *et al.*, 1995; Durlauf and Quah, 1999; Barro and Xala-i-Martin, 2004), less attention has been given to the inquiry of how trade and factor mobility affect the distribution of output across members of a fully integrated economy, and hence how these influences impact the relative economic position of members (Grossman and Helpman, 1991; Rivera-Batiz and Romer, 1991; Devereux and Lapham, 1994; Baldwin and Martin, 2004; Viaene and Zilcha, 2002). Such distributional consequences of economic integration are the focus of this study. This question is crucial since it has important implications for the characteristics of model that can be used to explain the growth processes of fully integrated members.

The analysis starts by revisiting the result of the previous chapter. It turns out that the equal-share relationship contrasts policies pursued in isolation by any fully integrated economy member with those that are instead harmonized across members. For instance, the relationship remains unchanged when a coordinated educational policy by all members of a fully integrated economy increases their stocks of human capital by the same proportion. In contrast, the same policy implemented by only one member increases that members's share of total fully integrated economy human capital as long as this policy is not imitated by other members. Therefore, if fully integrated economy members have harmonized economic and social policies then the equal-share property implies that the relative performance of each member remains unaffected by these policies. This implies that the relative performance of any one fully integrated economy member can be considered a random variable.

Given this, one can follow Gabaix's (1999a) specification by assuming that the share of variable output or factor evolves as geometric Brownian motion with a lower bound, and moreover, that the distribution of growth rates of these shares is common to all members. As in Gabaix (1999a), this implies that the limiting distribution of output and factor shares across fully integrated economy members will conform to a rank-share distribution that exhibit Zipf's law.

A rank-share distribution exists if the relationship between the natural logarithm of size and of rank is linear and exhibits a negative slope. Zipf's law arises when the slope value equals minus one. Such empirical regularity have been documented extensively in economic geography literature.[2] It indicates a specific link between the rank and the value of a variable, for example that the share value of the highest ranked country is twice the share value of the second ranked country and three times the share value of the third ranked country. The empirical findings of this study indicate that Zipf's law indeed holds for the distribution of these shares among U.S. states and also among E.U. countries, but does not hold for such distribution among members of a group of developing countries and among countries in the world.

The empirical significance of Zipf's law is consistent with a model that assumes that the growth process of the shares of output or productive factors for members of an integrated

[2] See for instance, Fujita, Krugman and Venables (1999), Neary (2001) and Ottaviano and Puga (1998).

economy is random and homogeneous across members, and hence strongly dependent on particular states of nature. Such randomness will be more true the greater the extent of economic integration among members, perhaps most exemplified by the integrated economy comprising U.S. states. Hence, it is more likely to be true the more harmonized are education systems and fiscal codes, when members do not run independent monetary policies, and when industrial policies are quickly imitated across members.

1.1.3 Human capital formation and income inequality

The previous results on the characteristics of economic integration stressed the importance of human capital, also known as effective labor. While the roles of labor in production and hence in growth are important, the issue concerning which factors that determine labor income inequality is still paramount and challenging. Much has been said about the driving forces of income inequality, including prevalent discrepancies in technological progress, asymmetric impacts of world trades and financial markets and cross-country differences in quality and quantity of education.[3] In particular, arguments related to education have received widespread support. In this study, a model which links the heterogeneity in human capital formation and international income inequality is constructed. The model, which can be viewed as an extension of Viaene and Zilcha (2003), incorporates two important features. First, an attempt is made to bring more realism by allowing for the elastic labor supply across families. Second, the contribution of capital markets integration in shaping distribution of income is examined.

A general equilibrium overlapping generations model that use two types of productive factors, physical capital and effective human capital, in producing a single good is analyzed. Effective human capital is represented by an interaction between labor supply, measured by time dedicated to work, and a continuum of skill produced by a process of human capital formation. Intergenerational transfers in the economy occur via two channels: (1) the provision of public education (2) the parents' investments in home education. During the study of capital markets integration, two economies are considered, a capital exporting and a capital importing economy. Post-integration is indicated by the equalization of returns to capital.

This model is able to derive a condition of poverty trap resulting from insufficient public education provision. Economies with high levels of aggregate human capital are less likely to face a poverty trap, namely that the boundary of aggregate human capital below which the poverty trap occurs is lower. Moreover, high levels of aggregate human capital ensure that the society's human capital increases. Such results differ with ones in Viaene and Zilcha (2003) where for instance, the assumption of inelastic labor makes the level of society's human capital not playing a role in the condition of poverty trap.

[3] For a survey, see Bertola *et al.*, 2005.

The model also suggests that cross-family variation of labor supply is conditional on the distribution of human capital in previous generation. Specifically, the lower the level of human capital of a particular family, the higher the optimal labor supply exerted by that family in the next period.

The model produces a prediction that the total output of the integrated economy after capital markets integration is higher then the sum of outputs of the corresponding autarkic economies at all dates. This result confirms the finding of Viaene and Zilcha (2002). However, unlike in Viaene and Zilcha (2002), the model constructed in this study implies that capital markets integration generates an intragenerational invariance in inequality, namely, capital mobility resulting from integration of capital markets do not alter the intragenerational inequality in each economy observed under autarky. The result stems from the fact that inequality in the economy is represented only by unequal human capital distribution. In the capital exporting country, capital markets integration results in lower wage rates in all subsequent periods. While income differences between families from labor earning will be reduced, it does not affect income inequality since all earnings are altered in the same proportion.

In this framework, the existence and characteristics of private and public education are central in determining the shift in income distribution. For instance, without public education, income inequality increases over time under constant and increasing returns on home tutoring. Initial endowments also determine the long-term income distribution, that is, an economy that begins with lower level of capital, but perhaps not less equal, has a better chance to maintain more inequality in its future distribution of income. Such results are qualitatively similar with ones in Viaene and Zilcha (2003). A simulation of the equilibrium paths of the model is performed, with parameters of the model calibrated using data of the Netherlands, with results confirming the prediction of the model.

1.1.4 Monetary integration and exchange rates dynamics

The roles of exchange rates in the decision making process of monetary policy, foreign direct investment and investments are critical. Among the goals of a regional integration that has already reached an advanced stage is to reduce exchange rate variability by means of policy coordination. This is what has happened with countries in Europe. In 1979, a process to accomplish this objective was started with the creation of the European Monetary System (EMS). Through a series of long and delicate negotiations, the process towards a monetary integration converged 17 years later. In December 1996, the European Council made a crucial decision to proceed toward a so-called stage three of Economic and Monetary Union (EMU), namely, the introduction of the euro on January 1, 1999.

The introduction of euro has produced a large body of literature examining the impacts of the common currency in Europe. But not surprisingly, most of the study focuses on the effects for countries that have adopted the euro. In this study, the gap is filled by looking into possible links of the euro with non-euro currencies, the currencies of other European countries which do not join euro. In particular, the behavior of daily exchange rates of the British pound, Norwegian krone, Swedish krona and Swiss franc against the U.S. dollar over the period from January 1, 1994 until December 31, 2003 is considered.

Convincing empirical evidence that large structural breaks in the unconditional correlation among all exchange rates considered took place at two points is found. First, the break occurred at the time the formal decision to proceed with the euro was made in December 1996. Second, the break happened at the time of the actual introduction of the euro in January 1999. Specifically, unconditional correlations were substantially lower during the intermediate period.

One motivation of this study is to gain some insights which would be beneficial to policy makers, particularly monetary authorities who routinely follow and analyze movements and properties of exchange rates, including volatilities and correlations, and decide, based on such analysis, whether some monetary policy interventions are deemed necessary. Specifically, the results offer a perspective concerning a unique behavior of multiple exchange rates which simultaneously observe an agenda of monetary integration in the neighborhood. Obviously, other economies who envisage engaging in a similar economic integration program can also reap the benefits. For general market participants, information on volatilities and correlations of exchange rates are important. Such information is required to construct and diversify portfolios in order to achieve the highest level of efficiency. By studying the findings, investors or portfolio managers would obtain an empirical knowledge on how markets would react if similar event occurs in the future.

Another motivation is to propose a new method concerning the dynamic conditional correlation (DCC) model introduced by Engle (2002), which is the econometric framework used to perform the analysis. How to extend this model to accommodate structural changes in the unconditional correlations is demonstrated. A successful application of this new method, as evidenced by this study, would bring numerous opportunities to conduct other empirical works which possibly involve structural changes in the unconditional correlations, for instance in stock or bond markets.

The lowering of correlations among all exchange rates considered is a consequence of increased heterogeneity of expectation during the intervening period among policymakers, who regards exchange rates as among their tools in conducting monetary policy, and investors, who regards European currencies as in their investment horizon, about the ultimate success of euro. The two camps, euro-advocates and the euro-skeptics, which had polarized already before the decision in December 1996, were then even more divided. The outcome of the Dublin meeting had resulted in more disparate expectations held by both the policy makers and the investors. These dissenting opinions on the certainty of the birth of euro had led to more heterogeneity both in the monetary decisions taken by central banks and in the financial decisions adopted by investors, the decisions which related to exchange rates of European countries. Consequently, the correlations among currencies of European countries, regardless of whether they are in or out of the euro project were weakened.

After the launch of the euro in January 1999, opinions among market participants and policy makers on the euro obviously became more homogenous, as the uncertainty of the euro existence had been resolved. Consequently, the monetary and financial decisions related to the euro and non-euro currencies taken by central banks and investors were more concerted compared to those taken during the intervening period. Therefore the correlations among euro and non-euro currencies were strengthened again.

1.2 Contributions of the thesis

The contributions of this thesis consist of four types of results:

(1) *Equal-share relationship.* A specific relationship between output and factor shares, termed equal-share relationship is derived. Such relationship represents the distribution of output and factors of an integrated economy in which there is no barrier to factor mobility and members share the same production technology. This construction offers a new perspective on convergence in production distribution, namely, in the limit each member's share of total integrated economy output will equal its shares of total integrated economy stocks of productive factors. An empirical analysis is conducted to examine for the existence of the equal-share relationship among alternative economic groupings: U.S. states, E.U. countries, a group of developing countries and the world comprising 55 countries. The integrated economy of U.S. states exhibits full conformity with the predicted relationship. The evidence only gives mixed support for equal-share relationship among E.U. countries while it strongly rejects this relationship among the developing countries and the world. The empirical relevance of the equal-share relationship emphasizes the importance of foreign direct investment since it increases the host member's share of physical capital and its return to human capital. Also, a country whose funding level of education is relatively high may experience an increase in its share of human capital. Since this rising of human capital share increases the return to physical capital, the resulting inflow of external physical capital and accumulation of local physical capital can increase the active member's share of output.

(2) *Zipf's law for an integrated economy.* The equal-share property for members of a fully integrated economy, together with an assumed harmonization of member's

economic policies, turn out to imply the existence of rank-share distribution that exhibits Zipf's law. The empirical evidence indicates that Zipf's law holds for the distribution of output and factor shares among U.S. states and also among E.U. countries. This finding is consistent with a model that assumes that the growth process of the shares of members of an integrated economy is random and homogeneous across members. Another important result is that, if Zipf's law holds, then the values of the output and factor shares for members of a fully integrated economy are completely determined once the number of members is specified. These shares are limiting values that are derived from the relative position (rank) of each member and would be expected to emerge as integrated economies approach full integration. Moreover, a comparison between the actual share values and the theoretically expected ones indicates that both groups have a high degree of agreement.

(3) *Human capital formation, endogenous labor supply and income inequality.* The model generates the invariance property of intragenerational income inequality following capital markets integration. This result suggests that although wage rates are equalized after capital markets integration and endogenous labor supply is introduced, intragenerational inequality remains unchanged since all individual incomes are affected by the same proportion. The significance of elastic labor is apparent when one derives conditions that allows for poverty trap and for positive growth of human capital to occur, namely, both conditions depend on the possibly time-varying levels of human capital in the economy. The model singles out the process of human capital formation as the main driving force to alter income distribution. Various features of the human capital formation are studied, which include: (a) the international environment, such as physical capital mobility (b) the initial conditions of stock of human capital (c) the level and externality of public education (d) the efficiency originated from education technology. Important insights concerning relations between income inequality and such features of human capital formation are offered.

(4) *Exchange rates dynamics surrounding the euro introduction.* The first contribution of this study is to further the understanding of the effects of the euro introduction, following the monetary integration among 12 European countries, on the properties of exchange rates for European countries outside the euro-zone. Specifically, convincing evidence for structural breaks in unconditional correlations between the U.S. dollar exchange rates of the British pound, Norwegian krone, Swedish krona, Swiss franc and the euro during the period 1994-2003 is found. Using an extension of the dynamic conditional correlation (DCC) model,

it is found that such breaks occurred both at the time the formal decision to proceed with the euro was made in December 1996 and at the time of the actual introduction in January 1999. The second contribution is methodological, concerning the dynamic conditional correlation (DCC) model introduced by Engle (2002), which is the econometric framework used to perform this empirical analysis. How to extend this model to accommodate structural changes in the unconditional correlations is shown. The analysis demonstrates that allowing for time-varying conditional volatilities and correlations by means of a standard DCC model may not be sufficient in this respect. Incorporating occasional structural breaks in unconditional volatilities and correlations may be necessary. The results have important consequences for monetary policy and financial decision making, particularly in modeling the volatility and correlation of exchange rates.

1.3 Outline of the thesis

The research discussed in this thesis concerns areas that can roughly be described by three keywords: economic integration, human capital formation and exchange rates dynamics. The outline of this thesis is as follows. Chapters 2 and 3 investigate how economic integration affects the distribution of production by incorporating the increasing trend of lower barrier to factor mobility and of similarity in production technology. In Chapter 2, the general form of equal-share relationship is derived and by introducing more stringent assumptions, reduced forms of such relationship are attained. A series of testings of this theory is performed and some implications of the results are drawn. Chapter 2 is based on Bowen, Munandar and Viaene (2005a).

Chapter 3 extends the results of Chapter 2 by examining the consequences of economic integration on distributions of output and productive factors across members of a fully integrated economy and how such full integration affects the relative position of the members. The analysis is conducted by extensively employing the concepts of Zipf's law and rank-size distribution. An estimation problem of the rank-size distribution is discussed and a solution of the problem is reached with the help of a Monte Carlo simulation. Another Monte Carlo simulation is performed with the objective to verify the emergence of Zipf's law. Chapter 3 is based on Bowen, Munandar and Viaene (2005b, 2006).

Chapter 4 develops a model exploring the implications of various processes of human capital formation on income inequality. After describing preferences of families and the properties of the human capital production technology, the competitive equilibrium is characterized and the determinants of income at the future date are derived. By stressing the importance of endogenous labor supply, the impact of non-parental participation in education is examined and the condition for poverty trap is developed. After introducing the notion of capital markets integration, the result of post-integration invariance in intragenerational income inequality is obtained. Further analyses are conducted concerning the roles of initial endowments, public education and education technology in altering income distribution. Lastly, a computable general equilibrium exercise is conducted using data from the Netherlands by means of calibration. Chapter 4 is an extension of Viaene and Zilcha (2003) in two directions: (1) endogenous labor supply and (2) capital markets integration.

Chapter 5 is an empirical study concerning the effects of an economic integration agenda on exchange rates. Specifically, the consequences of the euro introduction on properties of exchange rates of European countries outside the euro-zone are investigated and presented. The chapter starts with some motivations of the study, which are to help the making of monetary policies and financial decisions. Some relevant background concerning the monetary integration in Europe is explained, together with the reasons as to why the countries under consideration, which are outside the euro-zones, did not adopt the euro in the first place. After characterizing the data, the dynamic conditional correlation econometric framework of Engle (2002) is introduced along with a proposed improvement to accommodate the structural changes in the unconditional correlations. Further, empirical results are shown and discussed. At the end of the chapter, four robustness checks to validate and to substantiate the results are performed. Chapter 5 is based on Van Dijk, Hafner and Munandar (2005).

Chapter 6 gives a summary of the main findings in this thesis and discusses some topics for further research.

Chapter 2

A new perspective on convergence: implication of economic integration on the limiting distribution of production

Chapter 2 is based on Bowen, Munandar and Viaene (2005a).

2.1 Introduction

A surge of regional integration agreements over the past two decades have sought to reduce barriers to the exchange of goods, services and, in the extreme, factors of production among subsets of countries.[1] Examples include the NAFTA (United States, Canada and Mexico), the European Union's "Europe 1992" internal market program, the recent accession of 10 additional countries into the European Union (E.U.), and ongoing efforts to initiate or renew agreements among a variety of nations (e.g., the Free Trade for the Americas, MERCOSUR and ASEAN free trade agreements). The literature dealing with the economic implications of regional integration has mostly dealt with the effects of reducing barriers to the movement of goods. Less attention has been given to the implications of also allowing greater mobility of productive factors within an integrated economy. This omission from the literature is important not only because cross-border factor flows are

[1]Sachs and Warner (1995) chronicle these liberalization efforts.

becoming increasingly important,[2] but also the international trade literature has long recognized that goods trade and cross-border factor flows can evidence a substitute or complement relationship. Hence, reducing barriers to the movement of productive factors within an integrated area would be expected to affect the final distribution of production across members of an integrated economy.

The United States is commonly viewed to possess an ideal set of characteristics that allows for a high mobility of productive factors among U.S. states. These characteristic include not only the absence of barriers to labor and capital movements, but also a common language and currency, similar pension and tax schemes, and a "mobility mindset" embedded in its culture. Collectively, U.S. states then represent a club of economic subunits among which there is almost perfect factor mobility, and for this reason, the United States are often viewed as a benchmark for thinking about the economic effects of economic integration, in particular, the effect that complete factor mobility might have on the distribution of production consequent to integration.

Partly in response to a perception that superior economic performance by the U.S. deemed emanates of the close integration of U.S. states, the European Union (E.U.) began in 1987 reforms intended to better integrate the markets of E.U. member states. In particular, the E.U.'s 1992 internal market program sought to abolish remaining barriers to the free movement of goods and services and to also reduce or eliminate barriers to the movement of productive factors (capital and labor) among member states. These efforts were following reforms such as the Bologna Treaty which seeks to harmonize educational systems and foster labor mobility and the introduction of the euro. In 2004, the scope of such integration was expanded by the ascension of 10 new member countries into the E.U.

In this chapter the implications of allowing factor mobility within an integrated economy for the distribution of production across members are investigated. Employing factor price equalization as a driving force, it is presented that factor mobility among members of an integrated economy (IE) implies that each member's share of total IE output will equal its shares of the total IE stock of each productive factor (i.e., its shares of total physical and human capital). This theoretical prediction is termed the equal-share relationship and it is argued that this relationship offers a new perspective on convergence.

An important implication of the equal-share relationship is that it sets a constraint on the long-run relative growth performance of IE members. In particular, since the sum of output shares across IE members equals unity, the long-run expected growth rate of output shares must be zero. Therefore, it is not possible for every member of an IE to sustain

[2] The importance of factor mobility in many parts of the world is evidenced by the growing importance in many nations' balance of payments of remittances from abroad (e.g., International Monetary Fund, 2004). Capital flows in the form of foreign direct investment continue to be important among industrialized countries and they are increasingly also being directed toward developing countries.

a positive rate of growth of its output share in the long-run. Moreover, the constraint imposed by the equal-share relationship implies that in any given time period, the relative growth performance of IE members can be taken to be a random outcome contingent on alternative states of nature. The random behavior of member's relative growth is more true the greater the extent of economic integration among members. For example, it is truer if members do not run independent monetary or exchange rate policies, when fiscal policies are constrained by institutions, when education systems are harmonized, and when successful local industrial policies are rapidly imitated.

The implications of such analysis for growth relates to the existing growth literature in several respects. First, such analysis has a direct implication for the question of convergence in national outputs that has been extensively investigated in the growth literature (see e.g. Durlauf and Quah, 1999). Empirically, Evans and Karras (1996) and Evans (1997) find higher speeds of income convergence among U.S. states than for countries. These findings are consistent with the theoretical predictions of Barro et al. (1995) who show that an open economy with partial capital mobility has a higher rate of convergence than does a closed economy. Similarly, Rappaport (2005) introduces labor mobility in the neoclassical growth model to show that emigration creates a disincentive for gross capital investment. This disincentive partly offsets the positive contribution of labor mobility to faster income convergence. In this framework, the equal-share relationship implies that IE members will have the same output per efficiency unit of labor. This implication is the essence of the convergence hypothesis investigated by the growth literature, here interpreted in terms of efficiency units of labor and not per capita.

Debate on the issue of convergence, while largely conducted by macroeconomists is really a discovery that history matters. In this respect, Abramovitz (1986) has suggested that economists tackle a more challenging issue: explaining the relative wealth of nations in the last two centuries. Authors who respond to this issue have often done so by examining four episodes: the mid-nineteenth century (episode 1) representing an initial dispersion of wealth, an era of convergence 1870-1913 (episode 2), an era of divergence in the interwar period (episode 3), and a phase of very rapid convergence after 1950 (episode 4).[3] A conclusion of this body of work is that the mechanics of economic growth may have indeed been very different in different eras and for different groups of countries.

Williamson (1995) argued that mass migration in the "Greater Atlantic Economy" can explain the rapid convergence around 1870. He argues further that the emergence of quotas and other barriers to migration in the interwar period can help explain the cessation of the convergence process and also the divergence in episode 3. In subsequent work, Williamson (1996) interprets the resumption of convergence in episode 4 as being due to additional pro-convergence forces such as international technology transfer, as

[3]See Abramovitz (1986), Maddison (1991), Taylor (1996) and Williamson (1995).

well as factor mobility. Despite Williamson's observations on the potential contribution of international factor movements to income convergence, most studies focus on factor accumulation but neglect the role of international factor movements. The role of international factor movements therefore warrants more theoretical and empirical analysis (Taylor, 1996).

A different view of the processes generating economic converge is contained in the literature that relates financial services and growth. Financial intermediation pools funds and allocates these to those activities expected to produce the highest reward. A more efficient allocation of savings tends to increase rates of growth (Bencivenga and Smith, 1991). Internationally, greater integration of financial markets is expected to both lower the cost of financial capital and to foster a reallocation of capital from capital abundant to capital scarce countries. One effect of such a reallocation of capital resources may be to promote technological progress (e.g., venture capital) that can offset decreasing returns to physical capital and may generate endogenous growth (Greenwood and Jovanovic, 1990). Empirically, Levine (1997) found evidence of a cross-country pattern linking growth and domestic finance. However, Edison et al. (2002) and Eschenbach (2004), who also review the more recent literature, find weak evidence of a link between capital mobility and per capita income growth. A key contribution of current analysis is to show that capital market integration, and factor mobility in general, will lead to the emergence of the equal-share relationship that then introduces a constraint on the relative growth performance of members of an integrated area.

Having derived theoretically the equal-share relationship an empirical examination is conducted for the presence of this relationship for different collections of economic subunits. Specifically, whether this relationship holds among U.S. states, E.U. countries, developing countries, and finally the world as a whole is considered. This analysis is conducted by estimating a set of regressions that generally span the period from 1965 to 2000. In this way, one can examine the characteristics of different economic groupings vis-à-vis the predicted equal-share relationship. In this regard, one can examine, for example, whether the perception of almost perfect factor mobility among U.S. states is borne out by the data. Similarly one can assess whether the institutional arrangements within the E.U. have indeed induced a greater mobility of factors within the E.U.

The analysis offers a new approach to answering the question, central in the economic growth literature, of whether or not countries are or will converge in terms of their levels of output per capita.

Finally, the equal-share relationship also addresses Lucas' (1990) question as to why more capital does not flow from rich to poor countries. As will be demonstrated, the equal-share relationship implies that the question of why there is not enough factor mobility should be restated as the question of why the distribution of productions across countries is not equal. The theory developed in this chapter predicts that an economy with a low level (and hence a low share) of human capital will also have a low share of physical capital, and also a low share of output.

2.2 Output and factor shares in integrated economies

2.2.1 Equalization of rates of return

An economy (or economic unit) that produces a single good by means of a constant return to scale production function is considered:

$$Y_t = F(K_t, H_t), \tag{2.1}$$

where Y_t is the level of output, K_t is the level of physical capital stock and H_t is the level of human capital stock, all at time t. To facilitate interpretation it is assumed the production function takes the Constant Elasticity of Substitution (CES) form:

$$Y_t = \gamma \left\{ \delta K_t^{-\rho} + (1-\delta) H_t^{-\rho} \right\}^{-\frac{1}{\rho}}, \tag{2.2}$$

where γ is an efficiency parameter, δ the degree of physical capital usage, and ρ is a substitution parameter such that the elasticity of substitution between the two inputs is $\sigma = \frac{1}{(1+\rho)}$. Given (2.2), the marginal product of physical capital is:

$$(F_K)_t = \gamma\delta \left\{ \delta + (1-\delta)\left(\frac{K_t}{H_t}\right)^{\rho} \right\}^{-\frac{(1+\rho)}{\rho}}. \tag{2.3}$$

Combining (2.2) and (2.3) one can write:

$$(F_K)_t = \gamma^{-\rho}\delta \left(\frac{Y_t}{K_t}\right)^{1+\rho}. \tag{2.4}$$

Similarly, the expression for the marginal product of effective labor (human capital) is:

$$(F_H)_t = \gamma(1-\delta) \left\{ (1-\delta) + \delta\left(\frac{K_t}{H_t}\right)^{\rho} \right\}^{-\frac{(1+\rho)}{\rho}} \tag{2.5}$$

or

$$(F_H)_t = \gamma^{-\rho}(1-\delta) \left(\frac{Y_t}{H_t}\right)^{1+\rho}. \tag{2.6}$$

A second economy is now introduced and the implications of allowing factor mobility between the two economies are considered. If physical capital and human capital are perfectly mobile between the two economies then one would expect each factor to flow from the low to high rate of return country until each factor's rate of return (marginal product) is equalized between the two economies. However, if there are barriers to factor mobility then rates of return will only be partially equalized.[4] For simplicity, such barriers are represented by a time-varying proportional wedge in rates of return to physical capital ($\lambda_t(k) > 0$) and rates of return to human capital ($\lambda_t(h) > 0$). Given this, the relation between the rates of return between the two economies can be written:

$$\gamma^{-\rho}\delta\left(\frac{Y_t}{K_t}\right)^{1+\rho} = \lambda_t(k)(\gamma^*)^{-\rho^*}\delta^*\left(\frac{Y_t^*}{K_t^*}\right)^{1+\rho^*}, \tag{2.7}$$

$$\gamma^{-\rho}(1-\delta)\left(\frac{Y_t}{H_t}\right)^{1+\rho} = \lambda_t(h)(\gamma^*)^{-\rho^*}(1-\delta^*)\left(\frac{Y_t^*}{H_t^*}\right)^{1+\rho^*}, \tag{2.8}$$

where ‘ * ’ indicates second economy variables. The ratio of (2.7) to (2.8) gives the ratio of human to physical capital:

$$\frac{H_t}{K_t} = \eta(\lambda_t)^{\frac{1}{1+\rho}}\left(\frac{H_t^*}{K_t^*}\right)^{\theta}, \tag{2.9}$$

where:

$$\eta = \left[\frac{\delta^*(1-\delta)}{(1-\delta^*)\delta}\right]^{\frac{1}{1+\rho}}, \quad \text{implying} \;\; \eta = 1 \;\; \text{when} \;\; \delta = \delta^*,$$

$$\theta = \frac{1+\rho^*}{1+\rho}, \quad \text{implying} \;\; \theta = 1 \;\; \text{when} \;\; \rho = \rho^*,$$

$$\lambda_t = \frac{\lambda_t(k)}{\lambda_t(h)}, \quad \text{implying} \;\; \lambda_t = 1 \;\; \text{when} \;\; \lambda_t(k) = \lambda_t(h).$$

Using these definitions one can write (2.7) as:

$$\frac{Y_t}{K_t} = \nu\omega(\lambda_t(k))^{\frac{1}{1+\rho}}\left(\frac{Y_t^*}{K_t^*}\right)^{\theta}, \tag{2.10}$$

where:

$$\nu = \left(\frac{\delta^*}{\delta}\right)^{\frac{1}{1+\rho}},$$

$$\omega = \left[(\gamma^*)^{-\rho^*}\gamma^{\rho}\right]^{\frac{1}{1+\rho}}.$$

[4]Barriers to capital mobility can include sovereign and political risk, capital controls, and tax differences that can hinder cross-border investments. Barriers to human capital mobility include government regulations on immigration and work permits, differences in pension systems and languages between countries.

2.2.2 Productivity calculation

One is now fully equipped to illustrate the implications of the model for the distribution of output and factors between the two economies. To show the role of human capital, rewrite (2.8) as:

$$\frac{Y_t}{H_t} = \frac{\omega\eta}{\nu}(\lambda_t(h))^{\frac{1}{1+\rho}}\left(\frac{Y_t^*}{H_t^*}\right)^{\theta}. \tag{2.11}$$

Traditionally, (2.11) serves as a basis for productivity calculations and comparisons across countries. However, unlike the existing literature (e.g., Hall and Jones, 1999) where productivity is measured by output per worker, equation (2.11) expresses (like the endogenous growth literature) productivity in terms of output per effective unit of labor. For the sake of comparison, consider Hall and Jones' (1999) example of the United States and Niger. In 2000, U.S. output per worker was 38 times higher than output per worker in Niger. Using as a measure of human capital the number of persons with at least a secondary education, output per unit of human capital in Niger is instead measured to be 1.3 times higher than in the United States for the same period. This indicates the sensitivity of productivity comparisons to the measurement of human capital.

One then can rewrite (2.11) as follows:

$$\frac{Y_t}{H_t} = \left[\frac{\gamma^{\rho}(1-\delta)}{(\gamma^*)^{\rho^*}(1-\delta^*)}\lambda_t(h)\right]^{\frac{1}{1+\rho}}\left(\frac{Y_t^*}{H_t^*}\right)^{\frac{1+\rho^*}{1+\rho}} \tag{2.12}$$

From (2.12), one can perform a comparative static analysis and obtain the following results. First, output per effective unit of labor in the first economy increases with an increase in efficiency of the first economy (γ) or with a decrease in efficiency of the second economy (γ^*), or both. Second, productivity in the first economy rises when the degree of physical capital intensiveness in the first economy (δ) declines or when the variable in the second economy (δ^*) goes up, or both, indicating an increase in importance of human capital for the first economy relative to human capital for the second economy. Lastly, the higher the discrepancy of marginal rates of return of human capital between two economies ($\lambda_t(h)$), the wider the differences in output per human capital between both countries.

2.2.3 Differences in technology and barrier to factor mobility

To obtain a first expression of the equal-share relationship, note that (2.9) and (2.10) can be written respectively as follows:

$$\frac{H_t}{K_t} = \eta(\lambda_t)^{\frac{1}{1+\rho}}\left(\frac{H_t^*}{K_t^*}\right)^{\theta} = \frac{(H_t^*)^{\theta}\eta(\lambda_t)^{\frac{1}{1+\rho}}}{(K_t^*)^{\theta}}, \tag{2.13}$$

$$\frac{Y_t}{K_t} = \nu\omega(\lambda_t(k))^{\frac{1}{1+\rho}} \left(\frac{Y_t^*}{K_t^*}\right)^\theta = \frac{(Y_t^*)^\theta \nu\omega(\lambda_t(k))^{\frac{1}{1+\rho}}}{(K_t^*)^\theta}. \tag{2.14}$$

Following economic integration and taking into account differences in technology and barrier to factor mobility, equalization of marginal rates of return allows one to rewrite (2.13) and (2.14) as follows:

$$\frac{H_t}{K_t} = \frac{H_t + (H_t^*)^\theta \eta(\lambda_t)^{\frac{1}{1+\rho}}}{K_t + (K_t^*)^\theta}, \tag{2.15}$$

$$\frac{Y_t}{K_t} = \frac{Y_t + (Y_t^*)^\theta \nu\omega(\lambda_t(k))^{\frac{1}{1+\rho}}}{K_t + (K_t^*)^\theta}. \tag{2.16}$$

Combining these two expressions gives:[5]

$$\frac{H_t}{H_t + (H_t^*)^\theta \eta \lambda_t^{\frac{1}{1+\rho}}} = \frac{Y_t}{Y_t + (Y_t^*)^\theta \nu\omega\lambda_t(k)^{\frac{1}{1+\rho}}} = \frac{K_t}{K_t + (K_t^*)^\theta}. \tag{2.17}$$

Equation (2.17) establishes a link between the first economy's shares of the total output, physical capital, and human capital across the two economies. Differences in technology between the two economies imply only a rescaling of the original variables. A difference between γ^* and γ indicates a neutral difference in technologies that has no effect on the optimal selection of physical capital and human capital, but it does have an effect on the distribution of output through ω in (2.17). A difference between the substitution elasticities introduces the power θ whereas differences between the other parameters lead to a multiple rescaling of variables.

To get more specific insight on the roles of production technology, one can rewrite (2.17) as follows:

$$\frac{H_t}{H_t + \left[(H_t^*)^{1+\rho^*} \lambda_t \frac{\delta^*(1-\delta)}{(1-\delta^*)\delta}\right]^{\frac{1}{1+\rho}}} = \frac{Y_t}{Y_t + \left[(Y_t^*)^{1+\rho^*} \lambda_t(k) \frac{\delta^* \gamma^\rho}{\delta(\gamma^*)^{\rho^*}}\right]^{\frac{1}{1+\rho}}} = \frac{K_t}{K_t + (K_t^*)^{\frac{1+\rho^*}{1+\rho}}}. \tag{2.18}$$

Using (2.18), one can see more clearly that a discrepancy in production efficiencies (γ and γ^*) shape the distribution of output but not the distribution of human and physical capital. This is different with variation in degrees of capital intensiveness of production in both economies (δ and δ^*) which influence both distribution of output and of human

[5] One has (2.27), (2.28) and (2.29) for the home countries, but for the foreign country there should be some inverse relationship. Separate tests involving country dummies confirm the existence of such symmetry. Chapter 3 derives an alternative presentation by involving many partner countries. In that case a Cobb-Douglas specification function is assumed. See equations (3.1)-(3.8)

capital but not distribution of physical capital. Again, a difference between substitution elasticities affects distribution of all variables.

Equation (2.17) nests several share relationships that relate to different assumptions about technology and factor mobility. If technology is identical between the two economies then (2.17) simplifies to:

$$\frac{H_t}{H_t + H_t^* \lambda_t^{\frac{1}{1+\rho}}} = \frac{Y_t}{Y_t + Y_t^* \lambda_t(k)^{\frac{1}{1+\rho}}} = \frac{K_t}{K_t + K_t^*}. \tag{2.19}$$

In this new form of the equal-share relationship, some variables for the second economy are rescaled by the proportional differences in rates of return. For example, from (2.19), an absence of barriers to physical capital mobility ($\lambda_t(k) = 1$) implies equal output and physical capital shares that, however, differ from the human capital share. If it is assumed that both ($\lambda_t(k) = 1$) and ($\lambda_t(h) = 1$) then the equal-share relationship takes the simple form:

$$\frac{H_t}{H_t + H_t^*} = \frac{Y_t}{Y_t + Y_t^*} = \frac{K_t}{K_t + K_t^*}. \tag{2.20}$$

This states that when there are no barriers to factor mobility and technologies are identical, each economy's shares of total output, total physical capital and total human capital will be identical.[6,7]

2.3 Implications of equal-share relationship

The equal-share relationship (2.20) has three main implications. First, a reallocation of physical capital between IE economies, that is, $dK_t = -dK_t$, must be accompanied by an increase in output and either an inflow of foreign human capital or an accumulation of domestic human capital to rebalance the equality of world shares. Similarly, a policy that increases a country's share of total IE human capital will raise both the country's share of total IE output and its share of total IE physical capital (via either an inflow of foreign physical capital or accumulation of domestic capital).

[6]This result is closely related to the concept of integrated equilibrium, a description on the resource allocation the world would have if goods and factors were both perfectly mobile (Dixit and Norman, 1980, Helpman and Krugman, 1985; Grossman and Helpman, 1991).

[7]Some (but less than fully) integrated goods mobility (trade) combined with some factor mobility may produce the same results. In a one-good framework where $\bar{p}$=wL+rK with $\bar{p}$ being the fixed price of the good, it is sufficient to have such good to be mobile and any of capital to be mobile. However, in a multifactor multigoods setting, a form of "fuzzy world" may emerge in the sense that some goods mobility combined with less then full factor mobility may result in equal-share relationship. It is acknowledged that such multigoods setting is harder to test.

Second, this framework can be related to the broad topic of output convergence by noting that if (2.20) holds then the following two equalities will also hold:

$$\frac{Y_t}{H_t} = \frac{Y_t + Y_t^*}{H_t + H_t^*}, \tag{2.21}$$

$$\frac{Y_t}{H_t} = \frac{Y_t^*}{H_t^*}. \tag{2.22}$$

From (2.22) it is clear that, if the equal-share relationship holds, the two economies will have the same output per efficiency unit of labor. This implication is the essence of the productivity convergence hypothesis (Baumol, 1986), here interpreted in terms of efficiency units of labor and not per capita.

Third, the equal-share relationship (2.20) can be extended to the case of an integrated economy that comprises $j = 1, \ldots, N$ members. If all members have the same technology, and there is perfect mobility of either physical or human capital among members, then the equalization of factor rates of return implies:

$$\frac{H_{it}}{\sum_{j=1}^{N} H_{jt}} = \frac{Y_{it}}{\sum_{j=1}^{N} Y_{jt}} = \frac{K_{it}}{\sum_{j=1}^{N} K_{jt}} \qquad \text{for} \;\; i = 1, \ldots, N \tag{2.23}$$

This set of equalities express the distribution of output and factors among N members of a fully integrated economy. Like (2.17), expression (2.23) can be extended to allow for differences in technology and factor market imperfections among members.

2.4 Empirical analysis

In this section, the equal-share relationship with respect to alternative economic groups that may or may not meet the condition that they form a fully integrated economy is empirically examined. Four groupings are considered: the 50 U.S. states and the District of Columbia (hereafter the 51 U.S. states), 14 countries of the European Union (E.U.), 30 developing countries and a world consisting of 55 countries.

2.4.1 Testing the theory: regression specification

The equal-share relationship (e.g., (2.17)) implies three bivariate relationships that link member i's shares of total IE output ($\tilde{y}_i$), of total IE physical capital ($\tilde{k}_i$) and of total IE human capital ($\tilde{h}_i$):

$$\tilde{y}_i = \tilde{k}_i \tag{2.24}$$

$$\tilde{y}_i = \tilde{h}_i \tag{2.25}$$

$$\tilde{h}_i = \tilde{k}_i \tag{2.26}$$

Expressions (2.24)-(2.26) hold when outputs and factors are adjusted for any barriers to factor mobility or technological differences. However these adjustment factors, and hence the theoretical shares, are not observable. However it can be seen from (2.17) that these adjustment factors only affect measurement of the denominator of each share. This allows one to transform expressions (2.24)-(2.26) into testable propositions involving observed output and factor shares.

Let y_i, k_i and h_i denote member i's observed *shares* of output, physical capital and human capital. Similarly, let Y_i, K_i and H_i denote the observed *level* of each variable, and continue to let a '$\tilde{}$' over a variable denote its (unobserved) value when adjusted for any technological differences or factor mobility costs. Given this, one can, for example, transform (2.24) as follows:

$$\tilde{y}_i = \tilde{k}_i$$

$$\frac{Y_i}{\sum_{j=1}^N \tilde{Y}_j} = \frac{K_i}{\sum_{j=1}^N \tilde{K}_j}$$

$$Y_i = \left(\frac{\sum_{j=1}^N \tilde{Y}_j}{\sum_{j=1}^N \tilde{K}_j}\right) K_i$$

$$\frac{Y_i}{\sum_{j=1}^N Y_j} = \left[\left(\frac{\sum_{j=1}^N K_j}{\sum_{j=1}^N \tilde{K}_j}\right)\left(\frac{\sum_{j=1}^N \tilde{Y}_j}{\sum_{j=1}^N Y_j}\right)\right] \frac{K_i}{\sum_{j=1}^N K_j}$$

$$y_i = \beta_{yk} k_i \tag{2.27}$$

where $\beta_{yk} = \left(\frac{\sum_{j=1}^N K_j}{\sum_{j=1}^N \tilde{K}_j}\right)\left(\frac{\sum_{j=1}^N \tilde{Y}_j}{\sum_{j=1}^N Y_j}\right)$. If there are identical technologies and no barriers to capital mobility then $\sum_{j=1}^N \tilde{Y}_j = \sum_{j=1}^N Y_j$ and $\sum_{j=1}^N \tilde{K}_j = \sum_{j=1}^N K_j$ so that $\beta_{yk} = 1$.[8] Similar transformations of (2.25) and (2.26) yield the following expressions between observed output shares and observed factor shares:

$$y_i = \beta_{yh} h_i \tag{2.28}$$

$$h_i = \beta_{hk} k_i \tag{2.29}$$

Again, in (2.28), $\beta_{yh} = 1$ if there are no differences in technology or no barriers to human capital mobility. Treated as a system, equations (2.27)-(2.29) imply the restriction $\beta_{hk} = \frac{\beta_{yk}}{\beta_{yh}}$, so that $\beta_{hk} = 1$ when $\beta_{yk} = \beta_{yh}$.

Several tests of the equal-share relationship are conducted based on equations (2.27) to (2.29). The first is a "weak" test that considers pair-wise rankings of the output and factor shares across members of a given integrated economy without regard to the strict equalities among share values as stated in (2.27) to (2.29). A second set of tests is based on

[8]This would also be true in the singular case where technology differences exactly offset barriers to factor mobility.

regression estimates of the coefficients that link the output and factor shares. To conduct this second set of tests it is convenient to express (2.27) to (2.29) in the equivalent form:

$$\ln y_i = \theta_{yk} + \gamma_{yk} \ln k_i + \xi_{iyk} \tag{2.30}$$

$$\ln y_i = \theta_{yh} + \gamma_{yh} \ln h_i + \xi_{iyh} \tag{2.31}$$

$$\ln h_i = \theta_{hk} + \gamma_{hk} \ln k_i + \xi_{ihk} \tag{2.32}$$

where $\theta_{yk} = \ln \beta_{yk}$, $\theta_{yh} = \ln \beta_{yh}$ and $\theta_{hk} = \ln \beta_{hk}$. The disturbance term ($\xi$) added to each equation is assumed to have the standard properties (i.e., mean zero and possibly time-varying variance). However, it is clear (particularly from (2.31) and (2.32)) that these disturbances will be contemporaneously correlated.[9] To account for this parameter estimates are obtained using the Seemingly Unrelated Regression (SUR) procedure.

Except for U.S. states, data on countries' output and factor shares comprise a series of cross-sections at five-year intervals between 1965 and 2000. For U.S. States, the data are only available for 1990 and 2000. Given the time period spanned by the data, one might expect that for some groups (e.g., the E.U.) the equal-share relationship may hold in later periods but not in earlier periods. That is, there may be convergence toward the equal-share relationship over time due to increased integration among the members of a given group. To account for this possibility the equation system (2.30) to (2.32) are estimated separately using the cross-section data in each year. Subsequent analysis then examines hypotheses regarding coefficient homogeneity over time in order to assess the extent to which the data can instead be pooled over time.[10]

Given estimates of the parameters in (2.30) to (2.32), tests to examine for evidence of the equal-share relationship in each year are conducted. Each test, except one, involves a hypothesis that the intercept term in each equation is significantly different from zero. This follows since if any beta coefficient (β_{ij}) in (2.27) to (2.29) equals one (i.e., the equal-share relationship holds) then the corresponding intercept in (2.30) to (2.32) equals zero (i.e., if $\beta_{ij} = 1$ then $\theta_{ij} = \ln \beta_{ij} = 0$).

The simple hypothesis that the intercept term in a given equation equals zero is first tested. Failure to reject this hypothesis would support the equal-share relationship with respect to a particular pair of shares. A second test examines if the intercepts across the three equations are jointly equal to zero in a each year. In addition to these tests for a zero intercepts, tests are also conducted to check if the pseudo slope parameters (γ_{ij}) equal unity, both individually for each equation and jointly across the 3 equations, in a each year. Finally, as a check on the integrity of equation system (2.27)-(2.29), the

[9]One would also expect the disturbances in (2.31) and (2.32) to be serially correlated in a panel data setting.

[10]Hence, any a prior constraint on the parameter values between time periods are not imposed, as would be the case if the equation system using the entire panel across years and countries is instead estimated.

validity of the cross-equation parameter restriction $\beta_{hk} = \frac{\beta_{yk}}{\beta_{yh}}$ is also tested. In terms of system (2.30)-(2.32), this involves testing the restriction that $\exp\theta_{hk} = \frac{\exp\theta_{yk}}{\exp\theta_{yh}}$.

2.4.2 Summary of data

The construction of shares of output, physical capital and human capital is explained in the appendix of this thesis. Tables 2.1 and 2.2 present ratios of capital share on output share for each of the four clubs representing alternative integrated economies. The fact that the means of such ratios are close to unity gives a first indication of the 'weak' form of the equal share relationship. Observing the values of standard deviation, the equal share relationship seems to be stronger for U.S. states and weaker for developing countries and the world.

Table 2.1: Ratios of physical capital share (k) on output share (y), 1990

Club	Mean	Std. Deviation
U.S. states	1.020	0.169
E.U. countries	0.937	0.263
Developing countries	0.999	0.584
The World	0.928	0.430

Table 2.2: Ratios of human capital share (h) on output share (y), 2000

Club	Mean	Std. Deviation
U.S. states	0.969	0.129
E.U. countries	1.204	0.673
Developing countries	0.991	1.024
The World	1.485	1.547

Tables 2.3 to 2.6 report Spearman rank correlation coefficients between pairings of the output and factor shares for each of the four groups. These correlations offer a second indication of any tendency for output and factor shares to be related. All rank correlations are positive and highly significant for U.S. states (Table 2.3) and the three other economic groupings (Tables 2.4 to 2.6). These results offer strong evidence in favor of the existence of the equal-share relationship: that there will be conformity between (pair-wise) rankings of the output and factor shares across members of a given IE.[11]

[11]Critical values of the spearman rank correlation tests are obtained from Zar (1972).

Table 2.3: Spearman rank correlations for U.S. states

Year	Spearman Rank Correlation*		
	y and k	y and h	k and h
1990	0.987	0.977	0.980
1991	0.988		
1992	0.988		
1993	0.988		
1994	0.989		
1995	0.991		
1996	0.993		
1997	0.994		
1998	0.994		
1999	0.993		
2000	0.992	0.981	0.978

*$n = 51$ in each year; coefficients whose absolute value exceeds 0.326 are significantly different from zero at the 1% level.

Table 2.4: Spearman rank correlations for E.U. countries

Year	Spearman Rank Correlation*		
	y and k	y and h	k and h
1960		0.688	
1965	0.934	0.754	0.640
1970	0.912	0.881	0.789
1975	0.921	0.820	0.763
1980	0.921	0.943	0.903
1985	0.952	0.947	0.960
1990	0.956	0.776	0.829
1995	0.960	0.851	0.837
2000	0.956	0.820	0.881

*$n = 14$ in each year; coefficients whose absolute value exceeds 0.626 are significantly different from zero at the 1% level.

Table 2.5: Spearman rank correlations for Developing countries

Year	Spearman Rank Correlation*		
	y and k	y and h	k and h
1960		0.828	
1965	0.944	0.853	0.837
1970	0.955	0.831	0.826
1975	0.952	0.850	0.857
1980	0.944	0.893	0.881
1985	0.940	0.882	0.875
1990	0.951	0.895	0.888
1995		0.860	
2000		0.857	

*$n = 30$ in each year; coefficients whose absolute value exceeds 0.425 are significantly different from zero at the 1% level.

Table 2.6: Spearman rank correlations for the World

Year	Spearman Rank Correlation*		
	y and k	y and h	k and h
1960		0.824	
1965	0.964	0.864	0.842
1970	0.966	0.914	0.904
1975	0.972	0.898	0.898
1980	0.973	0.929	0.922
1985	0.974	0.947	0.938
1990	0.975	0.937	0.930
1995		0.923	
2000		0.920	

*$n = 55$ in each year; coefficients whose absolute value exceeds 0.314 are significantly different from zero at the 1% level.

Table 2.7: SUR Estimates of Output and Factor Share Equations for U.S. States

Year (obs)	Equation (i on j)	Intercept (θ_{ij})	Slope (γ_{ij})	Adj. R^2	Joint Hypothesis p-value: $\theta_{ij}=0$	$\gamma_{ij}=1$	Across Equation Restr.[a]
1990	y on k	-0.053(0.092)**	0.989(0.020)++	0.974			
($n=51$)	y on h	-0.045(0.092)**	1.000(0.019)++	0.946	0.9368	0.9539	0.9517
	h on k	-0.010(0.102)**	0.989(0.022)++	0.961			
2000	y on k	-0.128(0.076)**	0.963(0.016)+	0.985			
($n=51$)	y on h	0.052(0.089)**	1.025(0.019)++	0.957	0.2868	0.0344	0.9065
	h on k	-0.178(0.101)**	0.939(0.021)	0.956			
1990 &	y on k	-0.097(0.062)**	0.975(0.013)++	0.979			
2000	y on h	0.003(0.064)**	1.012(0.014)++	0.952	0.4259	0.1095	0.9842
($n=102$)	h on k	-0.101(0.073)**	0.963(0.016)+	0.957			

Note: y =output share; k =physical capital share; h =human capital share; standard errors in parentheses;
**cannot reject that coefficient is zero at 5% level. *cannot reject that coefficient is zero at 1% level;
++cannot reject that coefficient is unity at 5% level. +cannot reject that coefficient is unity at 1% level;
[a]Test of across equation restriction $\exp\theta_{hk} = \frac{\exp\theta_{yk}}{\exp\theta_{yh}}$.

Table 2.8: SUR Estimates of Output and Factor Share Equations for E.U. Countries

Year (obs)	Equation (i on j)	Intercept (θ_{ij})	Slope (γ_{ij})	Adj. R^2	Joint Hypothesis p-value: $\theta_{ij}=0$	Joint Hypothesis p-value: $\gamma_{ij}=1$	Joint Hypothesis p-value: Across Equation Restr.[a]
1965	y on k	-0.279(0.200)**	0.899(0.057)$^{++}$	0.941			
($n=14$)	y on h	-0.670(0.464)**	0.688(0.110)$^{+}$	0.421	0.3411	0.0231	0.6813
	h on k	0.177(0.681)**	1.188(0.189)$^{++}$	0.454			
1970	y on k	-0.218(0.185)**	0.915(0.053)$^{++}$	0.949			
($n=14$)	y on h	-0.395(0.363)**	0.814(0.093)$^{++}$	0.647	0.5701	0.1533	0.8552
	h on k	0.126(0.444)**	1.096(0.123)$^{++}$	0.689			
1975	y on k	-0.277(0.173)**	0.879(0.048)$^{+}$	0.945			
($n=14$)	y on h	-0.257(0.382)**	0.872(0.102)$^{++}$	0.636	0.4113	0.0841	0.7998
	h on k	-0.082(0.353)**	0.990(0.097)$^{++}$	0.754			
1980	y on k	-0.288(0.277)**	0.921(0.082)$^{++}$	0.885			
($n=14$)	y on h	-0.130(0.181)**	0.940(0.047)$^{++}$	0.875	0.7161	0.5346	0.8071
	h on k	-0.177(0.317)**	0.977(0.093)$^{++}$	0.831			
1985	y on k	-0.206(0.212)**	0.942(0.063)$^{++}$	0.926			
($n=14$)	y on h	-0.044(0.187)**	0.962(0.049)$^{++}$	0.882	0.8111	0.7684	0.8596
	h on k	-0.174(0.238)**	0.978(0.070)$^{++}$	0.896			
1990	y on k	-0.324(0.186)**	0.891(0.053)$^{++}$	0.929			
($n=14$)	y on h	0.083(0.280)**	1.048(0.081)$^{++}$	0.802	0.1102	0.0242	0.9146
	h on k	-0.396(0.197)**	0.848(0.056)$^{+}$	0.896			
1995	y on k	-0.358(0.213)**	0.871(0.061)$^{++}$	0.919			
($n=14$)	y on h	0.073(0.320)**	1.053(0.093)$^{++}$	0.751	0.2601	0.0648	0.9946
	h on k	-0.433(0.266)**	0.820(0.075)$^{+}$	0.806			
2000	y on k	-0.403(0.173)*	0.848(0.050)	0.942			
($n=14$)	y on h	-0.012(0.326)**	1.014(0.097)$^{++}$	0.732	0.0851	0.0087	0.8936
	h on k	-0.414(0.267)**	0.828(0.075)$^{+}$	0.794			
1965-00	y on k	-0.312(0.076)	0.890(0.022)	0.932			
($n=112$)	y on h	-0.303(0.126)	0.876(0.034)	0.683	0.0003	0.0000	0.3901
	h on k	-0.084(0.140)**	0.993(0.040)$^{++}$	0.720			
1980-00	y on k	-0.323(0.100)	0.892(0.029)	0.922			
($n=70$)	y on h	-0.027(0.117)**	0.996(0.033)$^{++}$	0.818	0.0102	0.0020	0.7436
	h on k	-0.313(0.123)*	0.891(0.035)	0.837			
1990-00	y on k	-0.364(0.112)	0.869(0.032)	0.932			
($n=42$)	y on h	0.048(0.178)**	1.038(0.052)$^{++}$	0.775	0.0019	0.0000	0.9707
	h on k	-0.415(0.142)	0.832(0.040)	0.841			

Note: y =output share; k =physical capital share; h =human capital share; standard errors in parentheses;
**cannot reject that coefficient is zero at 5% level. *cannot reject that coefficient is zero at 1% level; $^{++}$cannot reject that coefficient is unity at 5% level. $^{+}$cannot reject that coefficient is unity at 1% level;
[a]Test of across equation restriction $\exp\theta_{hk} = \frac{\exp\theta_{yk}}{\exp\theta_{yh}}$.

Table 2.9: SUR Estimates of Output and Factor Share Equations for Developing Countries

Year (obs)	Equation (i on j)	Intercept (θ_{ij})	Slope (γ_{ij})	Adj. R^2	Joint Hypothesis p-value: $\theta_{ij}=0$	$\gamma_{ij}=1$	Across Equation Restr.[a]
1965	y on k	-1.634(0.305)	0.620(0.060)	0.778			
($n=30$)	y on h	-1.242(0.252)	0.707(0.045)	0.709	0.0000	0.0000	0.1523
	h on k	-0.680(0.503)**	0.849(0.097)++	0.575			
1970	y on k	-1.459(0.308)	0.670(0.061)	0.800			
($n=30$)	y on h	-1.625(0.326)	0.609(0.057)	0.551	0.0000	0.0000	0.3519
	h on k	-0.181(0.690)**	1.003(0.135)++	0.419			
1975	y on k	-1.287(0.285)	0.696(0.058)	0.825			
($n=30$)	y on h	-1.022(0.271)	0.729(0.049)	0.700	0.0000	0.0000	0.2845
	h on k	-0.499(0.487)**	0.926(0.097)++	0.602			
1980	y on k	-1.155(0.270)	0.715(0.055)	0.846			
($n=30$)	y on h	-0.929(0.226)	0.678(0.037)	0.778	0.0000	0.0000	0.3019
	h on k	-0.419(0.486)**	1.036(0.097)++	0.671			
1985	y on k	-1.179(0.250)	0.707(0.050)	0.865			
($n=30$)	y on h	-0.669(0.246)*	0.751(0.043)	0.771	0.0000	0.0000	0.1510
	h on k	-0.754(0.418)**	0.925(0.082)++	0.690			
1990	y on k	-1.217(0.248)	0.696(0.049)	0.863			
($n=30$)	y on h	-0.557(0.212)*	0.792(0.037)	0.818	0.0000	0.0000	0.0815
	h on k	-0.867(0.356)*	0.872(0.069)++	0.764			
1965-90	y on k	-1.337(0.115)	0.681(0.023)	0.832			
($n=180$)	y on h	-1.065(0.111)	0.700(0.019)	0.705	0.0000	0.0000	0.0045
	h on k	-0.536(0.207)*	0.941(0.041)++	0.606			

Note: y =output share; k =physical capital share; h =human capital share; standard errors in parentheses;

**cannot reject that coefficient is zero at 5% level; *cannot reject that coefficient is zero at 1% level.

++cannot reject that coefficient is unity at 5% level; +cannot reject that coefficient is unity at 1% level.

[a]Test of across equation restriction $\exp\theta_{hk} = \frac{\exp\theta_{yk}}{\exp\theta_{yh}}$.

Table 2.10: SUR Estimates of Output and Factor Share Equations for the World

Year (obs)	Equation (i on j)	Intercept (θ_{ij})	Slope (γ_{ij})	Adj. R^2	Joint Hypothesis p-value: $\theta_{ij}=0$	$\gamma_{ij}=1$	Across Equation Restr.[a]
1965	y on k	-1.171(0.225)	0.764(0.037)	0.885			
($n=55$)	y on h	-0.768(0.220)	0.798(0.032)	0.793	0.0000	0.0000	0.2113
	h on k	-0.582(0.360)**	0.944(0.058)$^{++}$	0.724			
1970	y on k	-0.951(0.213)	0.803(0.035)	0.904			
($n=55$)	y on h	-0.842(0.210)	0.806(0.031)	0.808	0.0000	0.0000	0.5095
	h on k	-0.200(0.346)**	0.986(0.055)$^{++}$	0.754			
1975	y on k	-0.905(0.192)	0.802(0.032)	0.918			
($n=55$)	y on h	-0.607(0.211)	0.861(0.033)	0.815	0.0000	0.0000	0.4184
	h on k	-0.397(0.299)**	0.923(0.048)$^{++}$	0.780			
1980	y on k	-0.879(0.184)	0.811(0.031)	0.925			
($n=55$)	y on h	-0.652(0.182)	0.818(0.027)	0.852	0.0000	0.0000	0.4041
	h on k	-0.314(0.294)**	0.985(0.048)$^{++}$	0.809			
1985	y on k	-0.909(0.175)	0.805(0.029)	0.931			
($n=55$)	y on h	-0.444(0.181)*	0.887(0.028)	0.863	0.0000	0.0000	0.3366
	h on k	-0.552(0.257)*	0.903(0.042)$^{+}$	0.826			
1990	y on k	-0.966(0.176)	0.790(0.029)	0.927			
($n=55$)	y on h	-0.471(0.168)	0.916(0.027)	0.873	0.0000	0.0000	0.3929
	h on k	-0.559(0.231)*	0.859(0.037)	0.852			
1965-90	y on k	-0.965(0.080)	0.796(0.013)	0.915			
($n=330$)	y on h	-0.665(0.083)	0.840(0.013)	0.792	0.0000	0.0000	0.0279
	h on k	-0.406(0.125)	0.938(0.020)	0.742			

Note: y =output share; k =physical capital share; h =human capital share; standard errors in parentheses;

**cannot reject that coefficient is zero at 5% level; *cannot reject that coefficient is zero at 1% level.

$^{++}$cannot reject that coefficient is unity at 5% level; $^{+}$cannot reject that coefficient is unity at 1% level.

[a]Test of across equation restriction $\exp\theta_{hk} = \frac{\exp\theta_{yk}}{\exp\theta_{yh}}$.

2.4.3 Estimation results

Tables 2.7 to 2.10 report SUR estimates of the three-equation system (2.30)-(2.32) for each group in each sample year, and for the data pooled over all years. The results for U.S. states (Table 2.7) indicate a high degree of fit between output and factor shares: the minimum value of the adjusted R-square over all equations is 0.946. The results further indicate strong support for the equal-share relationship in each year and for the pooled sample.[12] Specifically, one cannot reject the hypothesis that the intercepts are different from zero, whether this hypothesis is tested individually for each equation, or when tested jointly across the three equations, in each year. One also cannot reject the equal-share hypothesis when using the pooled sample. In addition, in no case can one reject the cross-equation coefficient restriction. This indicates the overall integrity of the equation system relating output and factor shares. These results indicate strong support for the equal-share hypothesis among U.S. states.

For the E.U., the yearly cross-section results in Table 2.8 suggest that the equal-share relationship cannot be rejected, whether by testing that the intercepts are zero in each equation in each year, or testing that the intercepts are jointly equal to zero across the three equations in a given year. However, as indicated in the last part of Table 2.8, when the equations are estimated using the data pooled over all sample years, or pooled for subsets of the sample years, the equal-share relationship is rejected.[13] The different conclusion from the annual versus the pooled sample results likely reflects the small sample size (14 observations) of each cross-section.[14,15] While the equal-share relationship for E.U. countries is rejected in terms of the joint test that the intercepts are zero, the cross-equation coefficient restriction $\exp\theta_{hk} = \frac{\exp\theta_{yk}}{\exp\theta_{yh}}$ is not rejected, again indicating the overall integrity of the equation system relating output and factor shares. It is concluded that technological differences or barriers to factor mobility remain important obstacles preventing E.U. countries from comprising, unlike U.S. states, a fully integrated economy.[16]

[12]For each equation one could not reject the hypotheses of homogeneity of the intercepts and of the slopes across years. This means it is legitimate to estimate the three-equation system using the data pooled over time.

[13]As for the U.S., for each equation one could not reject the hypotheses of homogeneity of the intercepts and of the slopes across years. Hence, it is legitimate to estimate the three-equation system using the data pooled over time.

[14]To examine this, the equation system using data pooled across different subsets of years is estimated. Even for the minimal case of combining two years of data, a pooled sample of 28 observations, was sufficient to reject the equal-share relationship.

[15]Although tests of parameter stability confirm that it is legitimate to estimate using the data pooled over time, the availability of only 14 observations generate differences between cross-section and pooled estimation results. This suggests that the model clearly puts pressure on the estimation technique.

[16]For E.U. countries, the results of per-period cross-section estimation offer some information regarding the deviation toward equal-share relationship.

Notable is that the equal-share relationship is rejected for E.U. countries even in 2000, a period following more than a decade of E.U. reforms (that included implementation of complete labor mobility) intended to further integrate E.U. countries.

Finally, the results for Developing Countries (Table 2.9) and the World (Table 2.10) indicate no support for the equal-share relationship. For each group, the hypothesis that the intercepts equal zero is strongly rejected, for both the individual cross-sections and pooled samples,[17] whether the hypothesis is tested individually for each equation or tested jointly across the set of equations. However, in almost all cases the cross-equation coefficient restriction cannot be rejected, again indicating support for the basic structure of the equal-share equations. These results cast doubt on the importance of factors such as increasing flows of capital across countries (i.e., greater capital market integration) for creating convergence toward the equal-share relationship for these groups of countries. Instead, the results suggest that there remain significant barriers to technology transfer, factor flows, and goods flows between developing countries as well as in the world as a whole.

2.5 Concluding remarks

This chapter considers the implications for the distribution of output and factors among members of an integrated economy in which there is free exchange of goods and factors, and where members share the same production technology. In this setting, a theoretical result is derived and called the equal-share relationship which offers a new perspective on convergence. This relationship states that each member's share of total IE output will equal its shares of total IE stocks of productive factors. The equal-share relationship was also shown to hold in the presence of technological differences or costs of factor mobility among IE members if outputs and inputs are properly measured to reflect such differences or costs.

The results are readily applied in a context of provincial or state economies within a country or of countries within a regional integration organization or within the whole world itself. It turns out that the crucial elements in the distribution of production is not the formation of 'level' of factors among the economies under scrutiny, but the structure of 'share' of factors among them. Specifically, it is found that, under perfect factor mobility, the share of economic output of an economy is identical with its share of stock of physical capital and of human capital. The barriers to capital mobility and the

[17] For both groups, one could not reject for each equation the hypotheses of homogeneity of the intercepts and of the slopes across years. This means it is legitimate to estimate the three-equation system using the data pooled over time.

difference in technology weaken this relationship, but retain the structural pattern and the big picture.

Our empirical analysis examined for the existence of the equal-share relationship among alternative economic groupings: U.S. states, E.U. countries, Developing Countries and a World comprising 55 countries. Strong evidence for a weak form of the equal-share relationship involving a link between rankings of output and factor shares was found for each of the four groups representing alternative integrated economies. When strong forms of the equal-share relationship were instead examined, the results indicated that the integrated economy of U.S. states exhibits full conformity with the predicted equal-share relationship. U.S. states therefore represent a benchmark that can be used to understand the implications of full economic integration.

The empirical findings give only mixed support for the equal-share relationship among E.U. countries, and they strongly reject this relationship among Developing Countries and the World. The findings for Developing Countries and the World are perhaps not surprising and, in this sense, the findings serve as a check on the robustness of the empirical methods used to examine for the validity of equal-share relationship. The finding that E.U. countries do not yet appear to form a fully integrated economy suggests that efforts to more completely integrate E.U. member states have, as least for the time periods studied, failed to achieve the desired level of integration.

Though the equal-share relationship is a static characterization of integrated economy, it raises questions of a dynamic nature. One implication of the equal-share relationship is that the underlying growth mechanism of members of a fully integrated economy can differ markedly from those assumed by the existing growth literature. Specifically, it puts a constraint on the set of policies that can affect the economic position of a member relative to other IE members. The more harmonized are the economic policies of IE members the more likely is the relative growth experience of any one member to be a random outcome contingent on particular states of nature. Also, successful investment and education policies by an IE member may not increase its relative position if these policies are rapidly duplicated by other members. Hence, only independent and non-imitated investment and education policies undertaken by one member can increase the returns to that member's local productive factors which can then provide the incentive to accumulate and/or generate inflows of productive factors.

The empirical relevance of the equal-share relationship stresses the importance of foreign direct investment since it increases the host member's share of physical capital and its return to human capital. Also, a country whose funding level of education is relatively high may experience an increase in its share of human capital. Since this rising of human capital share increases the return to physical capital, the resulting inflow of external (foreign and/or from another IE member) physical capital and accumulation of local physical capital can increase the active member's share of output.[18] Of course, much depends on the institutional arrangements that characterize the policy space of IE members. It is hoped that the analysis presented here offers a convenient framework within which further research on such issues can be conducted.

[18]These predictions assume the integrated economy is 'closed', so that there are no flows of goods or resources between integrated economy members and economies that are not members of the given integrated economy. These predictions would therefore certainly apply to the integrated economy comprised of all economies (i.e., the World).

Chapter 3

Characterizing a fully integrated economy: empirics and consequences of Zipf's law

Chapter 3 is based on Bowen, Munandar and Viaene (2005b, 2006).

3.1 Introduction

Institutional arrangements under which countries open their borders differ in reality. Most international agreements are designed to increase international trade between markets but a few, like the European Union, also allow greater mobility of productive factors within the integrated area. In the limit, as discussed in Chapter 2, such integration would be represented by a fully integrated economy (FIE) in which there is free mobility of goods and factors among FIE members together with complete harmonization of economic and social policies.

An extensive body of work has explored the role of international trade and of factor mobility as mechanisms generating endogenous economic growth. For example, Grossman and Helpman (1991) show that trade generally enhances growth, particularly when it facilitates the international transmission of knowledge. Similarly, Rivera-Batiz and Romer (1991) show that increased trade due to economic integration may have both level and growth effects depending upon the processes by which R&D and information flow across borders. Devereux and Lapham (1994) extend Rivera-Batiz and Romer's model to show that, even without knowledge flows, the balanced growth rate when there is free trade in goods alone exceeds that in autarky, provided that initial levels of national income differ across countries.

With regards to factor mobility, Baldwin and Martin (2004) examine the relationship between growth and the agglomeration of economic activity and find that it depends crucially on the extent of capital mobility between regions. Similarly, Viaene and Zilcha (2002) show that while complete capital market integration among countries has a positive effect on outputs, it does not raise long-run growth rates above autarky values. Instead, these growth rates are affected only by parameters that describe the accumulation of human capital.

While prior work has demonstrated the potentially important role of trade and factor mobility as influences on economic growth, less attention has been given to the question of how trade and factor mobility impact the distribution of output across members of a FIE, and hence how these influences affect the relative economic position of members. Apart from being simply a question of distributional consequences, analysis of this question has important implications for the nature of models that can be used to characterize the growth processes of FIE members. Specifically, as will be shown in this chapter, the distribution of output and factor shares across FIE members can be expected to conform to a rank-share distribution that exhibit *Zipf's law*, which indicates a specific relationship between the rank and value of a variable. This result implies that models used to characterize the growth of members within an FIE must embody a key assumption: that the underlying growth process of shares is random and homogeneous across members.

Country shares of regional (or world) output, or shares of a region's total supplies of productive factors, have become increasingly important constructs in the international trade literature (e.g., Bowen *et al.*, 1987; Helpman and Krugman, 1985; Leamer, 1984; Viaene and Zilcha, 2002). In this regard, below it is first recalled that, within an FIE, each member's share of total FIE output will equal its shares of total FIE stocks of each productive factor (i.e., physical capital and human capital). If economic policies are largely harmonized across members then this equal-share property implies that the growth in any member's shares of FIE output and factor stocks can be taken to be a random outcome. Following Gabaix (1999a), if output and factor shares evolve as geometric Brownian motion with a lower bound, then the limiting distribution of these shares will exhibit Zipf's law. Given this result, it will be shown that the limiting values of each FIE member's output and factor shares are completely determined once the number of FIE members is specified.

Given the theoretical expectation of Zipf's law for output and factor shares, this law is empirically examined within two (presumably) integrated economies: the 50 U.S. states and the District of Columbia (hereafter the 51 U.S. states) and 14 countries of the European Union (E.U.). The data generally cover the period from 1965 to 2000. The empirical results convincingly support Zipf's law for U.S. states and for E.U. countries.

3.2 Equality of output and factor shares in integrated economies

Following the results in Chapter 2, the equality of output and factor shares for each member of a fully integrated economy is demonstrated again in an alternative way. Here an integrated economy that consists of $m = 1, \ldots, M$ members is considered, each producing a single good by means of a constant return to scale production function of the form:

$$Y_{mt} = F(K_{mt}, H_{mt}) \qquad m = 1, \ldots, M \tag{3.1}$$

where Y_{mt} is the level of output, K_{mt} the stock of physical capital, and H_{mt} the stock of human capital, all for country m at time t. The production function is assumed to satisfy all the neoclassical assumptions including diminishing marginal productivity with respect to each factor. For ease of exposition, the production function is assumed to take the Cobb Douglas form:[1]

$$Y_{mt} = A_{mt} K_{mt}^{\alpha_m} H_{mt}^{1-\alpha_m} \qquad m = 1, \ldots, M \tag{3.2}$$

where A_{mt} is a scale parameter and α_m is capital's share of total output. If physical capital and labor are perfectly mobile between the M economies then one would expect the marginal product of each factor to be equal. Barriers to capital mobility (e.g. corporate income tax differentials, capital controls) or labor mobility (e.g. language, different pension systems) would instead create persistent differences in factor rates of returns between members. Consider one reference member of this integrated economy that, without loss of generality, one can take to be country i. Let λ_{mt}^k and λ_{mt}^h define the proportional difference in rates of return to physical capital and to human capital between any country m and reference country i. The relation between rates of return to physical capital in the integrated economy can then be written as:

$$\nu_1 \lambda_{1t}^k \frac{Y_{1t}}{K_{1t}} = \ldots = \frac{Y_{it}}{K_{it}} = \ldots = \nu_M \lambda_{Mt}^k \frac{Y_{Mt}}{K_{Mt}}, \tag{3.3}$$

where $\nu_m = \frac{\alpha_m}{\alpha_i}$, implying $\nu_m = 1$ when $\alpha_m = \alpha_i$ $(m = 1, \ldots, M)$. Note that for $m = i$, $\lambda_{it}^k = 1$ and $\nu_i = 1$. Likewise, the relation between rates of return to human capital can be written:

$$\omega_1 \lambda_{1t}^h \frac{Y_{1t}}{H_{1t}} = \ldots = \frac{Y_{it}}{H_{it}} = \ldots = \omega_M \lambda_{Mt}^h \frac{Y_{Mt}}{H_{Mt}}, \tag{3.4}$$

where $\omega_m = \frac{1-\alpha_m}{1-\alpha_i}$, implying $\omega_m = 1$ when $\alpha_m = \alpha_i$ $(m = 1, \ldots, M)$. Note that for $m = i$, $\omega_i = 1$ and $\lambda_{it}^h = 1$. The ratio of (3.3) to (3.4) gives the following relationship between

[1] The Cobb-Douglas specification has wide empirical support (e.g., Mankiw *et al.*, 1992).

ratios of human to physical capital:[2]

$$\eta_1\lambda_{1t}\frac{H_{1t}}{K_{1t}} = \ldots = \frac{H_{it}}{K_{it}} = \ldots = \eta_M\lambda_{Mt}\frac{H_{Mt}}{K_{Mt}} = \frac{\sum_{m=1}^{M}\eta_m\lambda_{mt}H_{mt}}{\sum_{m=1}^{M}K_{mt}}, \tag{3.5}$$

where

$$\eta_m = \frac{\nu_m}{\omega_m} = \frac{\alpha_m(1-\alpha_i)}{\alpha_i(1-\alpha_m)}, \text{ implying } \eta_m = 1 \text{ when } \alpha_m = \alpha_i;$$

$$\lambda_{mt} = \frac{\lambda_{mt}^k}{\lambda_{mt}^h}, \text{ implying } \lambda_{mt} = 1 \text{ when } \lambda_{mt}^k = \lambda_{mt}^h.$$

Like in (3.5), one can rewrite (3.3) as:

$$\nu_1\lambda_{1t}^k\frac{Y_{1t}}{K_{1t}} = \ldots = \frac{Y_{it}}{K_{it}} = \ldots = \nu_M\lambda_{Mt}^k\frac{Y_{Mt}}{K_{Mt}} = \frac{\sum_{m=1}^{M}\nu_m\lambda_{mt}^kY_{mt}}{\sum_{m=1}^{M}K_{mt}}. \tag{3.6}$$

Combining (3.5) and (3.6) yields the following relationship between output and factor shares for reference member i of the integrated economy:

$$\frac{Y_{it}}{\sum_{m=1}^{M}\nu_m\lambda_{mt}^kY_{mt}} = \frac{K_{it}}{\sum_{m=1}^{M}K_{mt}} = \frac{H_{it}}{\sum_{m=1}^{M}\eta_m\lambda_{mt}H_{mt}} \qquad i = 1,\ldots,M \tag{3.7}$$

In Chapter 2 equation (3.7) is already termed equal-share relationship. This relationship determines the distribution of output and the distribution of factors across M members of an integrated economy. Expression (3.7) contains both observable variables (Y_{mt}, K_{mt}, H_{mt}) and unknown parameters $(\alpha_m, \lambda_m^k, \lambda_m^h)$. Differences in technology or factor market imperfections imply a multiplicative rescaling of the observable variables that is different for each ratio. For example, a difference in λ's leaves the observed values (and share) of physical capital unaffected but transforms the observed values of output and human capital in different ways (through ν_m and η_m respectively). If it is assumed that the M members of the integrated economy share the same technology ($\eta_m = \nu_m = \omega_m = 1$), and that there is costless (perfect) mobility of factors ($\lambda_{mt}^k = \lambda_{mt}^h = 1$), then the simplest expression of the equal-share relationship for any member i is obtained:

$$\frac{Y_{it}}{\sum_{m=1}^{M}Y_{mt}} = \frac{K_{it}}{\sum_{m=1}^{M}K_{mt}} = \frac{H_{it}}{\sum_{m=1}^{M}H_{mt}} \qquad i = 1,\ldots,M \tag{3.8}$$

Hence, with perfect capital mobility and similar technology, each economy's share of total FIE output, and each economy's share of total FIE physical capital stock, equals its share of the total FIE stock of human capital.[3]

[2] One has (3.5) for country i, but for other countries there should be some inverse relationship. Separate tests involving country dummies confirm the existence of such symmetry.

[3] See Dixit and Norman (1980), Helpman and Krugman (1985) and Grossman and Helpman, (1991) for a similar theoretical construct called integrated equilibrium.

Relationship (3.8) has an important implication. It contrasts the policies pursued in isolation by any given FIE member with those that are instead pursued jointly (harmonized) across members. For example, (3.8) remains unchanged when a coordinated educational policy by all FIE members increases their human capital by the same proportion. In contrast, the same policy implemented by only one member increases that member's share of total FIE human capital (as long as this policy is not imitated by other members). Hence, if FIE members have harmonized economic and social policies (e.g., fiscal, education, industrial policies) then the equal-share property implies that the relative performance of each member remains unaffected by these policies. In this sense, member shares can be considered to be a random variable whose outcome is dependent on the particular state of nature at time t. Such randomness can easily be understood from the fact that various kinds of random shocks, like discoveries, weather, or natural disasters, including some that are specific to a particular member, would give rise to new and different sets of shares for all members.

3.3 Rank-share distribution and Zipf's law

A rank-share distribution describes a particular relationship between the share and rank of a variable across a set of observational units. It is related to the concept of a rank-size distribution. For instance, a rank-size distribution for city size exists if the relationship between the natural logarithm of size and of rank is linear and exhibits a negative slope. Zipf's law arises when the slope value equals -1.

The existence of Zipf's law for city sizes is a widely documented empirical regularity.[4] Several explanations have been advanced for the observed regularity of Zipf's law with respect to the distribution of city sizes. Some argue it constitutes an optimal spatial pattern that arises when congestion and urbanization externalities interact as part of the process of development and growth of cities. Such forces are usually found in core models of urban and regional growth.[5] Others have stressed more mechanical forces that often involve a random growth process for city size. A recent example is Gabaix (1999a), who draws on Gibrat's law[6] to assume that cities follow a random but common growth process. Normalizing city population by a country's total population, Gabaix shows (his Proposition 1) that if population shares evolve as geometric Brownian motion with an infinitesimal barrier then the steady state distribution of population shares will be a rank-size distribution that exhibits Zipf's law.

[4]See e.g. Brakman *et al.* (2001), Fujita *et al.* (1999), Gabaix (1999b), Gabaix and Ioannides (2004), Eeckhout (2004) and Rose (2005).

[5]For example, see Eaton and Eckstein (1997), Black and Henderson (1999), Brakman *et al.* (1999).

[6]Gibrat's law (Gibrat, 1931) states that firm growth is independent of firm size.

As previously noted, the equal-share property for members of an FIE, together with an assumed harmonization of FIE member's economic policies, implies that the relative performance of any one FIE member can be considered a random variable. Given this, one can adopt Gabaix's (1999a) specification and assume that the share of variable j (e.g., $j =$ output) evolves as geometric Brownian motion with a lower bound, and moreover, that the distribution of growth rates of these shares is common to all FIE members (i.e., Gibrat's law). Note that the equal-share relationship implies that the common expected rate of growth is zero since the sum over i of the output and factor shares in (3.8) must be 1. One needs to prevent output and factors from falling below some lower bound in order to obtain a power law. Otherwise the distribution would be lognormal. A lower bound makes sense in integrated areas as important income transfers are institutionalized to prevent states / regions / countries to vanish. For example, the E.U. maintains a social fund and a regional fund. As in Gabaix (1999a), this implies that the limiting distribution of the shares of variable j across FIE members will be a rank-share distribution that exhibits Zipf's law.

Consider a FIE consisting of M members. Let S_{mj} denote m's share of the total FIE amount of variable j ($j =$ output (y), physical capital (k) or human capital (h)) and let R_{mj} denote the rank of member m in the ranking of shares of variable j across all members ($m = 1, \ldots, M$). We assume $R_{mj} = 1$ for the member with the largest share of variable j and $R_{mj} = M$ for the member with the lowest share of variable j. If variable j has a rank-share distribution then one can write:

$$S_{mj} = \gamma_j (R_{mj})^{\beta_j} \tag{3.9}$$

where $\beta_j < 0$ is the power-law exponent and $0 < \gamma_j < 1$ is the share of variable j for the member with the highest rank (i.e., $R_{mj} = 1$). Zipf's law corresponds to $\beta_j = -1$, and it implies a specific relationship among member shares, namely: $S_{1j} = 2S_{2j} = 3S_{3j} = \ldots = MS_{Mj}$. This states, for example, that the share value of the highest ranked country is twice the share value of the second ranked country.

To further substantiate Gabaix's (1999) claim on how a rank-share distribution that follows Zipf's law emerges, another Monte-Carlo exercise is performed with U.S. setting. Suppose that initially all 51 U.S. states have the same levels of output and hence the same shares (i.e. $0.0196 = \frac{1}{51}$). Each share S is perturbed randomly, that is, S evolves following the process of geometric Brownian motion with lower bound, $\frac{dS_t}{S_t} = \mu d_t + \sigma dB_t$ for $S_t > S_{min}$ and $dS_t = S_t \max(\mu dt + \sigma dB_t, 0)$ for $S_t \leq S_{min}$. Here $\mu < 0$ is a negative drift, $\sigma$is a standard deviation (volatility), B_t is a Brownian motion and S_{min} is a lower bound. A normalization such that the sum of all shares equal to 1 is performed at any time. Then one can verify whether after some years the distribution of the shares takes the form of a rank-share distribution that exhibits Zipf's law.[7] It is assumed arbitrarily

[7]In other words, here proposition 1 of Gabaix(1999a) is 'proved' by simulation.

that in each market day two random shocks occur.[8] We set the negative drift μ equal to -0.01 and the minimum barrier S_{min} 0.001.[9] We vary σ (volatility) with values 0.04, 0.05, 0.07 and 0.10. We also change the number of years in the simulation equal to 20, 50, 75, 100, 150, 200, 250 and 300. We find that rank-share distributions that exhibit Zipf's law are observed approximately after 100 years, with the required time to emerge varies depending on the volatility of the growth rate of the shares. The higher the volatility, the faster is the convergence to Zipf's law. For example, with volatility equal to 0.07 / shock (variance 2.47 / year), Zipf's law emerges after 100 years.[10] Table 3.1 provides the simulation results and Figure 3.1 gives an illustration on how the shares converge to Zipf's law. Note that during early periods, clear divergence of share paths is observed but such divergence disappears when Zipf's law has been reached.[11]

3.3.1 Empirical specification

To empirically assess the hypothesis that output and factor shares conform to a rank-share distribution that exhibits Zipf's law one can take the natural logarithm of each side of (3.9) to obtain:

$$\log(S_{mj}) = \theta_j + \beta_j \log(R_{mj}) + \upsilon_{mj} \qquad m = 1, \ldots, M; \quad j = y, k, h \qquad (3.10)$$

where $\theta_j = \log(\gamma_j) < 0$ and υ_{mj} is an error term assumed to have the usual properties (mean zero and possibly time-varying variance).[12] Estimates of the intercept and of the slope parameter in (3.10) are crucial to the analysis and are obtained by regressing the share of variable j on variable j's rank value across FIE members.[13]

We estimate (3.10) separately for the output share, physical capital share and human capital share with respect to the 51 U.S. states and the 14 E.U. countries. For U.S.

[8]A market day in the U.S. arguably channels two shocks to all the states (each shock is related to a morning or an afternoon session). The impact of a shock on each state is independent of state size (Gibrat's law). One calendar year consists of 252 market days (Monday to Friday), and hence 504 shocks.

[9]As a robustness check, different values of this barrier are tried: 0.0005, 0.0001, 0.00005 and 0.00001, but find the same qualitative result.

[10]On the other hand, the separate simulation shows that, with lower volatilities (0.01, 0.02 and 0.03), convergence has not been reached in 300 years.

[11]Table 3.1 shows this situation. For example, with volatility equal to 0.07 per shock, the slope decreases from 1.306 to 1.271 between year 200 and year 300. Persistent divergence would have led to an increase (not a decrease) of this slope.

[12]It is plausible to assume the existence of heteroskedasticity here; subsequent estimations will use White heteroskedastic standard errors.

[13]Clearly β_j is the focus of the model estimation, giving the slope of the supposedly log-linear relationship between shares and ranks. But in this framework the intercept has a meaning: e^{θ_j} is the estimated largest (first-ranked) share of m. This is obtained by setting $R_{mj} = 1$ (first rank) and $log(1) = 0$. Significant deviation between the estimated and the actual first-rank shares would give an indication of possible unfitness of the model.

Table 3.1: Emergence of rank-share distribution exhibiting Zipf's law for 51 U.S. states starting with initial equal shares.

Volatility (Shock)	Estimates[a]	Time span (years)							
		20	50	75	100	150	200	250	300
	Slope	0.205	0.310	0.385	0.484	0.586	0.675	0.767*	0.747*
0.04	Std. error	0.017	0.015	0.022	0.026	0.029	0.032	0.038	0.049
	Z-statistic	4.423	3.894	3.517	3.017	2.499	2.053	1.587	1.687
	Slope	0.256	0.387	0.481	0.604	0.733*	0.843*	0.959*	0.934*
0.05	Std. error	0.022	0.019	0.028	0.032	0.036	0.040	0.047	0.062
	Z-statistic	4.164	3.503	3.031	2.407	1.760	1.201	0.619	0.744
	Slope	0.359	0.542	0.673	0.846*	1.025*	1.173*	1.306*	1.271*
0.07	Std. error	0.030	0.026	0.039	0.045	0.051	0.053	0.053	0.073
	Z-statistic	3.646	2.721	2.061	1.186	0.281	0.462	1.136	0.959
	Slope	0.513	0.774*	0.961*	1.205*	1.368*	1.442*	1.417*	1.337*
0.10	Std. error	0.043	0.037	0.056	0.062	0.045	0.039	0.085	0.045
	Z-statistic	2.869	1.548	0.605	0.625	1.449	1.821	1.699	1.292

Note:
[a] Slope is the OLS slope estimate, std. error is the OLS std. error estimate, both are computed from Monte-Carlo simulation results. Z-statistic is computed following Nishiyama and Osada (2004) as the OLS slope estimate plus 0.081 (the bias) minus −1 divided by the asymptotic approximation of the true standard error (given as minus the OLS slope estimate times $0.198 = \left(\frac{2}{51}\right)^{0.5}$) . All slope coefficients with (*) are not significantly different from −1 at the 5% level based on Z-statistic. For more on the Z-statistic, see subsection 3.3.2.

states, annual cross-section data covering the period from 1990 to 2000 are used. For E.U. countries the data instead consist of cross-sections equally spaced at 5-year intervals; these data generally cover the period from 1965 to 2000. The appendix of this thesis provides a complete description of data methods and sources.

3.3.2 Problems with OLS estimates

Given estimates of (3.10) for a given dependent variable, evidence against Zipf's law can be assessed by testing if the estimated slope coefficient is significantly different from minus one. However, Gabaix and Ioannides (2004) and Nishiyama and Osada (2004) recently demonstrate that both the OLS estimate of β_j in (3.10) and its associated standard error are expected to be biased downward, with these biases diminishing as the number of observational units (M) increases. Hence, without some correction for these inherent biases, one is likely to more often reject Zipf's law when it is in fact true.

To correct for these biases, Gabaix and Ioannides (2004) is followed and a Monte Carlo analysis of the OLS slope estimates derived from (3.10) under the assumption that Zipf's

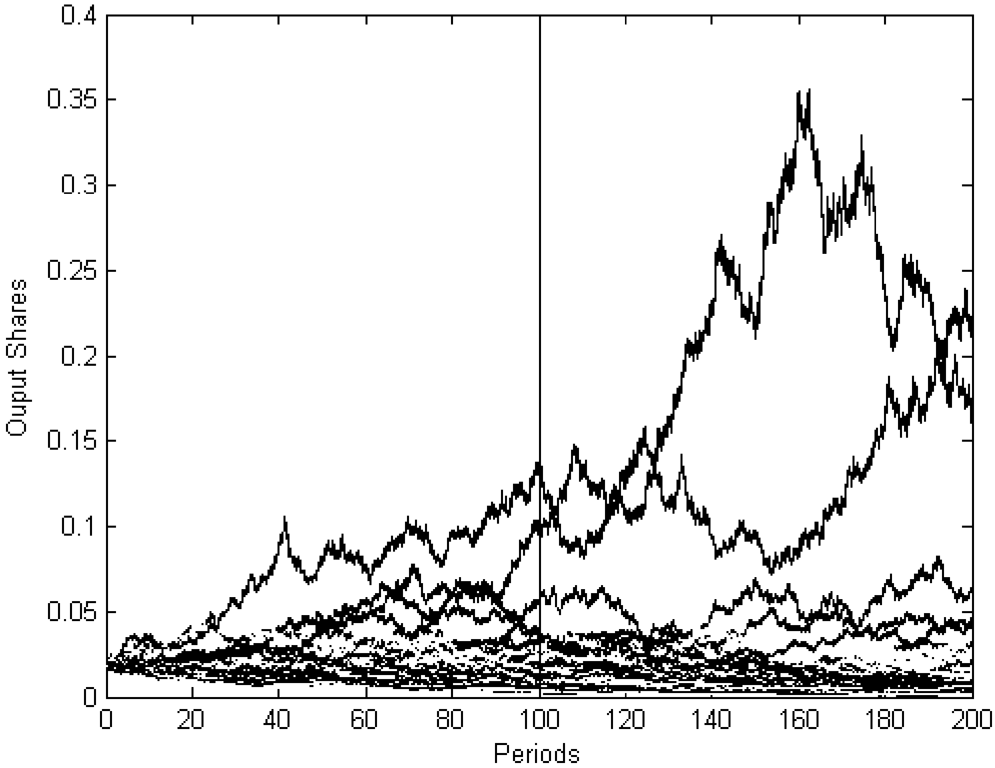


Figure 3.1: An example of simulated path of 51 U.S. states' output shares following Geometric Brownian Motion with lower bound starting with initial equal shares; parameter values are: drift=-0.01, volatility=0.07 and minimum barrier=0.001; the vertical line indicates the starting period from which β_y is not significantly different from –1 (Zipf's law holds). The same estimation method as for Tables 3.3 and 3.4 is used.

law holds is conducted. For a given sample size M, 100,000 Monte Carlo simulations are performed drawing from an exact power law with coefficient 1 (Zipf's Law). This involved drawing M i.i.d. variables ξ_m, uniformly distributed in the interval [0,1], and then constructing sizes $L_m = \frac{1}{\xi_m}$. The sizes L_m are then normalized into shares S_m that were then ordered and assigned a rank value R_m. We then perform 100,000 OLS regressions using the specification $\log(S_{mj}) = \theta_j + \beta_j \log(R_{mj}) + \upsilon_{mj}$. The complete results are presented in Table 3.2.

Three facts emerge from this analysis. First, the OLS estimates are indeed biased downwards (row 3). Second, the OLS standard errors are also biased downward relative to the true standard errors (rows 5 and 6). Third, the magnitude of each bias falls the higher the number of members (observations). The difference between the true slope value (-1) and the average of the OLS slope estimates gives an estimate of the downward bias, which is -0.172 for $M = 14$ and -0.081 for $M = 51$. Given these estimates of the bias for

Table 3.2: OLS estimates and Monte-Carlo simulation results of rank-share relationship

Statistic	Number of Members in Integrated Economy (N)				
	14 (E.U.)	20	51 (U.S. States)	100	200
OLS slope ($E[\hat{\beta}]$)	-1.1721	-1.1415	-1.0810	-1.0536	-1.0338
True slope (β)	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
Bias ($E[\hat{\beta}] - \beta$)	-0.1721	-0.1415	-0.0810	-0.0536	-0.0338
Prob($\hat{\beta} < \beta$)	0.6292	0.6321	0.6335	0.6286	0.6186
OLS std. err. for ($E[\hat{\beta}]$)	0.0886	0.0647	0.0285	0.0158	0.0086
True std. err. for ($E[\hat{\beta}]$)	0.4012	0.3296	0.2001	0.1416	0.0997
True 95% confidence interval for OLS slope ($E[\hat{\beta}]$)	[-2.1044, -0.5444]	[-1.8929, -0.6097]	[-1.5170, -0.7337]	[-1.3542, -0.8016]	[-1.2410, -0.8508]

each M, an estimate of the true slope coefficient is obtained by adding the estimated bias to the OLS estimate derived from (3.10).

To obtain a bias adjusted estimate of the standard error Nishiyama and Osada (2004) is followed and the asymptotic approximation to the true standard error of the OLS slope estimate given as $-\hat{\beta}_j\sqrt{\frac{2}{M}}$ is used, where $\hat{\beta}_j$ is the OLS estimate of the slope in (3.10). The test statistic formed using these bias corrected values has asymptotically a normal distribution (Nishiyama and Osada, 2004), and therefore it is termed the Z-statistic.

Another method for estimating the parameters of a power law distribution is the maximum likelihood Hill estimator (Hill, 1975). However, as Gabaix and Ioannides (2004) remark, the properties of the Hill estimator in finite samples can be "very worrisome," and in particular their theoretical results predict a large bias in parameter estimates and associated standard errors in small samples. We computed the Hill estimators (results not shown) and indeed found very high downward biases in both parameter estimates and standard errors.

3.3.3 Estimation results

The third and fourth columns of Table 3.3 report OLS estimates of (3.10) for the share of output, physical capital and human capital for the sample of U.S. states; the third and fourth columns of Table 3.4 report the OLS estimates for the sample of E.U. countries.[14] Over both set of results, the adjusted-R^2 fall in the range from 0.791 to 0.945, indicating a strong relationship between the share and rank of each variable. The fifth column of

[14]The standard errors associated with the OLS estimates are heteroskedasticity-corrected following White (1980).

both tables presents bias-corrected slopes using results of the Monte-Carlo analysis. The corrected estimates range from –1.062 to –0.973 for U.S. states and from –1.931 to –1.043 for E.U. countries, providing strong signals that Zipf's law may hold in both integrated economic areas.

In Table 3.3, the column labeled "Z-statistic Testing Slope = -1" indicates strong support for the hypotheses that the output and factor shares for U.S. states conform to a rank-share distribution that exhibits Zipf's law; in no case can one reject (at the 5% level) the hypothesis that the slope coefficient is significantly different from -1. This is strong evidence that, for U.S. States, each of the three share distributions exhibit Zipf's law.

Likewise, the column labeled "Z-statistic Testing Slope = -1" in Table 3.4 indicates also strong support for the hypotheses that the output and factor shares for E.U. countries conform to a rank-share distribution that exhibits Zipf's law: one cannot reject (at 5% level) the hypothesis that the slope coefficient is significantly different from -1. These findings for U.S. states and for E.U. countries are striking empirical results.[15] By comparison, similar tests for 30 developing countries and a world of 55 countries are performed but no evidence of Zipf's law was found at the usual significance levels.[16]

3.3.4 Equal-share relationship

The empirical findings of the preceding section have further implications regarding the characterization of integrated economies. One implication is the potential empirical validity of the equal-share relationship as derived in (3.8) since, if Zipf's Law holds, the output shares across countries, or shares of any given factor, are proportional. Hence, if the equal-share relationship holds for one country then it must then also hold for all other countries. A second implication is that if Zipf's Law holds then the limiting share values across FIE members are completely determined once the number of FIE members is specified.

A test for the equal-share relationship involves the null hypothesis given by equation (3.8) against the alternative hypothesis given by (3.7). Evidence in favor of the equal-share relationship can be obtained in two steps: (1) test for homogeneity of the OLS slope estimates (i.e., whether $\beta_y = \beta_k = \beta_h$) to verify that the distributions of shares come from a common power-law distribution and (2) test for homogeneity of the intercepts across the three share equations (i.e., whether $\theta_y = \theta_k = \theta_h$) to examine if the equal-share

[15]The fact that Zipf's law holds for *all* periods for both U.S. states and E.U. countries indicate the robustness of this regularity. The results of subsequent Kolmogorov-Smirnov nonparametric tests further prove such robustness.

[16]This series of finding does not seem to support the claim of Gan *et al.* (2006) that Zipf's law is merely a statistical phenomenon.

Table 3.3: Estimates of rank-share relationships for U.S. states

Variable	Year	OLS Intercept[a]	OLS Slope[b]	Bias-corrected Slope[c]	Z-statistic Testing Slope$= -1$[d]	OLS Adj. R^2
	1990	-1.179(0.248)	-1.101(0.081)	-1.020	-0.092	0.887
	1991	-1.194(0.248)	-1.093(0.081)	-1.012	-0.055	0.884
	1992	-1.199(0.252)	-1.090(0.082)	-1.009	-0.042	0.883
	1993	-1.207(0.258)	-1.085(0.084)	-1.004	-0.019	0.881
Output	1994	-1.208(0.265)	-1.084(0.086)	-1.003	-0.014	0.876
Share	1995	-1.209(0.265)	-1.083(0.086)	-1.002	-0.009	0.874
($M = 51$)	1996	-1.205(0.267)	-1.085(0.087)	-1.004	-0.019	0.872
	1997	-1.192(0.271)	-1.091(0.088)	-1.010	-0.046	0.868
	1998	-1.173(0.272)	-1.100(0.088)	-1.019	-0.087	0.868
	1999	-1.168(0.271)	-1.103(0.088)	-1.022	-0.101	0.866
	2000	-1.164(0.266)	-1.106(0.087)	-1.025	-0.114	0.868
	1990	-1.199(0.246)	-1.092(0.080)	-1.011	-0.051	0.892
	1991	-1.207(0.247)	-1.089(0.080)	-1.008	-0.037	0.891
	1992	-1.200(0.251)	-1.092(0.081)	-1.011	-0.051	0.892
Physical	1993	-1.197(0.257)	-1.093(0.083)	-1.012	-0.055	0.890
Capital	1994	-1.196(0.266)	-1.092(0.086)	-1.011	-0.051	0.884
Share	1995	-1.173(0.275)	-1.102(0.089)	-1.021	-0.096	0.879
($M = 51$)	1996	-1.168(0.276)	-1.105(0.089)	-1.024	-0.110	0.878
	1997	-1.126(0.286)	-1.125(0.093)	-1.044	-0.198	0.870
	1998	-1.126(0.283)	-1.126(0.091)	-1.045	-0.202	0.876
	1999	-1.108(0.283)	-1.135(0.092)	-1.054	-0.240	0.875
	2000	-1.093(0.282)	-1.143(0.091)	-1.062	-0.274	0.880
Human						
Capital	1990	-1.244(0.280)	-1.064(0.091)	-0.983	0.081	0.854
Share	2000	-1.264(0.293)	-1.054(0.096)	-0.973	0.129	0.839
($M = 51$)						

Note: OLS standard errors in parentheses.

[a] All intercept coefficients significantly different from zero at 1% level.

[b] All slope coefficients significantly different from zero at 1% level.

[c] Computed as the OLS slope estimate plus 0.081 (the bias)

[d] Computed as the OLS slope estimate plus 0.081 (the bias) minus –1 divided by the asymptotic approximation of the true standard error (given as minus the OLS slope estimate times $0.198 = \left(\frac{2}{51}\right)^{0.5}$) following Nishiyama and Osada (2004). All slope coefficients are not significantly different from –1 at the 5% level.

Table 3.4: Estimates of rank-share relationships for E.U. countries

Variable	Year	OLS Intercept[a]	OLS Slope[b]	Bias-corrected Slope[c]	Z-statistic Testing Slope= -1^d	OLS Adj. R^2
	1960	-0.645(0.397)	-1.461(0.192)	-1.289	-0.523	0.908
	1965	-0.665 (0.416)	-1.435(0.204)	-1.263	-0.485	0.889
	1970	-0.699 (0.433)	-1.406(0.212)	-1.234	-0.440	0.867
Output	1975	-0.742 (0.435)	-1.366(0.211)	-1.194	-0.376	0.859
Share	1980	-0.755 (0.419)	-1.357(0.202)	-1.185	-0.361	0.870
($M = 14$)	1985	-0.763 (0.417)	-1.354(0.199)	-1.182	-0.356	0.872
	1990	-0.772 (0.420)	-1.346(0.198)	-1.174	-0.342	0.872
	1995	-0.777 (0.405)	-1.343(0.187)	-1.171	-0.337	0.878
	2000	-0.857 (0.376)*	-1.272(0.170)	-1.100	-0.208	0.885
	1965	-0.816 (0.417)	-1.293(0.217)	-1.121	-0.248	0.851
	1970	-0.825 (0.396)	-1.275(0.208)	-1.103	-0.214	0.858
Physical	1975	-0.836 (0.388)*	-1.262(0.203)	-1.090	-0.189	0.858
Capital	1980	-0.760 (0.484)	-1.332(0.245)	-1.160	-0.318	0.828
Share	1985	-0.732 (0.404)*	-1.358(0.205)	-1.186	-0.362	0.870
($M = 14$)	1990	-0.670 (0.398)	-1.418(0.206)	-1.246	-0.459	0.873
	1995	-0.632 (0.330)	-1.457(0.174)	-1.285	-0.518	0.908
	2000	-0.658 (0.382)	-1.431(0.186)	-1.259	-0.479	0.904
	1960	-0.147 (0.448)	-2.103(0.287)	-1.931	-1.171	0.791
	1965	-0.343 (0.341)	-1.890(0.184)	-1.718	-1.005	0.880
Human	1970	-0.529 (0.280)*	-1.639(0.176)	-1.467	-0.754	0.865
Capital	1975	-0.642 (0.236)**	-1.518(0.126)	-1.346	-0.603	0.928
Share	1980	-0.683 (0.239)**	-1.433(0.122)	-1.261	-0.482	0.933
($M = 14$)	1985	-0.747 (0.185)**	-1.409(0.092)	-1.237	-0.445	0.945
	1990	-0.895 (0.191)**	-1.241(0.112)	-1.069	-0.147	0.912
	1995	-0.897 (0.201)**	-1.225(0.115)	-1.053	-0.114	0.912
	2000	-0.905 (0.196)**	-1.215(0.110)	-1.043	-0.094	0.919

Note: OLS standard errors in parentheses.

[a] All intercept coefficients significantly different from zero at $^{**} = p < 0.05$ or $^{*} = p < 0.10$

[b] All slope coefficients significantly different from zero at 1% level.

[c] Computed as the OLS slope estimate plus 0.172 (the bias)

[d] Computed as the OLS slope estimate plus 0.172 (the bias) minus –1 divided by the asymptotic approximation of the true standard error (given as minus the OLS slope estimate times $0.3779 = \left(\frac{2}{14}\right)^{0.5}$) following Nishiyama and Osada (2004). All slope coefficients are not significantly different from –1 at the 5% level.

Table 3.5: Testing results of the equal-share relationship

Integrated Economy	Year	$p-$values for testing across-equation homogeneity of: intercepts	slopes
U.S. States	1990	0.9680	0.9014
	2000	0.8241	0.5964
	1965	0.6063	0.0445[a]
	1970	0.8011	0.2797
	1975	0.8619	0.3655
European Union	1980	0.9689	0.8461
	1985	0.9969	0.9305
	1990	0.8111	0.6034
	1995	0.7124	0.3697
	2000	0.7291	0.4072

Note:
[a] Cross-equation homogeneity rejected at 5% level.

relationship holds with respect to the highest ranked member of each FIE (i.e., California for U.S. states and Germany for E.U. countries).[17] Failure to reject the null hypothesis would imply that technological differences and factor market imperfections are not strong enough to prevent the equal-share relationship from holding in a statistical sense.

Table 3.5 reports p-values for testing the hypotheses of slope homogeneity and of intercept homogeneity across the three share distributions in each sample year.[18] For U.S. states, in neither of the two years for which data are available on all three shares (1990 and 2000) can one reject the hypotheses of intercept equality and slope equality, supporting the equal-share relationship for U.S. states. The results for E.U. countries also indicate support for the equal-share relationship. These test results are based on slope estimates uncorrected for bias. However, correcting for the expected downward bias would only strengthen the support for the equal-share relationship evidenced here.

[17]Equally, it can be demonstrated that the equal-share property obtains if one assumes 1) that output shares alone exhibit Zipf's law and 2) that FIE members have identical, homogenous of degree one, production functions.

[18]These tests were performed by establishing, in each year, a system comprising the three share equations but without initially imposing any cross-equation parameter restrictions.

3.3.5 Limiting distribution of shares

Let V_{mj} denote the level of variable j for member m. Assume, without loss of generality, that member 1 has the highest value of variable j and let δ_{mj} be member m's value of variable j relative to that of member 1 (i.e., $\delta_{mj} = \frac{V_{mj}}{V_{1j}}$), so that $\delta_{1j} = 1$. Now order the values of variable j in descending order. This ordering of the values of variable j across the $m = 1, \ldots, M$ members can be written:

$$V_{1j} > \delta_{2j}V_{1j} > \delta_{3j}V_{1j} > \ldots > \delta_{Mj}V_{1j} \tag{3.11}$$

Since the total FIE amount of variable j is $(1 + \delta_{2j} + \delta_{3j} + \ldots + \delta_{Mj})V_{1j}$, (3.11) implies the following relations between member ranks and shares:

$$\begin{aligned}
&Rank\ \ 1: \quad S_{1j} = \frac{1}{1 + \delta_{2j} + \delta_{3j} + \ldots + \delta_{Mj}};\\
&Rank\ \ 2: \quad S_{2j} = \frac{\delta_{2j}}{1 + \delta_{2j} + \delta_{3j} + \ldots + \delta_{Mj}};\\
&Rank\ \ 3: \quad S_{3j} = \frac{\delta_{3j}}{1 + \delta_{2j} + \delta_{3j} + \ldots + \delta_{Mj}};\\
&\quad\vdots \qquad\qquad\qquad\qquad \vdots\\
&Rank\ \ M: \quad S_{Mj} = \frac{\delta_{Mj}}{1 + \delta_{2j} + \delta_{3j} + \ldots + \delta_{Mj}}.
\end{aligned} \tag{3.12}$$

Expressions (3.12) indicate that sequence of shares S_{mj} is a Harmonic series, where each share value S_{mj} depends on the values of the δ's and the number of members M. Accepting the preceding empirical evidence that the distribution of shares exhibits Zipf's law then $\delta_{2j} = \frac{1}{2}$, $\delta_{3j} = \frac{1}{3}$, $\delta_{4j} = \frac{1}{4}$, etc., so that *the theoretical shares* in (3.12) can be computed once the number of members (M) is specified. For example, the theoretical share values for the $M = 51$ U.S. states are: 0.2213, 0.1106, 0.0738, 0.0553,. . ., 0.0043. For the $M = 14$ E.U. countries the theoretical share values are: 0.3075, 0.1538, 0.1025, 0.0769,. . ., 0.0220.

Next whether the observed distribution of shares and the theoretically expected distribution of shares computed using (3.12) differ significantly is investigated. This is equal to conducting a test toward the whole distribution. To this end, a series of two-sample Kolmogorov-Smirnov nonparametric test on the shares for U.S. states and E.U countries in 1990 and 2000 is performed. This test involves the null hypothesis that both groups of shares arise from a common distribution against the alternative hypothesis that the two samples do not originate from a similar distribution. The results, shown in Table 3.6, convincingly fail to reject the null, implying that the actual shares and the theoretical shares indeed come from the same distribution.

Table 3.6: Two-sample Kolmogorov-Smirnov nonparametric tests between actual and theoretical output and factor shares for U.S. states and E.U. countries, 1990 and 2000

Integrated Economy	Year	Kolmogorov-Smirnov D-Statistic Between Actual Shares and Theoretical Shares of [a] Output	Physical Capital	Human Capital
U.S. States	1990	0.2157**	0.2157**	0.2353**
	2000	0.2353**	0.2745*	0.2157**
European Union	1990	0.3571**	0.3571**	0.3571**
	2000	0.3571**	0.3571**	0.2143**

Note:

[a] *D*-statistic whose value is lower than a critical value indicates that one cannot reject that both actual and theoretical shares come from a common distribution; for U.S. states, the critical values are 0.3228 at 1% level and 0.2693 at 5% level; for E.U. countries, the critical values are 0.6161 at 1% level and 0.5140 at 5%.

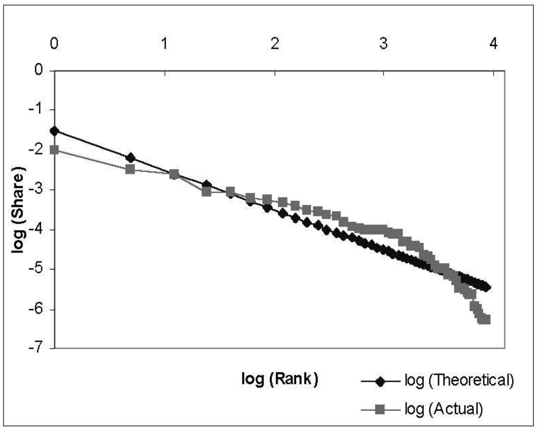
** Cannot reject a common distribution at 5% level.

* Cannot reject a common distribution at 1% level.

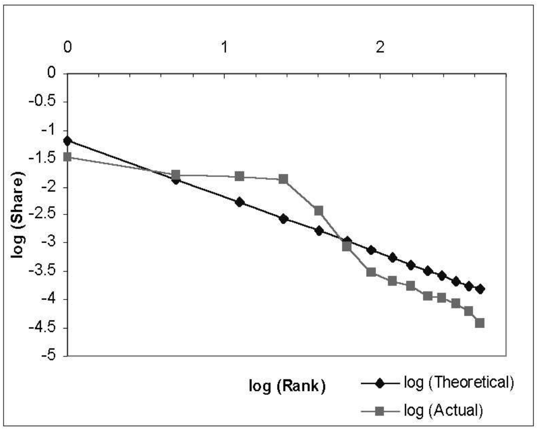
Furthermore, correlation and graphical analyses are conducted to gain insight on whether the observed distribution of shares conforms to the theoretically expected distribution of shares computed using (3.12). The relationship between actual shares and those computed from (3.12) is investigated in Table 3.7 which reports simple correlation coefficients between the natural logarithms of these shares for U.S. states and E.U countries in 1990 and 2000. The correlations range from 0.9176 to 0.9619 and all are highly significant, indicating a strong positive relationship between actual and theoretical shares.

Figure 3.2 provides a graphical presentation of the share distributions by plotting the logarithm of the theoretically expected shares assuming Zipf's law holds and the logarithm of the actual shares in 2000 for each integrated economy. By definition, the theoretical shares (in logs) lie on a straight line with slope -1. Examination of the figures indicates that similar patterns between actual and theoretical shares appear for all three variables, whether for U.S. states or for E.U. countries. For example, for U.S. states, the graphs indicate that the share for the first observation (rank 1) is below the theoretical first share while in the middle range of the distribution the actual share is above the theoretical share. For E.U. countries the actual first share is instead very close to the theoretical share.

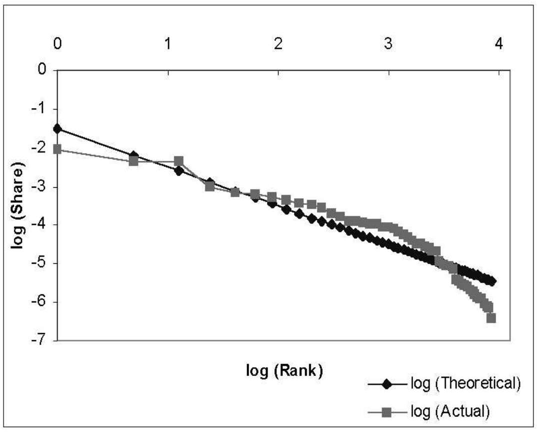
There are several explanations for the observed deviation in actual share values from their theoretical values. One is that the theoretical share distribution is a steady state prediction and our sample values may not represent this ideal. Another is that our



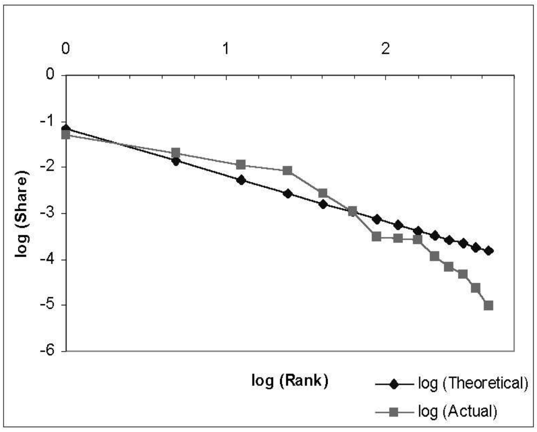
(a) U.S. Output 2000



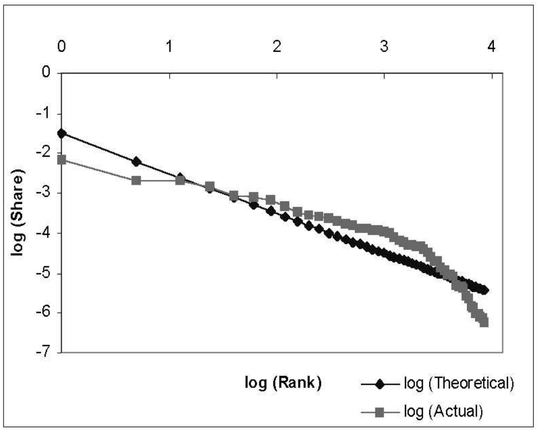
(b) E.U. Output 2000



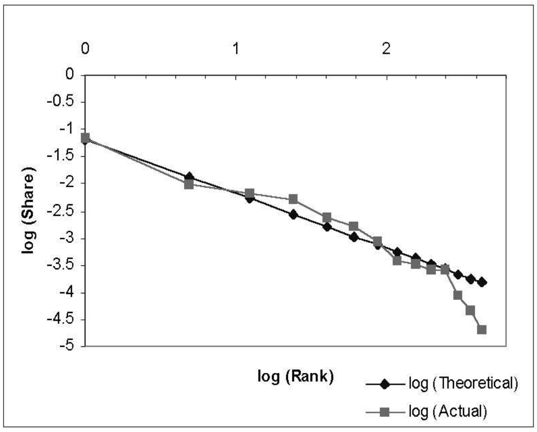
(c) U.S. Physical Capital 2000



(d) E.U. Physical Capital 2000



(e) U.S. Human Capital 2000



(f) E.U. Human Capital 2000

Figure 3.2: Theoretical and Actual Share Distributions for U.S. States and E.U. Countries

Table 3.7: Correlations between Logarithm of Actual and Theoretical Output and Factor Shares for U.S. States and E.U. Countries, 1990 and 2000

Integrated Economy	Year	Correlation Between Logarithm of Actual Shares and Theoretical Shares of		
		Output	Physical Capital	Human Capital
U.S. States	1990	0.9429	0.9456	0.9258
	2000	0.9332	0.9393	0.9176
European	1990	0.9392	0.9397	0.9397
Union	2000	0.9453	0.9548	0.9619

theoretical model assumes that each FIE is 'closed,' in that goods and factor flows arise only between FIE members. In reality, both U.S. states and E.U. countries have important trade and factor flow linkages with entities outside these defined integrated economies. A third is that, since the shares for a given variable sum to unity across observations, the sum of their differences at each rank (i.e., the 'residual') must be zero. Hence, the sum of any positive "residuals" must be offset by the sum of negative 'residuals.' To an approximation, this same result will hold for the sum of the difference between the shares at each rank when measured in logarithms.

3.4 Concluding remarks

We examined empirically for evidence that the distribution of output and factor shares exhibit Zipf's law with respect to two integrated economies: the 51 U.S. states and 14 E.U. countries. The findings indicate that Zipf's law indeed holds for the distribution of these shares among U.S. states and also among E.U. countries. While there may be several explanations for this empirical finding, the evidence on the empirical significance of Zipf's law is consistent with a model that assumes that the growth process of the shares of members of an integrated economy is random and homogeneous across members.

Our empirical results also supported the existence of the equal-share relationship for both U.S. states and E.U. countries. This evidence leads to several implications regarding the characterization of integrated economies which strengthen the conclusion of Chapter 2. First, the equal-share relationship addresses Lucas' (1990) question as to why capital does not flow from rich to poor countries. Namely, an economy with a low level (and hence a low share) of human capital will also have a low share of physical capital, and also a low share of output. Second, if the equal-share relationship holds, then all members of an integrated economy will have the same output per efficiency unit of labor. This implication is the essence of the absolute convergence hypothesis (Barro and Sala-i-Martin, 2004, p.47), here interpreted in terms of efficiency units of labor, not in per capita terms. Finally, the empirical significance of the equal-share relationship is consistent with the relative growth performance of members of an integrated economy being largely random, and hence strongly dependent on particular states of nature. Such randomness will be more true the greater the extent of economic integration among members, perhaps most exemplified by the integrated economy comprising U.S. states. Hence, it is more likely to be true the more harmonized are education systems and fiscal codes, when members do not run independent monetary policies, and when industrial policies are quickly imitated across members.

We also derived the result that, when Zipf's law holds, the values of the output and factor shares for members of a fully integrated economy are completely determined once the number of members is specified. These shares are limiting values that are derived from the relative position (rank) of each member and would be expected to emerge as integrated economies approach full integration. Nonetheless, a comparison of actual share values to these theoretically expected share values indicated a high degree of agreement.

In providing evidence for Zipf's law and the equal-share relationship with respect to members of an integrated economy, this chapter indicates that these empirical characterizations should be kept in mind when studying the implications of alternative policies on the relative growth of members of an integrated economic area.

Chapter 4

Human capital formation and income inequality: the significance of endogenous labor supply and capital markets integration

Chapter 4 is an extension of Viaene and Zilcha (2003) in two directions: (1) endogenous labor supply and (2) capital markets integration.

4.1 Introduction

Social mobility and persistent inequality are two issues that assume considerable importance from both theoretical and policy-making perspectives. The questions of how families can climb the ladder of social and economic status and what determines their income are interesting and important. Also, the inquiries of what establishes income inequality in equilibrium and why it differs across countries remain challenging and crucial. The traditional explanations include cross country differences in technological progress and asymmetric impacts of globalization of world trade and financial markets. Nonetheless, conventional wisdom dictates that an attempt to provide explanation concerning both issues simultaneously must place education into the center stage. This chapter adopts this view and focuses on the process of human capital formation to examine the above issues.

Various international organizations compile extensive lists of indicators that compare schooling accomplishments across countries. A primary characteristic of these indicators is that formal education, parental tutoring and other ways of acquisition of knowledge take place differently in various parts of the world. The level and efficiency of public education, the contribution of parents and the utilization of current technology differ across economies and the variation can be enormous. If one accepts that processes that describe the human capital formation influence economic output and income distribution, then one needs to formalize such processes to find out how they may be significant.

4.1.1 Education, openness and income inequality

A large literature has improved understanding of the determinants of income inequality. Atkinson (1999), Corneo and Jeanne (2001) show that social norms are crucial determinants of income distribution. Various studies have been conducted to analyze the role of human capital accumulation on income distribution in various contexts. [see, e.g. Benabou (1996), Chiu (1998), Fernandez and Rogerson (1998) and Acemoglu (2003)].

There are numerous literatures linking the components of education and differences in income distribution. Becker and Chiswick (1966) demonstrate that income inequality is positively correlated with the schooling inequality and negatively correlated with schooling level. Based on data from nine countries, Chiswick (1971) claims that earning inequality increases with educational inequality. Moreover, using larger sample countries, Adelman and Morris (1973) and Chenery and Syrquin (1975) show that higher levels of schooling reduce income inequality. However, recent progress in technology do not affect the formation of human capital in various countries in similar fashion. The model proposed in this chapter will try to differentiate between cross-country technological variation mostly affecting home education and those mainly affecting public education.

Recent scholarship has documented that experiences from different countries offer conflicting explanations about the relationship between openness and income inequality. Wood (1998) argues that trade was to blame for the recent American surge in income inequality. However, Feenstra and Hanson (1999) estimate that only 15 to 33 percent of increasing inequality was a result of trade competition. Moreover, other sources apparently claim that income inequality has nothing to do with globalization, but with other factors like a decline in growth of per labor skill supply and biased technological change that stop the demand for unskilled relative to skilled labors (Williamson, 2006). These seemingly contradictory results offer a hint that economic integration may not have a significant impact on income inequality.

While up to the mid-1980 only American and British had experienced rising inequality, starting mid-1980 however 20 out of 21 OECD countries had a significant increase in inequality (Burniaux *et al.,* 1998). This study reveals that in most OECD countries, *full-time* labor earnings did not become more unequal. Therefore it indicates that many countries suffer their inequality in the form of higher unemployment and working-time reduction. This last finding clearly encourages one to include elastic labor supply in any model which tries to explain income inequality.

Despite the limited literature on liberalization and income inequality connection in developing countries, the assessment differ sharply across regions. Income gaps seem to decline when Japan, South Korea and Taiwan liberalized late 1960s. But wage inequality generally expanded when the six Latin American countries liberalized after the late 1970s (Hanson and Harrison, 1999; Robbins, 1997). This again indicates the importance of answering the question whether economic integration is associated with a decrease or an increase in income inequality.

It seems plausible, as Wood (1998) correctly highlighted, that historical context is important, since other things were not equal during these liberalizations. An example is the Latin wage widening, which appears to disprove Stolper-Samuelson prediction, was the Mexican Liberalization in 1985-1990. This pro-globalization policy unfortunately coincided with the emergence of China and other Asian exporters into world markets, forcing Mexico to deal with new competition in all export markets. Competition from other low-wage countries was far less extreme when the three Asian tigers opened up in late 1960s compared with the late 1970s when the Latin Americans pulled down their barriers.

Although rising income inequality in China, India, and Russia seems to dominate global trends in within-generation gap, it is probably very little to do with economic integration policy (Williamson, 2006). Much of the gap-widening occurrences during the liberalization phases of those countries seems connected with the fact that the opening was incomplete and selective. That is, the increase in gap appears to have excluded much of the population from the benefits of globalization. An example is China where the gains from the liberalization have been so heavily enjoyed in the coastal area. Another example concerns Mexico. After GATT-related liberalization in 1986 and NAFTA-related liberalization in 1994, Mexico has undergone rising inequality, not falling inequality as most observers predicted. Hanson (2002) has presented that much of this result has been traced to an uneven regional stimulus and, in particular, to the sudden development along the U.S. border. Robertson (2001) has shown that the increase in wage-gap was reversed after three to five year lag.

Nonetheless, it is clear that the effect of economic integration on income inequality has been hotly debated. This chapter is an attempt to contribute to the discussion of solving this puzzle.

4.1.2 Heterogeneous agents and overlapping generations economy

An overlapping generations economy is constructed, containing heterogeneous agents that produces a single good using two types of production factors: physical capital, and human capital represented by an interaction between labor supply and a continuum of skills. Each individual lives for three periods, where during the 'childhood' time (in which no economic decision is made) education is obtained. Intergenerational transfers in the economy occur via two channels: (1) the provision of public education financed by labor income tax and (2) the investments made by parents in tutoring their own children at home. Additionally, every child is endowed with a random inborn ability.

A government has two roles in the economy: first, in providing public education budget by taxing wage incomes and, second, in conducting public education itself and determining its level. Public education may consist of formal education in schools and expenditure related to schooling (e.g. public library and media). However, in our framework, the level of public education represents the effective educational inputs related to teaching and not to other public education expenditures.

Home education is provided by the immediate family and performed mainly through parental coaching, social interaction and learning technology available at home (e.g. books and internet). In this case, the level of human capital of parents and the time they devote to tutoring are essential factors.

Various economic models have constructed similar mechanisms to describe human capital formation. Such processes usually concentrate on very few parameters to maintain tractability.[1] In current model the human capital formation process displays a few important properties. First, individuals from above-average human capital families have a lower return to investment in public education than those from below-average families. Also, the cost of attaining a particular human capital level for the younger generation is smaller for families endowed with relatively higher levels of human capital. Other models exhibiting these features include Tamura (1991) and Fischer and Serra (1996). Second, the significance of parental human capital in shaping the human capital of an offspring has been developed. Burnhill *et al.* (1990) show that the education level of parents affects entry to higher education more that the influence of the social class of them. More recently, Barro and Lee (2001) and Brunello and Checchi (2005) discover that family characteristics, including parental education, improve student's achievement. A reason that is offered is that the level of education of parents contributes to the quality of parental involvement at home.[2]

When analyzing the effect of capital markets integration two economies are considered, one capital exporting and the other capital importing. This setting leads to post-integration equalization of returns to capital. There are previous literatures dealing with differences in cross-country returns to capital, for instance Lucas (1990) and Leidierman and Razin (1994). Notably, Viaene and Zilcha (2002) show the theoretical allocation of world output among countries following capital markets integration and its consequences on income distribution. However, the model seems to be more realistic since different

[1]For example, see e.g., Eckstein and Zilcha (1994), Orazem and Tesfatsion (1997) and Hanushek (2002).

[2]For more discussions see Hanushek (1986) and Glaeser (1994).

roles between the parental and public education are allowed and an elastic labor supply across families is incorporated.[3]

Using the model, the usual explanatory factors of income inequality like physical capital mobility and technological progress in production are demonstrated to play no role in determining income distribution in equilibrium. Initial condition on stock of human capital is relevant in the sense that a country that starts from a higher level of human capital, not necessarily more equal, has a better chance to experience more equality over time. But, physical capital mobility resulted from this gap in endowments do not affect the income inequality following capital markets integration although the effects on welfare can be substantial. These findings isolate processes of human capital formation as the main source of discrepancy in income inequality. Such result stands in contrast with those of Viaene and Zilcha (2002) which suggest that following capital markets integration, inequality in intragenerational income distributions changes in all dates. This difference exists because they assume the existence of intergenerational transfer of physical capital (bequest). However, the empirical evidence seems to suggest that among families, bequests are far from universal (Laitner, 1997).

4.1.3 Model characteristics

Our model implies the following features to hold in equilibrium: (a) utility maximization leads to endogenous labor supply; (b) it allows some parents not to participate to the education of their own child, which is a stylized fact of some economies; (c) under a certain condition, the choice of public education determines whether poverty trap exists; (d) increasing the provision of public education will reduce income inequality.

With the model it is also demonstrated that when government plays no role in the education process (i.e., zero provision of public education), the economy generates an endogenously determined intragenerational income distribution. In this case, inequality emerges from both the random inborn ability and the differences in parents' human capital. The role of education here is to dampen the variation emerging from families' human capital and therefore lower the inequality of both human capital and income distributions. In other words, if one compares two economies that differ in public education provision only, the economy that invests more in public education faces lower income inequality along the whole equilibrium path. In particular, when the level of public education is very low, the economy may enter a poverty trap, that is, a decrease of stock of human capital over time. Contrary to this situation, higher levels of public education guarantee that the aggregate human capital increases over time.

[3]Wharton and Blair-Loy (2006) provides empirical evidence on the relationship between work hours and family life in the United States, London, and Hong Kong.

On the other hand, the heterogeneity in parents' human capital generates a certain pattern of heterogeneity in children's labor supply. In particular, the lower the level of human capital of parents, the higher the labor supply exerted by the corresponding offspring in the next period. Again, such feature does not affect intragenerational income inequality, even after capital markets integration.

In this work, technological improvement for education matters. It has the opposite effects on inequality depending on whether such improvement occurs in the public education or in the home education. Specifically, a more efficient public education decrease inequality while a more efficient home tutoring rises inequality.

The remainder of the chapter is arranged as follows. Section 2 elaborates an Overlapping Generation Model with heterogenous agents and analyzes the properties of the model, including equilibrium conditions, future income, role of parents, poverty trap and variation of labor supply. Section 3 explains the capital markets integration with its implication to wage rates of domestic and foreign economies. Section 4 analyzes the impacts of human capital formation on various facets of income inequality, including the roles of public education, initial endowments and education technology. Section 5 calibrates the dynamic general equilibrium model using data from the Netherlands over the period 1975-2000. A numerical simulation computes the response of income inequality to various processes of human capital formation and confirms the results of the previous section. Section 6 concludes. To facilitate the reading all proofs are relegated to the Appendix.

4.2 Human capital formation

4.2.1 Preferences and technology

Consider an overlapping generations economy with no population growth in which continuum of individuals live for three periods. During the first period, children obtain education but do not involve in any economic decision making. After finishing school, they become economically active during the next two periods, a working period followed by a retirement period. At the end of the first period, every individual gives birth to one offspring. Indicate by G_t the set of individuals born at the beginning of period $t-1$ and refer to these individuals as generation t. Denote the set of families in each generation by $\Omega = [0, 1]$ and the Lebesgue measure on Ω by μ. Each individual in G_t is characterized by its family name $\omega \in \Omega$.

In this economy, agents are endowed with two units of time that can be allocated to labor, leisure and self-educating the offspring. Parents care about the welfare of the children. More specifically, it is assumed that parents, during their working period, derive utility from the future income of the children. Labor is elastic and hence each family's supply of labor and human capital is the result of utility maximization.[4] Let $l_t(\omega)$ and $h_t(\omega)$ the levels of labor supply and human capital respectively, of individual $\omega \in G_t$.

The production of human capital is modelled consisting of two components: informal education initiated and provided by parents at home, public education provided by the government by, for example, constructing schools and employing teachers. The parental education depends on the time spent by the parents to this purpose, indicated by $e_t(\omega)$ and the quality of parental guidance represented by human capital level of the parents, $h_t(\omega)$. The level of public education is denoted by e_{gt}. The labor supply and human capital of the teachers determine the quality of public education, and hence the formation of new generation's human capital. Instructors in each generation are assumed to be selected randomly from the population of that generation.[5] The random inborn ability of child $\omega \in G_t$, expressed as $\theta_t(\omega)$, is assumed to have been known already when parents make decisions about labor supply and parental tutoring. Moreover, all the random variables $\theta_t(\omega)$ are assumed to be independent and identically distributed with values in $[\underline{\theta}, \overline{\theta}]$, where $0 < \underline{\theta} < \overline{\theta} < \infty$, and denote its mean by $\hat{\theta}$ and define, without loss of generality, $\hat{\theta} = 1$.[6] For some parameters $\beta_1 > 1, \beta_2 > 1, \upsilon > 0$ and $\eta > 0$, the evolution process of the human capital of each family $\omega \in G_{t+1}$ is assumed to be as follows:

$$h_{t+1}(\omega) = \theta_t(\omega) \left[\beta_1 e_t(\omega) h_t^{\upsilon}(\omega) + \beta_2 e_{gt} \bar{l}_t \overline{h}_t^{\eta}\right] \tag{4.1}$$

where the labor supply and human capital involved in public schooling, denoted by $\overline{l_t}$ and $\overline{h_t}$ respectively, are the average/aggregate labor supply and average/aggregate human capital of generation t. The constants β_1 and β_2 represent the efficiencies of parental and public education in contributing to human capital. β_1 is affected by the home environment, family size and interaction among family members while β_2 is influenced by the schooling system, facilities, size of classes, social interaction, and so forth. The parameters υ and η indicates the externalities derived from parents' and society's human capital respectively. Brunello and Checchi (2005) provides support for (4.1) by demonstrating the importance of both home and public education in human capital formation using Italian data.

[4] This setting is a generalization of Viaene and Zilcha (2003) which assumes that each family supplies one unit labor inelastically.

[5] A market of education without government can be established; the obvious example would be the market of private school. In this setting, various "education products", which would have different qualities, and hence different 'prices', would be consumed by different groups of young individuals. Therefore, such education market is expected to have characteristics between those of parental education and of public education. The market of education is ignored in this model.

[6] This seems to be somewhat restricted given recent literature suggesting that innate abilities are correlated across generations (Plug and Vijverberg, 2003; Björklund *et al.*, 2006). For instance, Plug and Vijverberg (2003) conclude that more than half of the intergenerational transfer of ability is genetically determined. In this framework, accommodating this finding will result in a more persistent income inequality while in terms of modeling, $\theta(\omega)$ will take a slightly more sophisticated form. This is left for further research.

The human capital formation given by (4.1) exhibits the characteristics that public education smooths the family attributes. Individuals from poor family have a greater return to human capital derived from public schooling than those born to above-average human capital families. In this setting, the representation of private and public inputs in the production of human capital is through allocation of time. It is argued that the learning time, together with the human capital of instructors, should be the relevant variables in such a process. This is in line with Hanusek (2002) who suggests that considering the efficiency in the provision of public education is more relevant than focusing on the expenditure of public education. This difference is crucial since in the dynamic framework the cost of producing a particular level of human capital varies with relative factor price.

Consider $y_t(\omega)$ as the lifetime income of individual $\omega \in G_t$, which is earned in the second period. As it is common to all, individual income is determined by the effective human capital, that is the interaction of the labor supply and the human capital. Suppose w_t is *the wage rate per effective human capital* in period t and τ_t is the tax rate on labor income, then

$$y_t(\omega) = w_t(1 - \tau_t)l_t(\omega)h_t(\omega) \tag{4.2}$$

The existence of public education regime is assumed such that the taxes on incomes are used to finance public education costs of the young generation. Using (4.1) and (4.2), balanced government budget implies the equality of public education expenditure with tax income,

$$\int_\Omega w_t e_{gt} \bar{l}_t \bar{h}_t d\mu(\omega) = \int_\Omega \tau_t w_t l_t(\omega) h_t(\omega) d\mu(\omega)$$

and equivalently,

$$e_{gt} = \tau_t \tag{4.3}$$

that is, the proportion of the economy's labor supply used for public education is equal to the tax rate on labor.[7]

Production in this economy is carried out by competitive firms that produce a single commodity, using physical capital and effective human capital. This commodity is both consumed and used as production input. There is a full depreciation of physical capital, K_t. The per-capita effective human capital in date t, $\bar{l}_t\bar{h}_t$, is an input in the aggregate production process. In particular the per-capita production function is taken to be:

$$q_t = F(K_t, (1 - e_{gt})\bar{l}_t\bar{h}_t) \tag{4.4}$$

Moreover, $F(\cdot, \cdot)$ is assumed to exhibit constant returns to scale, it is strictly increasing, concave, continuously differentiable and satisfies $F_K(0, (1-e_{gt})\bar{l}_t\bar{h}_t) = \infty$, $F_H(K_t, 0) = \infty$ and $F(0, (1 - e_{gt})\bar{l}_t\bar{h}_t) = F(K_t, 0) = 0$.

[7] Here it is assumed that $l_t(\omega)$ and $h_t(\omega)$ are independent as $h_t(\omega)$ depends only on primitives at $t-1$ through human capital production function (4.1). A weaker condition would resulth in $e_{gt} = b_t\tau_t$ with $b_t = \frac{\int_\Omega l_t(\omega)h_t(\omega)d\mu(\omega)}{\bar{l}_t\bar{h}_t}$, which does not change subsequent qualitative results.

4.2.2 Competitive equilibrium

In this chapter it is assumed that the political process which determines the levels of public provision of education is exogenous. The subsequent analysis, however, does not depend on these positive public education level, e_{gt}. In other words, if $\{e_g\}_{t=0}^{\infty}$ is determined by some social welfare function maximization all the results hold.[8]

At time t, given the level of public education provision e_{gt}, agent ω maximizes lifetime utility, which depends on consumption, labor supply, leisure and income of the children, so as to maximize

$$\max_{e_t, s_t, l_t} u_t(\omega) = c_{1t}(\omega)^{\alpha_1} c_{2t}(\omega)^{\alpha_2} y_{t+1}(\omega)^{\alpha_3} [2 - l_t(\omega) - e_t(\omega)]^{\alpha_4}, \tag{4.5}$$

subject to constraints

$$c_{1t}(\omega) = y_t(\omega) - s_t(\omega) \geq 0, \tag{4.6}$$

$$c_{2t}(\omega) = (1 + r_{t+1}) s_t(\omega), \tag{4.7}$$

where h_{t+1} and y_{t+1} are defined by (4.1) and (4.2). The α_i's are known intensity parameters and $\alpha_i > 0$ for $i = 1, 2, 3, 4$. The c_{1t} and c_{2t} denote, respectively, consumption in first and second period of agent's economically active life. Implicitly it is assumed that c_1 covers consumption of children in the family. Savings is represented by $s_t(\omega)$ while labor supply is indicated by $l_t(\omega)$. Leisure is given by $[2 - l_t(\omega) - e_t(\omega)]$. The interest factor at date t is $1 + r_{t+1}$. The children's income $y_{t+1}(\omega)$ enters parents' utility function directly and represents the motivation for parents' investment in tutoring.

Given some tax rates (τ_t), the initial physical capital k_0 and the initial distributions of labor supply $l_0(\omega)$ and of human capital $h_0(\omega)$, a competitive equilibrium is $\{l_t(\omega), e_t(\omega), s_t(\omega), K_t; w_t, r_t\}$ such that for all t and all individuals $\omega \in G_t$, $\{l_t(\omega), e_t(\omega)$ and $s_t(\omega)\}$ are the solution to the above problem given $\{w_t, r_t\}$. In the equilibrium, the following market clearing conditions hold:

$$w_t = F_H(K_t, (1 - e_{gt}) \bar{l}_t \bar{h}_t), \tag{4.8}$$

$$1 + r_t = F_K(K_t, (1 - e_{gt}) \bar{l}_t \bar{h}_t) \tag{4.9}$$

$$K_{t+1} = \int_{\Omega} s_t(\omega) d\mu(\omega) \tag{4.10}$$

Equations (4.8) and (4.9) are clearing conditions on factor markets. Equation (4.10) is a clearing condition for physical capital, equating aggregate savings at time t with the

[8]For example the equilibrium public education level can be determined by a median-voter political equilibrium model (Persson and Tabellini, 2000) or a rational dynamic voting model (Hassler *et al.*, 2002).

aggregate capital stock at date $t+1$. The first order conditions that are necessary and sufficient for an optimum are:

$$\frac{c_{1t}(\omega)}{c_{2t}(\omega)} = \frac{\alpha_1}{\alpha_2(1+r_{t+1})} \tag{4.11}$$

$$\frac{\alpha_4}{2-l_t(\omega)-e_t(\omega)} = \frac{\beta_1\alpha_3(1-\tau_{t+1})w_{t+1}l_{t+1}(\omega)h_t^{\upsilon}(\omega)\theta_t(\omega)}{y_{t+1}}, \qquad \text{if} \quad e_t(\omega)>0 \tag{4.12}$$

$$\geq, \qquad \text{if} \quad e_t(\omega)=0 \tag{4.13}$$

Equation (4.12) optimally divides the unit of time into labor supply, leisure and the time spent on tutoring by the parents. Equation (4.13) takes care the situation in which individuals derive a negative marginal utility from spending time educating their children. Such individuals would use their time instead either to enjoy leisure or to work or both.

Assuming that the externality of individual labor supply to society public education is negligible,[9] the following first order condition exists:

$$\frac{\alpha_4}{2-l_t(\omega)-e_t(\omega)} = \frac{\alpha_1 w_t(1-\tau_t)h_t(\omega)}{c_{1t}(\omega)} \tag{4.14}$$

From (4.6), (4.7) and (4.11):

$$c_{1t}(\omega) = \left[\frac{\alpha_1}{\alpha_1+\alpha_2}\right] y_t(\omega) \tag{4.15}$$

and combining (4.6) and (4.15):

$$s_t(\omega) = \left[\frac{\alpha_2}{\alpha_1+\alpha_2}\right] y_t(\omega) \tag{4.16}$$

which allocate present income into current consumption and savings based on the intensities of both consumptions in the utility function.

Whenever $e_t(\omega)>0$, using (4.2) and (4.15), one can rewrite (4.14) as follows:

$$l_t(\omega) = \left[\frac{\alpha_1+\alpha_2}{\alpha_1+\alpha_2+\alpha_4}\right](2-e_t(\omega)) \tag{4.17}$$

and using (4.1), (4.2), (4.3) and (4.12):

$$e_t(\omega) = \frac{\alpha_3}{\alpha_3+\alpha_4}\left[2-l_t(\omega)-\frac{\alpha_4\beta_2}{\alpha_3\beta_1}\frac{\tau_t\bar{l}_t\bar{h}_t^{\eta}}{h_t^{\upsilon}(\omega)}\right] \tag{4.18}$$

[9]Note that in human capital production function (4.1), society public education depends on the average labor supply. In the limit, the contribution of each individual labor supply to the average is negligible.

After substituting (4.17) into (4.18):

$$e_t(\omega) = \frac{1}{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4}\left[2\alpha_3 - (\alpha_1 + \alpha_2 + \alpha_4)\frac{\beta_2}{\beta_1}\frac{\tau_t \bar{l}_t \overline{h}_t^{\eta}}{h_t^{v}(\omega)}\right] \tag{4.19}$$

Therefore, $e_t(\omega)$ increases with the parents' human capital $h_t(\omega)$ but decreases with the tax rate τ_t. The higher the human capital level of parents, the lower the return to public education, and hence in optimum parents will dedicate more time to tutor their children. The higher the tax rate, the higher the return to public education and hence the more optimal for parents to devote less time in educating their children. Also, $e_t(\omega)$ decreases with the intensities of consumptions, α_1 and α_2. If current or future consumption is more important, then more time will be allocated for working which implies more income, and less time for tutoring offspring. As expected, higher relative importance on leisure in parents' utility α_4 decreases tutoring time $e_t(\omega)$ as well. Note that intensities of consumption play no role in a model with inelastic labor supply since the parental tutoring time has no income effect for working generation (Viaene and Zilcha, 2003).

Moreover, substituting (4.19) into (4.17) results in:

$$l_t(\omega) = \left[\frac{\alpha_1 + \alpha_2}{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4}\right]\left[2 + \frac{\beta_2 \tau_t \bar{l}_t \overline{h}_t^{\eta}}{\beta_1 h_t^{v}(\omega)}\right] \tag{4.20}$$

that is, $l_t(\omega)$ increases with the tax rate τ_t but decreases with the parents' human capital $h_t(\omega)$.[10] A higher tax rate lower income in (4.2) which is then compensated by high labor. Parents with high human capital exert less labor and spend time more to educate their children or to enjoy leisure. High values attached to consumptions (i.e., high α_1 and α_2) induce people to work more.

However, when $e_t(\omega) = 0$, from (4.17):

$$l_t(\omega) = \frac{2(\alpha_1 + \alpha_2)}{\alpha_1 + \alpha_2 + \alpha_4} \tag{4.21}$$

suggesting that labor supply increases with intensities of consumptions, decreases with importance of leisure and independent of the share of children's expected incomes in the utility function.

4.2.3 Income at the future date

It is important to note that $e_t(\omega)$ in (4.19) and $l_t(\omega)$ in (4.20) are *independent of the inborn ability* of their offspring. Using results from previous subsection, an expression of

[10] The contribution of individual labor supply to society labor supply is negligible due to the continuum nature of individuals.

income at date $t+1$, $y_{t+1}(\omega)$ is developed. To achieve this, (4.12) and (4.13) are applied and (4.1), (4.2) and (4.3) are used:

$$y_{t+1}(\omega) = (1-\tau_{t+1})w_{t+1}l_{t+1}(\omega)h_{t+1}(\omega) \tag{4.22}$$

where,

$$h_{t+1}(\omega) = \left[\frac{\alpha_3}{\alpha_1+\alpha_2+\alpha_3+\alpha_4}\right]\theta_t(\omega)\left[2\beta_1 h_t^v(\omega) + \beta_2\tau_t\bar{l}_t\overline{h}_t^\eta\right] \tag{4.23}$$

whenever $e_t(\omega) > 0$, and

$$h_{t+1}(\omega) = \beta_2\theta_t(\omega)\tau_t\bar{l}_t\overline{h}_t^\eta \tag{4.24}$$

if $e_t(\omega) = 0$.

Expressions (4.22)-(4.24) show the individual income at the future date in terms of the wage rate at date $t+1$, the parents' human capital, the current public education input ($\tau_t = e_{gt}$), the society's levels of labor supply and human capital at date t and the externalities in education. When $e_t(\omega) > 0$, an increase in any of these variables results in a higher income of the future generation. Also, the more parents care about their children (i.e., higher α_3) the more time they are willing to devote to tutor their children, and hence, the higher is the income of the next working generation.

With individual and aggregate labor supplies both being determined endogenously, expressions (4.22)-(4.24) convincingly justify the importance of human capital as the only source of endogenous growth.[11] These results suggest that future income of each individual is completely determined by individual and aggregate levels of human capital along with parameters describing the economy, even in the absence of provision of public education.

4.2.4 Absence of parental participation

The withdrawal of parents from education process is a stylized fact of education systems in some advanced and developing countries that has attracted the attention of policy-makers.[12] This situation, where utility maximization is attained at $e_t(\omega) = 0$, occurs under certain conditions. To obtain this, recall that (4.12) and (4.13) establish a negative relationship between public education and home tutoring, namely public education substitutes for parental education. For each individual there exists a particular tax rate such that $e_t(\omega) = 0$, that is, when the marginal utility of working or leisure is larger than the additional utility from an increase in the offspring's human capital due to higher level of parental tutoring. Consider the families which optimally choose $e_t(\omega) = 0$ and denote this set of families in generation t by $A_t \subset G_t = [0,1]$. In fact, using (4.1) and (4.2),

[11] In this sense, the model is in line with Romer (1986), Lucas (1988) and Becker *et al.*

[12] See Lareau, 1989 for a survey.

condition (4.13) holds if:

$$2 - l_t(\omega) - e_t(\omega) < \frac{\alpha_4}{\beta_1\alpha_3}\left[\beta_1 e_t(\omega) + \beta_2 e_{gt}\frac{\bar{l}_t\overline{h}_t^{\eta}}{h_t^v(\omega)}\right]$$

Therefore, for each individual ω, $\omega \in A_t$ is obtained whenever:

$$h_t^v(\omega) < \frac{(\alpha_1 + \alpha_2 + \alpha_4)\beta_2}{2\alpha_3\beta_1} e_{gt}\bar{l}_t\overline{h}_t^{\eta} \tag{4.25}$$

Set A_t consists of individuals with sufficiently low level of human capital. This set increases as the efficiency or the level of public education increases, confirming the substitute nature of parental tutoring and public education while it increases as parents in the society care their children very much or as the efficiency of home learning increases, for instance due to technological advancement. Notice also that this set increases with the importance of consumptions or of leisure as individuals prefer spending their time earning income or taking leisure rather than tutoring their children. Consumption parameters α_1 and α_2 play no role in establishing set A_t when labor is inelastic since they have no effect on labor income (see Viaene and Zilcha, 2003). On the contrary, in this framework such parameters determine individual income through (4.20) and (4.2).

4.2.5 Endogenous labor supply and lack of human capital as determinants of poverty trap

As demonstrated in (4.1), endogenous labor supply plays a crucial role in the construction of aggregate human capital stock at all dates. Although parental tutoring and public education are imperfect substitutes to each other, the long run human capital stock along the equilibrium path is affected by a provision of public education. Decreasing the level of public education below a certain time-varying threshold, conditional on the aggregate human capital level, results in a negative growth rate of the stock of human capital, while a higher provision of public education results, along the equilibrium path, in a positive growth rate. Therefore, a poverty trap is allowed by the model. An important point is that, because of the existence of endogenous labor supply, such thresholds are conditional on the level of aggregate human capital stock at each period. This is among the main contributions of endogenous labor supply in the model.

To simplify the analysis, a stationary provision of public education is assumed, i.e., $e_{gt} = e_g = \tau$ and $\underline{h}_t = \int_\Omega \frac{1}{h_t^v(\omega)} d\mu(\omega)$. A set of plausible restrictions on the parameters are required to establish the following claim: the level of public education in the economy determines the positive or negative accumulation of human capital. Therefore it is assumed *in this section only* that the parameters in the economy satisfy the following conditions:

(A1) $\frac{2\alpha_3\beta_1}{\alpha_1+\alpha_2+\alpha_3+\alpha_4} < 1-\xi$, for some $\xi > 0$.

(A2) The initial distributions of $l_0(\omega)$ and $h_0(\omega)$ satisfy $\overline{l}_0 \geq 1$ and $\overline{h}_0 \geq 1$, respectively.

(A3) $\eta = 1$ and $\upsilon = 1$.

(A4) $\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$.

Proposition 1. *Assume that (A1) - (A4) hold. Then:*

(a) If e_g satisfies:

$$e_g \leq \left[\frac{1-2\beta_1}{2\beta_2(\alpha_1+\alpha_2)}\right]\left[1+[1-2\alpha_3\beta_1]\frac{1}{2\beta_2}\overline{h}_t\underline{h}_t\right]^{-1} \tag{4.26}$$

for all t, then along the equilibrium path, the aggregate human capital decreases, that is, $\overline{h}_{t+1} < \overline{h}_t$ for $t = 0, 1, 2, \cdots$

(b) If e_g satisfies:

$$e_g \geq \left[\frac{1-2\alpha_3\beta_1}{2\alpha_3\beta_2(\alpha_1+\alpha_2)}\right]\left[1+\left[\frac{1}{2\alpha_3\beta_1}-1\right]\overline{h}_t\underline{h}_t\right]^{-1} \tag{4.27}$$

for all t, then aggregate human capital increases, i.e., $\overline{h}_{t+1} > \overline{h}_t$ for all t

Proof. See the appendix.

This result emphasizes the crucial role played by the *level* of aggregate human capital which is determined by endogenous labor supply and the *level* of public education. To underline this point, consider two countries which differ in the provision of public education and in their initial distributions of human capital, given that each economy satisfies (A1)–(A4). If e_g is chosen to be low in one country at all times, assuming that condition (4.26) satisfies, while in the other country it is higher at all times, in the sense that condition (4.27) holds, then a poverty trap is obtained in the first country while the second has a positive rate of growth.

More importantly, economies with high level of aggregate human capital are less likely to face a poverty trap, namely, the boundary of aggregate human capital below which the poverty trap occurs is lower.[13] Also, high levels of aggregate human capital guarantee that the aggregate human capital increases. Incorporating endogenous labor supply to the model clearly offers a new and more realistic insight.[14]

[13] A higher $\overline{h}_t$ means a higher $\overline{h}_t\underline{h}_t$ which implies a more difficult attainment of poverty trap.

[14] This result differs with one in Viaene and Zilcha (2003) where the assumption of fixed labor supply makes the level of society's human capital not playing a role in the condition of poverty trap.

4.2.6 Cross-family variation of endogenous labor supply

Explaining the relationship between human capital formation and future income inequality is the main theme of this chapter. In such relationship, labor supply plays an intermediate role since it determines future income through (4.22) and it is driven by the process of human capital formation.[15]

To see the effect of current family's human capital on future labor supply, the following steps are taken. A constant return to scale, i.e., $\eta = 1$ and $\upsilon = 1$ and the existence of no-poverty-trap condition (4.27) are assumed. Without loss of generality, it is determined that $\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$. After integrating both sides of (4.20) and conducting some manipulations:

$$\bar{l}_t = \frac{2(\alpha_1 + \alpha_2)\beta_1}{(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4)\beta_1 - (\alpha_1 + \alpha_2)\beta_2\tau_t\overline{h}_t\underline{h}_t} \tag{4.28}$$

and at time $t+1$, (4.28) is substituted back to (4.20):

$$l_{t+1}(\omega) = (\alpha_1 + \alpha_2)\left[2 + \frac{2(\alpha_1 + \alpha_2)\beta_1\beta_2\tau_{t+1}(2\beta_1 + \beta_2\tau_t\bar{l}_t)}{\theta_t(\omega)\left[2\beta_1\frac{h_t(\omega)}{\overline{h}_t} + \beta_2\tau_t\bar{l}_t\right]\left[\beta_1 - (\alpha_1 + \alpha_2)\beta_2\tau_{t+1}\overline{h}_{t+1}\underline{h}_{t+1}\right]}\right] \tag{4.29}$$

Equation (4.29) suggests that a higher current aggregate human capital induces next-period working generation to exert higher labor supply. But individual responses to aggregate human capital differ as explained by the following proposition.

Proposition 2. *Consider an economy consisting of individuals with different levels of human capital. Then, the lower the level of human capital of parents at a particular period, the higher the labor supply exerted by the corresponding offspring in the next period.*
Proof. The proof is directly taken from (4.29).

Thus, families with high relative human capital will supply less labor in the future than those with low relative human capital. The difference between the level of a family's human capital and the average level of human capital in the society is crucial as stated in the following corollary.

Corollary. *Consider two groups of individuals in a particular time, one with below-average human capital and the other with above average human capital. Then in the next period any individual from the former group will supply higher labor than any individual from the latter group.*

Parents with above average human capital would transfer their high human capital to their children and as the result, their highly capable children would exert labor less than

[15] See (4.1) and one step ahead of (4.20).

those with lower human capital. Empirically this is common in countries with weakly-regulated labor market such as in Asia or Latin America.

4.3 Capital markets integration

The per capita production function (4.4) is rewritten into the aggregate production function as follows:

$$Q_t = F(K_t, L_t^e) \tag{4.30}$$

where Q_t is the aggregate output, $K_t = \int_\Omega s_{t-1}(\omega)d\mu(\omega)$ is the aggregate physical capital and $L_t^e = (1-\tau_t)L_t = (1-\tau_t)\int_\Omega l_t(\omega)h_t(\omega)d\mu(\omega)$ is the aggregate human capital. From this point onward, the aggregate production function in the economy is assumed to take the Cobb-Douglas form:

$$F(K_t, L_t^e) = AK_t^\phi (L^e)_t^{1-\phi} \tag{4.31}$$

where in equilibrium, the following expressions are therefore obtained: $w_t = (1-\phi)A(\frac{K_t}{L_t^e})^\phi$ and $1 + r_t = \phi A(\frac{K_t}{L_t^e})^{(\phi-1)}$.

Substituting (4.10) and (4.11) to (4.6) while making use of (4.7), the economy's aggregate income at date t:

$$\int_\Omega y_t(\omega)d\mu(\omega) = \left(1 + \frac{\alpha_1}{\alpha_2}\right) K_{t+1} \tag{4.32}$$

It is known that (4.2) gives income at date t and using this one can write aggregate income as a proportion of aggregate output as:

$$\int_\Omega y_t(\omega)d\mu(\omega) = (1-\phi)Q_t \tag{4.33}$$

4.3.1 Comparing two economies under autarky

Assume that the world consists of two economies: domestic and foreign. Assume also that domestic is initially endowed with more physical capital and the endowments of labor supply and of human capital in the two countries are similar. Foreign variables are marked with (*). The growth factor of aggregate effective human capital is defined as:

$$\gamma_t = \frac{L_{t+1}}{L_t} = \frac{\int_\Omega l_{t+1}(\omega)h_{t+1}(\omega)d\mu(\omega)}{\int_\Omega l_t(\omega)h_t(\omega)d\mu(\omega)}. \tag{4.34}$$

Therefore, $\gamma_t = \gamma_t^*$ and hence $L_t = L_t^*$ for all t. From (4.32) and (4.33):

$$\frac{K_{t+1}}{K_t} = \left[\frac{(1-\phi)A\alpha_2}{\alpha_1 + \alpha_2}\right]\left[\frac{L_t^e}{K_t}\right]^{1-\phi} \tag{4.35}$$

Dividing by (4.34) results in:

$$\frac{K_{t+1}}{L_{t+1}} = \left[\frac{(1-\phi)A\alpha_2(1-\tau_t)^{1-\phi}}{\gamma_t(\alpha_1+\alpha_2)}\right]\left[\frac{K_t}{L_t}\right]^{\phi} \tag{4.36}$$

This is the dynamic path of capital-labor ratio of each economy in Autarky. Clearly, if $\frac{K_0}{L_0} > \frac{K_0^*}{L_0^*}$, then $\frac{K_t}{L_t} > \frac{K_t^*}{L_t^*}$ for all t, which implies $Q_t > Q_t^*$ and $K_t > K_t^*$ for t. The following proposition summarizes this result.

Proposition 3. *Consider the domestic and foreign economies in autarky under the assumptions: $l_0(\omega) = l_0^*(\omega)$, $h_0(\omega) = h_0^*(\omega)$ and $K_0 > K_0^*$. Then $Q_t > Q_t^*$ and $K_t > K_t^*$ for all dates.*

Proof. See above.

Therefore, the economy which starts from higher capital stock, while other parameters are equal, attains higher output in all subsequent periods.

4.3.2 Equilibrium under capital markets integration

Consider that at time $t = 0$ the domestic and foreign economies integrated to form a single commodity market and a single capital market while labor remains internationally immobile. The two economies are assumed to be identical in all aspects including public education expenditure, $\tau_t = \tau_t^*$ except for the distribution of human capital. After the integration of capital markets, physical capital will flow from the low return to the high return economy until rates of return are equalized. This type of international capital movement involves a change in location but not a change in ownership. Post-integration variables are marked with (~).

$\tilde{K}_t$ is defined as capital stock used in production in the domestic country and $\tilde{T}_t$ as capital stock, located at home and abroad, owned by domestic residents. (4.10) after integration is rewritten as follows:

$$\tilde{T}_{t+1} = \int_{\Omega} \tilde{s}_t(\omega)d\mu(\omega). \tag{4.37}$$

Since positive $\tilde{T}_t - \tilde{K}_t$ corresponds to a net outflow of domestic capital abroad, the following identity must hold:

$$\tilde{T}_t + \tilde{T}_t^* = \tilde{K}_t + \tilde{K}_t^*. \tag{4.38}$$

Positive $\tilde{K}_t - \tilde{T}_t$ therefore corresponds also to net inflow of capital in foreign country. Substituting (4.37) into (4.38) leads to:

$$\int_{\Omega} [\tilde{s}_t(\omega) + \tilde{s}_t^*(\omega)]d\mu(\omega) = \tilde{K}_{t+1} + \tilde{K}_{t+1}^* \tag{4.39}$$

which is an analog of (4.10) for the integrated economy. Similar with autarky equilibrium in (4.32) and (4.33):

$$\int_{\Omega} [\tilde{y}_t(\omega) + \tilde{y}_t^*(\omega)] d\mu(\omega) = \left(1 + \frac{\alpha_1}{\alpha_2}\right) \left[\tilde{K}_{t+1} + \tilde{K}_{t+1}^*\right] \tag{4.40}$$

$$\int_{\Omega} [\tilde{y}_t(\omega) + \tilde{y}_t^*(\omega)] d\mu(\omega) = (1 - \phi) \left[\tilde{Q}_{t+1} + \tilde{Q}_{t+1}^*\right] \tag{4.41}$$

Proposition 4. *Total output of the integrated economy after capital markets integration is higher than the sum of outputs of the autarkic economies at all dates.*
Proof. See the appendix.

Equality of returns to capital has implication for capital labor ratio as follows:

$$\frac{\tilde{K}_t}{\tilde{L}_t^e} = \frac{\tilde{K}_t^*}{\tilde{L}_t^{e*}} = \frac{\tilde{K}_t + \tilde{K}_t^*}{\tilde{L}_t^e + \tilde{L}_t^{e*}}, \qquad t = 0, 1, 2, \cdots . \tag{4.42}$$

And from the assumptions of identical and linear homogenous production functions:

$$\frac{\tilde{Q}_t}{\tilde{K}_t} = \frac{\tilde{Q}_t^*}{\tilde{K}_t^*} = \frac{\tilde{Q}_t + \tilde{Q}_t^*}{\tilde{K}_t + \tilde{K}_t^*}, \qquad t = 0, 1, 2, \cdots .$$

Combining these two expressions:

$$\frac{\tilde{Q}_t}{\tilde{Q}_t + \tilde{Q}_t^*} = \frac{\tilde{K}_t}{\tilde{K}_t + \tilde{K}_t^*} = \frac{\tilde{L}_t^e}{\tilde{L}_t^e + \tilde{L}_t^{e*}} \tag{4.43}$$

Therefore, following capital markets integration, each country's share of output and share of physical capital stock in the integrated economy is equal to its share in the stock of effective human capital. This is basically the equal-share relationship discussed in Chapter 2.

More importantly, equality of returns implies equality of capital labor ratio and hence equality of equilibrium real wage rate as presented below:

$$\tilde{w}_t = (1 - \phi) A \left(\frac{\tilde{K}_t}{\tilde{L}_t^e}\right)^{\phi} = (1 - \phi) A \left(\frac{\tilde{K}_t^*}{\tilde{L}_t^{*e}}\right)^{\phi} = \tilde{w}_t^* \tag{4.44}$$

As has been demonstrated by (4.20) and (4.21), although capital markets integration may affect equilibrium real wage rate, it does not affect labor supply. This is because in this framework a change in wage rate will simply vary incomes of all individuals in the same proportion and hence it will not be optimal for any person to respond by altering individual labor supply.

4.4 Endogenous labor supply, openness and income inequality

Distributional equity is a paramount issue both in theory and in practice. Such issue is increasingly pressing economists and policy makers following the globalization with the integration of capital markets as one of its consequences. There is a conventional wisdom that the relationship between income inequality and economic growth depends on the conditions in each country and education policies implemented by each government. To simplify analysis, the focus is on intragenerational income distributions for the domestic and foreign economies. It will be shown that a nation's distribution of income is not affected by capital markets integration.

Consider X and W as two random variables with values in a bounded interval in $(-\infty, \infty)$ and let m_x and m_w represent their respective means. Let F_x and F_w be the cumulative distribution functions of $\hat{X}$ and $\hat{W}$, respectively where $\hat{X} = \frac{X}{m_x}$ and $\hat{W} = \frac{W}{m_w}$. Let $[a, b]$ be the smallest interval enclosing the supports of $\hat{X}$ and $\hat{W}$.

Definition. F_x is more equal than F_w if, for all $t \in [a, b]$, $\int_a^t [F_x(s) - F_w(s)]ds \leq 0$ for all t, $a \leq t \leq b$ and $F_x(s) \neq F_w(s)$ for some s.

This is identical with the requirement that the Lorentz curve corresponding to W is everywhere below that of X (Atkinson, 1970). It is defined that X is *more equal* than W if F_x is more equal than F_w. From this point, the relation X is more equal than W is indicated as $X \gg W$. It is stated that X is equivalent to W, denoted with $X \sim W$, if $X \gg W$ and $X \ll W$.

Without loss of generality, it is assumed again that $\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$, $\tau_t = \tau_{t+1} = \tau$ and there is constant returns to scale in the human capital production. Some results derived in previous sections will be employed to express the individual income at time $t+1$, y_{t+1}, in terms of initial human capital $h_0(\omega)$, time-varying endogenous labor supply $l_t(\omega)$, and human capital $h_t(\omega)$. One may think that endogeneous labor supply plays a role in determining income inequality since decisions concerning labor supply by individuals are heterogeneous. To check whether this is true, one rewrites (4.2) using (4.20):

$$y_t(\omega) = (\alpha_1 + \alpha_2)\frac{\beta_2}{\beta_1} w_t(1-\tau)\tau \tilde{l}_t \tilde{h}_t + 2(\alpha_1 + \alpha_2) w_t (1 - \tau_t) h_t(\omega). \tag{4.45}$$

Assuming parental participation, $e_t(\omega) > 0$, using (4.23) and after some manipulations, the next-period individual income can be expressed using (4.45) as follows:

$$y_{t+1}(\omega) = (\alpha_1 + \alpha_2) w_{t+1}(1-\tau) \left[\frac{\beta_2}{\beta_1} \tau \tilde{l}_{t+1} \tilde{h}_{t+1} + 2\alpha_3 \beta_2 \tau \tilde{l}_t \tilde{h}_t \theta_t(\omega) + 4\alpha_3 \beta_1 \theta_t(\omega) h_t(\omega) \right]. \tag{4.46}$$

After a few manipulations, it turns out that that the evolution process of human capital of a family can be written:

$$h_t(\omega) = [\Psi_t(\omega) + \Delta_t(\omega) h_0(\omega)] \tag{4.47}$$

where

$$\Psi_t(\omega) = \sum_{k=0}^{t-1} 2^k \alpha_3^{k+1} \beta_1^k \beta_2 \tau \tilde{l}_{t-1-k} \tilde{h}_{t-1-k} \phi_{r=0}^{k} \theta_{t-1-r}(\omega)$$

and

$$\Delta_t(\omega) = [2\alpha_3\beta_1]^t \, \phi_{k=0}^{t-1} \theta_k(\omega).$$

With such representation of $h_t(\omega)$, the impact of capital markets integration on the intragenerational income inequality in an economy with endogenous labor supply will be examined. One can rewrite (4.46) as follows:

$$y_{t+1}(\omega) = (\alpha_1+\alpha_2) w_{t+1} (1-\tau) \left[\frac{\beta_2}{\beta_1} \tau \tilde{l}_{t+1} \tilde{h}_{t+1} + 2\alpha_3\beta_2\tau \tilde{l}_t \tilde{h}_t \theta_t(\omega) + 4\alpha_3\beta_1\theta_t(\omega) \left[\Psi_t(\omega) + \Delta_t(\omega) h_0(\omega)\right] \right] \tag{4.48}$$

For families without parental participation, $e_t(\omega) = 0$, (4.2) is rewritten using (4.21):

$$y_t(\omega) = \frac{2(\alpha_1 + \alpha_2)}{\alpha_1 + \alpha_2 + \alpha_4} w_t (1-\tau) h_t(\omega) \tag{4.49}$$

The next-period individual income can be expressed using (4.49) and (4.24) as follows:

$$y_{t+1}(\omega) = \frac{2(\alpha_1 + \alpha_2)\beta_2}{\alpha_1 + \alpha_2 + \alpha_4} w_{t+1} (1-\tau) \tau \theta_t(\omega) \bar{l}_t \bar{h}_t \tag{4.50}$$

Proposition 5. *Given the initial distributions in both countries at date 0, assume that* $K_0 > K_0^*$. *Capital mobility resulting from integration of capital markets, with labor supply determined endogenously, do not alter the intragenerational income inequality in each economy observed under autarky.*
Proof. See the appendix.

Inequality in the economy results from one source only, that is, unequal human capital distribution. In the domestic economy, capital markets integration results in lower wage rates in all subsequent periods. Consequently, income differences between families resulting from labor earnings due to human capital inequality and also due to variation in labor supply will be reduced. However, by the proof of Proposition 5, despite the existence of endogenous labor supply, such change in income discrepancy does not affect inequality in income distribution, since all incomes are varied in the same proportion. Therefore, in the equilibrium, it is not optimal for any individual to change labor supply decision following such capital markets integration.

Equally important is that under certain condition, Proposition 5 implies an invariant relationship of income inequality between domestic and foreign.

Corollary 1. *Assume that initial labor supplies and human capital distributions satisfy* $l_0(\omega) = l_0^*(\omega)$ *and* $h_0(\omega) = h_0^*(\omega)$ *while* $K_0 > K_0^*$*. Then, before and after integration, intragenerational income inequality within a country will be the same.*

It is widely recognized that capital markets integration has a significant impact on wages, output and interest rates of the two economies. However, it is obvious from equations (4.46)-(4.50), that in this framework, such variations in the equilibrium factor prices do not affect the results concerning intragenerational income inequality since labor incomes change in the same proportion. Hence capital markets integration plays no role in explaining intragenerational income inequality in this model.

Corollary 2. *Assume that initial labor supplies and human capital distributions satisfy* $l_0(\omega) = l_0^*(\omega)$ *and* $h_0(\omega) = h_0^*(\omega)$ *while* $K_0 > K_0^*$*. Then, intergenerational income inequality across countries will be lower under capital markets integration than that under autarky.*

As demonstrated by (4.44), capital markets integration leads to equalization of wage rates across economies. Consequently, after opening up incomes in capital-exporting countries will be lower than before capital markets integration. On the other hand, after integration incomes in capital-importing countries will be higher than incomes under autarky. Such shifts of incomes result in a situation in which the same individuals ω in both countries will have the same level of income. Thus, in aggregate, less inequality across countries will be observed.

Introducing intergenerational transfer of physical capital (bequest) in the economy will modify some of the results because movement in factor prices affects individuals differently. However, there is an ongoing debate as to the importance of such transfer between generations. The magnitude of bequest-motivated saving remains unclear. More importantly, the empirical evidence suggests that among families, bequests are far from universal (Laitner, 1997).

4.5 Initial endowments, public education and education technology as sources of income inequality under endogenous labor specification

Corrolary 1 and Corrolary 2 after Proposition 5 explain the intergenerational income inequality in a specific situation, that is, when the initial endowments of the domestic and foreign economies are identical. One can consider a situation where one economy has a higher level of human capital while retaining the assumption that the initial inequality of human capital distributions is the same.

Proposition 6. *Consider two economies which differ only in their initial human capital distribution,* $h_0(\omega)$ *and* $h_0^*(\omega)$*. Labor supply is determined endogenously. Assume that* $h_0^*(\omega) > h_0(\omega)$ *for all* ω*, but the initial distributions of both labor supply and human capital have the same level of inequality. Then, the equilibrium from the economy with* $h_0^*(\omega)$ *will have lower income inequality than the equilibrium from the economy with* $h_0(\omega)$ *at all dates.*

Proof. See the appendix.

Despite the existence of endogenous labor supply, the initial inequality of human capital matters for income distribution: an economy that begins with lower levels of human capital, but perhaps not less equal, has a better chance to maintain more inequality in its future distribution of income.[16] Unlike in the fixed labor supply situation, endogenous labor specification allows aggregate labor supply and parameters related to preferences of consumptions and leisure play some role when one compares income distribution between the two economies which differ in their initial human capital distribution.[17]

Suppose now that the government does not contribute to human capital formation, that is, $\tau_t = 0$. In this situation:

$$y_{t+1}(\omega) = w_{t+1} l_{t+1}(\omega) h_{t+1}(\omega). \tag{4.51}$$

From (4.25), set A_t is empty and from (4.19):

$$e_t(\omega) = e^*(\omega) = \frac{2\alpha_3}{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4} \qquad \text{for all } \omega \tag{4.52}$$

which is a constant. It is clear that when public education is unavailable, the initial distribution of human capital is the only source of income inequality. In particular:

$$y_{t+1}(\omega) = \frac{2(\alpha_1 + \alpha_2)\beta_1}{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4} \left[w_{t+1} e^*(\omega) h_t^v(\omega) \right] \theta_t(\omega). \tag{4.53}$$

[16] This result also explains an element related to persistence of income across generation. A lower level of initial human capital is associated with a more persistence of income.

[17] See Proof of Proposition 6.

Although endogenous labor regime introduces parameters related to current consumption (α_1), future consumption (α_2) and leisure (α_4), such parameters do not affect income distribution since the contributions vary proportionately with time-varying individual human capital ($h_t(\omega)$) corrected for externality (υ). The following proposition summarizes the above examination.

Proposition 7. *In an economy with endogenous labor supply regime, without public education provision, income inequality (i) declines over time under decreasing returns (i.e., if $\upsilon < 1$), (ii) increases over time under increasing returns (i.e., if $\upsilon > 1$) and (iii) remains constant over time under constant returns (i.e., if $\upsilon = 1$).*
Proof. The proof is directly taken from (4.53).

In equilibrium, the economy generates an intragenerational income distribution with inequality endogenously determined by the externality of parental tutoring. On one hand, when $\upsilon < 1$, inequality declines even in the absence of public education. On the other hand, when $\upsilon > 1$, severe inequality in the form of "poverty trap" may arise (i.e., $h_t(\omega)$ goes to zero) for some families whose initial human capital is below a certain threshold level, that is when:

$$h_0(\omega) < \left[\frac{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4}{2\beta_1\alpha_3\theta_0(\omega)}\right]^{\frac{1}{\upsilon-1}} \tag{4.54}$$

Clearly such threshold is affected by labor supply being endogenous.[18] The situation divides the population into two segments: families whose human capital below this threshold face a permanent decrease in human capital while those with human capital above this critical level undergo a permanent improvement. The empirical evidence of such situation is found in some developing countries such as China, India or Indonesia, where increasing returns in parents' human capital and very low public education expenditure have been observed (Knight and Shi, 1996).

Next one can assume the existence of public education provision whose level is determined exogenously. Following (4.3), the level at date t is e_{gt} and it is financed by taxing income at a fixed rate τ_t ($= e_{gt}$). To simplify the analysis in the sequel it is assumed that $\upsilon \leq 1$, $\eta \leq 1$ and $\upsilon \leq \eta$.

The relation between public education and income inequality is summarized as follows. If one let $h_0(\omega)$ be any initial human capital distribution in an economy with endogenous labor regime, the the following should follow: (i) If the tax rate that finances public education is the same for all dates, then income inequality at date $t + 1$ is smaller than that in date t. (ii) Increasing the tax rate (hence, the public education provision) results

[18] Again, one finds the roles of parameters on current consumption (α_1), future consumption (α_2) and leisure (α_4)

in a more equal intragenerational distribution in all subsequent period. A formal analysis on how to achieve this result is relegated to the appendix.

This result underlines the role of public education to weaken the effect of family characteristics. This is because public education is provided to all children of the same generation *equally* independent of their parents' human capital. Such dampening feature makes human capital (and hence income) more equal over time. In other words, when human capital formation has a constant or decreasing returns to scale, public education forces the current economic disparities to decrease over time.The role of endogenous labor supply does not seem to exist.[19]

Moreover, if one compares two economies whose all attributes are similar except for the level of public education, the country which invests more will face a lower inequality *along the equilibrium path* and *for all subsequent periods.*

One can analyze cross country variation in technology of human capital formation (4.1) and its impact on income inequality. Introducing a new technology brings an improvement to the human capital production. Such an improvement can be conducted by increasing *efficiency* of education process, for instance through the introduction of more advanced facilities (computer, internet, e-library, etc.), the reduction of class size, the increase of teaching hours and the improvement of school management. This equals to increasing the parameters β_1 or β_2 or both. Another improvement can be by enhancing the effectiveness of 'school teachers' or 'tutoring parents' through for example, better training for teachers and providing information to parents on how to educate their children. Such improvement is equivalent with rising the parameters υ or η or both. Here it is assumed that $\upsilon \leq 1$, $\eta \leq 1$ and $\eta \geq \frac{1}{2}\upsilon$, which can be loosened in most cases.[20]

A technological improvement of the production of human capital in a particular economy may result in a more efficient parental tutoring or more efficient public education, or both. The provision of public education becomes more efficient if either $\frac{\beta_2}{\beta_1}$ is higher while neither β_1 nor β_2 declines, or η increases, or both. The provision of private education is more efficient if $\frac{\beta_1}{\beta_2}$ is larger without lowering neither neither β_1 nor β_2, or υ is higher, or both. The educational technological is called neutral in the case where both parameters β_1 and β_2 rises while the ratio $\frac{\beta_1}{\beta_2}$ continues unchanged.

In this case, it turns out that the results of Viaene and Zilcha (2003) for an economy with inelastic labor supply carries over into an economy with endogenous labor regime although the details on how to show such results differ substantially.

Thus, if one consider improvements in the production process of human capital, then: (a) If the provision of public education becomes more efficient, the inequality in intra-

[19] This result is qualitatively similar with one in Viaene and Zilcha (2003) but analytically different in terms of how to attain.

[20] It is hardly possible that the human capital of teachers or parents can be *fully* 'transferred' to the children.

generational distribution of income decreases in all periods; (b) If the provision of private education becomes more efficient then inequality rises in all periods; (c) If the technological improvement is neutral inequality continues unchanged at period 1 but declines for all periods afterwards. A more formal analysis on this result can be found in the appendix.

The result shows the opposite effects on inequality between a technological improvement that occurs in the public education and the one that exists in home education. The inequality in human capital distribution declines following a more efficient public education because all children are taught by instructors whose level of human capital is the same: the above-average children have a lower return to public education than below-average children. Conversely, a more efficient private education increases inequality. The reason is that when the family-specific education becomes more efficient, the family attributes are intensified. An example of this is the experience of "digital-divide" in a number of developing countries, where above-average families reap more benefit from information technology as learning tools than below-average families.

4.6 Numerical simulation

In this section the equilibrium paths will be computed by simulation for an example. Then the properties concerning inequality, growth, wage rental ratio, parental tutoring and family labor supply are compared.

The previous propositions mark education systems as the main driving force of income inequality in equilibrium. Although the human capital production processes vary substantially across countries, it is interesting to gain insight whether such discrepancy is significant in explaining observed differences in income inequality. The objective of this simulation is to quantify the response of income inequality to changes in the parameters of education technology. A dynamic computable general equilibrium model with heterogenous agents will be established based on the theory. This method tracks the time path follows by each family and investigates how they respond to different education systems. The simulation generates some aggregation variables such as the Gini coefficient, the growth rate of output and the wage rental ratio.

Two base settings are constructed, one with random inborn abilities and the other with deterministic abilities. After calibrating the parameters, the equilibrium paths of all the families are generated in the following stages. (1) For the first scenario, a random number generator draws an innate ability θ_t at each date t ($t = -1, 0, \cdots$) from a normal distribution with mean 1 and standard deviation 0.1. For the second base setting, θ_t is simply set to 1. (2) Assuming fixed education expenditure, the human capital of any individual at date t is given by (4.23) and (4.24). (3) The labor supply is given by (4.20) and (4.21). (4) The level of aggregate effective human capital, L_t^e is computed and the level of aggregate capital stock, K_t, is equated to past savings. (5) After constructing q_t, w_t and $(1 + r_t)$, each individual income $y(\omega)$ is computed and the Gini coefficient is derived. (6) Given the wage rate w_t, the interest factor $(1+r_t)$ and income of each family $y_t(\omega)$, each individual can compute $e_t(\omega)$, $l_t(\omega)$, $c_{1t}(\omega)$, $c_{2t}(\omega)$ and $s_t(\omega)$.

Table 4.1: Simulation results on the equilibrium paths

Variable	No random inborn ability (deterministic solution)	With random inborn ability (stochastic solution)
Gini coefficient	0.325	0.323
	0.252	0.265
	0.140	0.164
	0.077	0.124
Growth rate of output	58.87%	58.39%
	24.51%	24.04%
	19.01%	19.06%
	19.01%	19.42%
Wage-rental ratio	2.381	2.391
$(\frac{w_t}{1+r_t})$	3.411	3.427
	3.592	3.590
	3.592	3.575
Parental tutoring	0.033	0.047
(poorest family, $e(A)$)	0.112	0.116
	0.184	0.162
	0.205	0.171
Family labor supply	1.501	1.489
(poorest family, $l(A)$)	1.438	1.435
	1.381	1.398
	1.365	1.391

Notes: Column (1) reports the equilibrium achieved assuming the calibrated parameters of Table A.2 and random inborn ability fixed to unity. Column (2) assumes random ability. For each variable, the first entry is the solution at date $t = 0$, the second, third and fourth rows present the averages over the first 10 periods, the second 10 and the third 10, respectively.

Table 4.1 presents the solutions of the calibrated economy with and without random abilities. Using the parameters in Table A.2 and the initial conditions at $t = -1$, the economy starts at $t = 0$ and an equilibrium path is computed for 200 periods. Since patterns appear within 30 periods, the last 170 periods are ignored and the results are shown for $t = 0$ and the averages over the first 10 periods, the second 10 and the third 10. The results without random abilities in column (1) is the closest to the actual data of Table A.1 while those with random abilities in column (2) approximate the solution.

Because of public education, intragenerational income inequality declines over time and confirmed by simulation result in Table 4.1. Moreover, though families start with different endowments at date $t = -1$, such discrepancy is dampened within 30 periods. As expected, in the scenario with random abilities the speed of family convergence is reduced.

Proposition 1 suggests the possibility of poverty trap for economies with low education expenditure. Although Dutch public education spending (5.1%) is low by international standard, Dutch economy always experience non-negative growth. It is still the case even if there is no public education provision ($e_g = \tau = 0$). The reason is that given the calibrated parameters, there is no possibility of poverty trap. Direct computations of the right hand side of (4.26) for the periods under investigation always give a negative value. Hence set A_t in (4.25) would be empty since all families increase their participation in home education over time.

Table 4.2: Response elasticities on the equilibrium paths

Variable	τ	β_1	β_2	υ	η
Gini coefficient	-0.7881	0.3644	-0.3844	4.2828	-0.3565
	-1.5657	0.7966	-0.7906	6.3404	-1.4756
Growth rate of output	0.7480	5.1699	0.3628	8.7955	0.4614
	0.8142	5.8894	0.3851	9.8938	0.9803
Wage-rental ratio	-0.1865	-1.1468	-0.0926	-2.6800	-0.1091
$(\frac{w_t}{1+r_t})$	-0.1865	-1.2037	-0.0870	-2.7812	-0.2280
Parental tutoring	-3.9123	1.7481	-1.8827	-0.7671	-2.6851
(poorest family, $e(A)$)	-1.4704	0.6441	-0.7018	-0.2176	-2.3843
Family labor supply	0.1808	-0.0811	0.0871	0.2500	-0.1678
(poorest family, $l(A)$)	0.1288	-0.0565	0.0615	0.1745	-0.1763

Notes: For each variable, the first row reports the average elasticity over the first 10 periods and the second row, the average elasticity over the second 10 periods.

Next the setting of the Dutch economy with random inborn ability as the hypothetical economy is taken and the parameters $\beta_1, \beta_2, \upsilon, \eta$ and τ are perturbed one by one. The small changes involve an increase or a decrease of the parameters by 10%. Table 4.2 presents the response elasticities along the equilibrium path of the aggregate variables Gini coefficient, the growth rate output and the wage rental ratio. The table also shows the parental tutoring and the labor supply of the poorest family at $t = -1$.

Column 1 of Table 4.2 shows the response with respect to τ_t and therefore compare economies with different exogenous levels of educational expenditures. This column confirms the results that an economy with 10 percent more educational expenditure than in the Netherlands will experience a 8 percent drop in Gini coefficient during the first 10 periods and a 16 percent drop during the second 10 periods. This trend to equality is coupled with a considerable increase of output growth: a 7 percent rise during the first 10 periods and a 8 percent rise during the second 10 periods. As parental tutoring decreases, the effects on wage-rental ratio and labor supply are moderate as evidenced by the small elasticities. Column (2) to (5) report the response elasticities with respect to education parameters. These elasticities describe economies with different characteristics of parental tutoring (i.e., different β_1 and υ) and of public education (i.e., different β_2 and η). Elasticities in columns (2) and (3) are calculated for an increase in β_1 and in β_2 while those in columns (4) and (5) are computed for a decrease in υ and in η to reflect plausible situations. It is clear that when β_1 or υ increases, more inequality in income distribution exists and it is coupled with higher economic growth. On the other hand, when β_2 or η increases, less inequality in income distribution is observed, also together with higher growth. This simulation result confirms the theoretical findings of Proposition 9. Moreover, they provide insights in explaining the ambiguous relationships between income inequality and economic growth.

4.7 Concluding remarks

The consequences of various processes of human capital formation on income inequality in an overlapping generations economy with heterogenous agents have been studied. The heterogeneity in the model emanates from the initial distribution of human capital across individuals and from the random inborn abilities. The results offer some insights concerning a relation between income inequality and various features of the process of human capital formation, which includes: (a) the international environment, such as physical capital mobility (b) the initial conditions of stock of human capital (c) the level and externality of public education (d) the efficiency originated from education technology.

This chapter also shows the invariance property of intragenerational income inequality. This feature suggests that although wage rates are equalized after capital markets integration, inequality remains unchanged since all individual incomes are affected by the same proportion. However, across countries, intergenerational income distribution after opening up is more equal. A condition that allows for poverty trap and for positive growth of human capital to occur is derived, both of which depending on the current level of human capital in the economy.

The framework makes a specific assumption regarding the functional form of the human capital production which may raise some robustness issues. First, the inclusion of parental role in the human capital formation process is in fact justified due to its empirical relevance in a number of countries. Second, labor is assumed to have no specialization. They are capable to teach and to produce consumption goods with the same quality (perfect substitute). Third, there is no tax on the returns to savings, but incorporating such tax will not change the results concerning income inequality.

4.A Proofs and derivation

Proof of Proposition 1

To proof part (a), consider the inequality (4.25) which defines the set A_t ($A_t \neq 0$). Using (4.23), (4.24), (A3) and (A4):

$$\overline{h}_{t+1} = 2\alpha_3\beta_1 \int_{\sim A_t} h_t(\omega)d\mu(\omega) + (1-\mu(A_t))\alpha_3\beta_2 e_g \bar{l}_t \overline{h}_t + \mu(A_t)\beta_2 e_g \bar{l}_t \overline{h}_t \tag{4.55}$$

Therefore,

$$\overline{h}_{t+1} < 2\alpha_3\beta_1 \int h_t(\omega)d\mu(\omega) + \alpha_3\beta_2 e_g \bar{l}_t \overline{h}_t + \mu(A)(\alpha_1+\alpha_2+\alpha_4)\beta_2 e_g \bar{l}_t \overline{h}_t$$

To have $\overline{h}_{t+1} < \overline{h}_t$, one need to show that:

$$\alpha_3 \left[2\beta_1 + \beta_2 e_g \bar{l}_t (1 + \mu(A_t)\frac{\alpha_1+\alpha_2+\alpha_4}{\alpha_3}) \right] \leq 1 \tag{4.56}$$

Thus, if $\mu(A_t)$ is replaced by 1, then from (4.56):

$$e_g \leq \left[1 - 2\alpha_3\beta_1\right] \beta_2{}^{-1} \bar{l}_t{}^{-1} \tag{4.57}$$

Integrating both sides of (4.20):

$$\bar{l}_t{}^{-1} = \frac{1}{2(\alpha_1+\alpha_2)} - \frac{\beta_2}{2\beta_1} e_g \overline{h}_t \underline{h}_t \tag{4.58}$$

and after substituting (4.58) into (4.57) the inequality (4.26) is obtained. (Q.E.D.)

To proof part (b) consider (4.55) above. It is clear that:

$$\overline{h}_{t+1} = 2\alpha_3\beta_1\overline{h}_t - 2\alpha_3\beta_1 \int_{A_t} h_t(\omega)d\mu(\omega) + \alpha_3\beta_2 e_g \bar{l}_t \overline{h}_t + (\alpha_1+\alpha_2+\alpha_4)\mu(A_t)\beta_2 e_g \bar{l}_t \overline{h}_t.$$

However, using inequality (4.25): $\int_{A_t} h_t(\omega)d\mu(\omega) < \mu(A_t)\frac{(\alpha_1+\alpha_2+\alpha_4)\beta_2}{2\alpha_3\beta_1} e_g \bar{l}_t \overline{h}_t$ and therefore:

$$\overline{h}_{t+1} > 2\alpha_3\beta_1\overline{h}_t + \alpha_3\beta_2 e_g \bar{l}_t \overline{h}_t$$

Thus $\overline{h}_{t+1} > \overline{h}_t$ holds whenever $2\alpha_3\beta_1 + \alpha_3\beta_2 e_g \bar{l}_t \geq 1$ or:

$$e_g \geq \frac{1-2\alpha_3\beta_1}{\alpha_3\beta_2} \bar{l}_t{}^{-1} \tag{4.59}$$

Substituting (4.58) into (4.59), the inequality (4.27) is obtained. (Q.E.D.)

Proof of Proposition 4

To simplify, L will be used to represent L^e. At date $t = 0$:

$$K_0 + K_0^* = \tilde{K}_0 + \tilde{K}_0^*.$$

With integration:

$$\frac{\tilde{L}_0}{\tilde{K}_0} = \frac{\tilde{L}_0^*}{\tilde{K}_0^*} = \frac{\tilde{L}_0 + \tilde{L}_0^*}{\tilde{K}_0 + \tilde{K}_0^*}.$$

Denote $\lambda_t = \frac{K_t}{K_t + K_t^*}$ for $t = 1, 2, \cdots$. Since at date t_0, $L_0 = \tilde{L}_0$ and $L_0^* = \tilde{L}_0^*$ are given:

$$\frac{\tilde{L}_0}{\tilde{K}_0} = \frac{\tilde{L}_0 + \tilde{L}_0^*}{\tilde{K}_0 + \tilde{K}_0^*} = \frac{L_0 + L_0^*}{K_0 + K_0^*} = \frac{L_0}{K_0 + K_0^*} + \frac{L_0^*}{K_0 + K_0^*} = \lambda_0 \frac{L_0}{K_0} + (1 - \lambda_0)\frac{L_0^*}{K_0^*}$$

or:

$$\frac{L_0 + L_0^*}{K_0 + K_0^*} = \lambda_0 \frac{L_0}{K_0} + (1 - \lambda_0)\frac{L_0^*}{K_0^*}$$

Therefore, by the concavity of the production function:

$$\frac{Q_0 + Q_0^*}{K_0 + K_0^*} = \lambda_0 F\left(1, \frac{L_0}{K_0}\right) + (1 - \lambda_0) F\left(1, \frac{L_0^*}{K_0^*}\right)$$

$$< F\left(1, \lambda_0 \frac{L_0}{K_0} + (1 - \lambda_0)\frac{L_0^*}{K_0^*}\right) = F\left(1, \frac{\tilde{L}_0}{\tilde{K}_0}\right) = F\left(1, \frac{\tilde{L}_0^*}{\tilde{K}_0^*}\right)$$

Thus,

$$\frac{Q_0 + Q_0^*}{K_0 + K_0^*} < \frac{\tilde{Q}_0}{\tilde{K}_0} = \frac{\tilde{Q}_0^*}{\tilde{K}_0^*} = \frac{\tilde{Q}_0 + \tilde{Q}_0^*}{\tilde{K}_0 + \tilde{K}_0^*}$$

However, since $K_0 + K_0^* = \tilde{K}_0 + \tilde{K}_0^*$, then $Q_0 + Q_0^* < \tilde{Q}_0 + \tilde{Q}_0^*$. From (4.41), this implies that $\int_\Omega [y_0(\omega) + y_0^*(\omega)] d\mu(\omega) < \int_\Omega [\tilde{y}_0(\omega) + \tilde{y}_0^*(\omega)] d\mu(\omega)$. Therefore, from (4.40), $K_1 + K_1^* < \tilde{K}_1 + \tilde{K}_1^*$. But since aggregate effective human capital is unaffected by capital markets integration:

$$\frac{Q_1 + Q_1^*}{K_1 + K_1^*} = \lambda_1 F\left(1, \frac{L_1}{K_1}\right) + (1 - \lambda_1) F\left(1, \frac{L_1^*}{K_1^*}\right) < F\left(1, \lambda_1 \frac{L_1}{K_1} + (1 - \lambda_1)\frac{L_1^*}{K_1^*}\right) = F\left(1, \frac{L_1 + L_1^*}{K_1 + K_1^*}\right)$$

Rewriting this expression:

$$Q_1 + Q_1^* < F(K_1 + K_1^*, L_1 + L_1^*) < F(\tilde{K}_1 + \tilde{K}_1^*, \tilde{L}_1 + \tilde{L}_1^*)$$

Dividing both sides by $\tilde{K}_1 + \tilde{K}_1^*$:

$$\frac{Q_1 + Q_1^*}{\tilde{K}_1 + \tilde{K}_1^*} < F\left(1, \frac{\tilde{L}_1 + \tilde{L}_1^*}{\tilde{K}_1 + \tilde{K}_1^*}\right) = F\left(1, \frac{\tilde{L}_1}{\tilde{K}_1}\right) = F\left(1, \frac{\tilde{L}_1^*}{\tilde{K}_1^*}\right) = \frac{\tilde{Q}_1}{\tilde{K}_1} = \frac{\tilde{Q}_1^*}{\tilde{K}_1^*} = \frac{\tilde{Q}_1 + \tilde{Q}_1^*}{\tilde{K}_1 + \tilde{K}_1^*}$$

Hence, $Q_1 + Q_1^* < \tilde{Q}_1 + \tilde{Q}_1^*$ which again from (4.41) and (4.40) implies that $K_2 + K_2^* < \tilde{K}_2 + \tilde{K}_2^*$. This process continues for all $t = 2, 3, 4, \cdots$ proving the claim that $Q_t + Q_t^* < \tilde{Q}_t + \tilde{Q}_t^*$. (Q.E.D.)

Proof of Proposition 5

In this framework, the inequality in incomes originates from inequality in human capital distribution since the same wage rate multiplies $h_t(\omega)$ [see (4.46) and (4.49)]. International capital mobility will result in equal wages in both countries. However, there is no effect on the optimal choices of labor supply and of parental investment in their education, namely, $l_t(\omega)$ and $e_t(\omega)$ will not vary.

This can be verified directly from (4.20), (4.21) and (4.19). Given $h_t(\omega)$, $l_t(\omega)$ and $e_t(\omega)$, h_{t+1} will not vary as w_{t+1} is changed as well. Therefore, the human capital accumulation process will not vary and the sets A_t will not as well [see (4.25)]. Using (4.48) and (4.50) it can be verified that, following the changes in wage rate, the distribution of $y_{t+1}(\omega)$ will not change for $t = 0, 1, 2, \cdots$. (Q.E.D.)

Proof of Proposition 6

Using (4.20), (4.21), (4.23) and (4.24), (4.22) is rewritten as follows:

$$y_{t+1}(\omega) = C_t \left[4h_t^{\upsilon}(\omega) + 4\left(\frac{\beta_2}{\beta_1}\right) e_{gt}\bar{l}_t\overline{h}_t^{\eta} + \left(\frac{\beta_2}{\beta_1}\right)^2 \frac{(e_{gt}\bar{l}_t\overline{h}_t^{\eta})^2}{h_t^{\upsilon}(\omega)} \right] \qquad \text{for } \omega \notin A_t$$

$$y_{t+1}(\omega) = C_t \left[\frac{2}{\alpha_1 + \alpha_2 + \alpha_4} \left(\frac{\beta_2}{\beta_1}\right) e_{gt}\bar{l}_t\overline{h}_t^{\eta} \right] \qquad \text{for } \omega \in A_t$$

Similarly,

$$y_{t+1}^*(\omega) = C_t^* \left[4h_t^{*\upsilon}(\omega) + 4\left(\frac{\beta_2}{\beta_1}\right) e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta} + \left(\frac{\beta_2}{\beta_1}\right)^2 \frac{(e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta})^2}{h_t^{*\upsilon}(\omega)} \right] \qquad \text{for } \omega \notin A_t^*$$

$$y_{t+1}^*(\omega) = C_t^* \left[\frac{2}{\alpha_1 + \alpha_2 + \alpha_4} \left(\frac{\beta_2}{\beta_1}\right) e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta} \right] \qquad \text{for } \omega \in A_t^*$$

where C_t and C_t^* are some positive constants. Since h_0 and h_0^* are equally distributed, the same holds for $h_0^{\upsilon}(\omega)$ and $[h_0^*(\omega)]^{\upsilon}$. Moreover, since $\overline{h}_0 < \overline{h}^*$, from (4.23) it is obtained that $h_1^*(\omega)$ is more equal than $h_1(\omega)$ [see, Lemma 2 in Karni and Zilcha (1994)]. Also from (4.23), it is obtained that $h_1(\omega)$ are lower than $h_1^*(\omega)$ for all ω.

Note that since:

$$y_1^*(\omega) = C_0^* \left[\frac{2}{\alpha_1 + \alpha_2 + \alpha_4} \left(\frac{\beta_2}{\beta_1}\right) e_{g0}\bar{l}_0^*\overline{h}_0^{*\eta} \right] \qquad \text{for } \omega \in A_0^*$$

and

$$y_1(\omega) = C_0 \left[\frac{2}{\alpha_1 + \alpha_2 + \alpha_4} \left(\frac{\beta_2}{\beta_1}\right) e_{g0}\bar{l}_0\overline{h}_0^{\eta} \right] \qquad \text{for } \omega \in A_0$$

and on these sets $y_1^*(\omega) > y_1(\omega)$, the above argument is not affected by the existence of A_0 and A_0^* with positive measure. In particular, it is obtained that $[h_1^*(\omega)]^\upsilon$ is more equal than $[h_1(\omega)]^\upsilon$ [see Theorem 3.A.5. in Shaked and Santikumar (1994)]. Also $[\overline{h}_1]^\eta < [\overline{h}_1^*]^\eta$. Using (4.23) this implies that $h_2^*(\omega)$ is more equal than $h_2(\omega)$. It is easy to see that this process can be continued to generalize for all periods. (Q.E.D.)

Public education and income inequality under endogenous labor regime

Here an explanation is provided to support the claim that if the tax rate that finances public education is the same for all dates, then income inequality at date $t+1$ is smaller than that in date t. One starts by showing that in each generation, individuals with higher level of human capital choose at the optimum, higher level of time to be allocated for private education of their offspring. This is clear from (4.19). Next one can show that such a property generates less inequality in the distribution of $y_{t+1}(\omega)$ compared to $y_t(\omega)$. One applies (4.22), which represents the period $t+1$ income $y_{t+1}(\omega)$ as a function of the date t income $y_t(\omega)$ via the human capital evolution.

Define the function $Q : R \rightarrow R$ such that $Q[h_t(\omega)] = h_{t+1}(\omega)$ using (4.23) whenever $\omega \in A_t$, that is,

$$Q[h_t(\omega)] = \left[\frac{\alpha_3}{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4}\right] \theta_t(\omega) \left[2\beta_1 h_t^\upsilon(\omega) + \beta_2 \tau_t \bar{l}_t \overline{h}_t^\eta\right]$$

and when $\omega \in A_t$, this function is defined using (4.24) by:

$$Q[h_t(\omega)] = \beta_2 \theta_t(\omega) \tau_t \bar{l}_t \overline{h}_t^\eta$$

This function is monotone non-decreasing and satisfies $Q(x) > 0$ for any $x > 0$ and $\frac{Q(x)}{x}$ is decreasing in x. Therefore [see Shaked and Shantikumar (1999)], the human capital distribution $h_{t+1}(\omega)$ is more equal than the distribution in date t, $h_t(\omega)$. This implies that $y_{t+1}(\omega)$ is more equal than $y_t(\omega)$.

Next it will be shown that increasing the tax rate (hence, the public education provision) results in a more equal intragenerational distribution in all subsequent period. For this purpose, it is sufficient to assume that $e_t(\omega) > 0$ for all $\omega \in G_t$. When this is not the case, raising e_{gt} entails higher income for all low income individuals $\omega \in A_t$ which only reinforces the claim.

One can consider (4.1) for $t = 0$. Since $h_0(\omega)$ and $l_0(\omega)$ are given, $h_t^\upsilon(\omega)$, $\bar{l}_0$ and $\overline{h}_0$ are fixed. By raising e_g0, the distribution of the human capital for generation 1, $h_1(\omega)$, becomes more equal. This follows from Lemma 1 in Karni and Zilcha (1995). Moreover, from (4.23) one can claim that the average human capital in generation 1 increases as well. Increasing e_{g0} will result in higher $h_1(\omega)$ for all ω and higher levels of $\bar{l}_1$ and $\overline{h}_1$.

Moreover, it also implies that $h_1^v(\omega)$ will have a more equal distribution [see Shaked and Shanthikumar (1994), Theorem 3.A.5].

Now, one considers $t = 1$. Increasing e_{g1} will imply $\beta_2 e_{g1} \bar{l}_1 \overline{h}_1^{\eta}$ is larger than its value before the level of public education is increased. Using (4.23) and the same lemma as before, it is obtained that $h_2(\omega)$ becomes more equal. This process can be continued for $t = 2, 3, 4, \cdots$, which establishes the claim. Now, let one consider the set of families with $e_t(\omega) = 0$. To simplify the argument assume that initially $e_{g0} = 0$, then as e_{g0} increases $h_1(\omega)$ will be equal or larger than in the private provision case for all $\omega \in G_1$ where $\omega \in A_0$. This fact certainly reinforces the earlier case since at the lower tail of the distribution of income, one raises and equalizes the income for all $\omega \in G_1$ where $\omega \in A_0$. This process can be continued for all generations.

More efficient provision of public education and income distribution under endogenous labor regime

It will be presented that when one considers improvements in the production process of human capital, if the provision of public education becomes more efficient, then the inequality in intragenerational distribution of income decreases in all periods.

Let the initial distribution of human capital $h_0(\omega)$ be given. One can compares two equilibria from the same initial conditions: the first with the human capital process given by (4.1) and the second with the same process but β_2 is replaced by a larger coefficient $\beta_2^* > \beta_2$. β_1 is kept unchanged.

Consider again the following:

$$y_{t+1}(\omega) = C_t \left[4h_t^v(\omega) + 4\left(\frac{\beta_2}{\beta_1}\right) e_{gt}\bar{l}_t\overline{h}_t^{\eta} + \left(\frac{\beta_2}{\beta_1}\right)^2 \frac{(e_{gt}\bar{l}_t\overline{h}_t^{\eta})^2}{h_t^v(\omega)} \right] \qquad \text{for } \omega \notin A_t$$

$$y_{t+1}(\omega) = C_t \left[\frac{2}{\alpha_1 + \alpha_2 + \alpha_4} \left(\frac{\beta_2}{\beta_1}\right) e_{gt}\bar{l}_t\overline{h}_t^{\eta} \right] \qquad \text{for } \omega \in A_t$$

$$y_{t+1}^*(\omega) = C_t^* \left[4h_t^{*v}(\omega) + 4\left(\frac{\beta_2^*}{\beta_1}\right) e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta} + \left(\frac{\beta_2^*}{\beta_1}\right)^2 \frac{(e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta})^2}{h_t^{*v}(\omega)} \right] \qquad \text{for } \omega \notin A_t^*$$

$$y_{t+1}^*(\omega) = C_t^* \left[\frac{2}{\alpha_1 + \alpha_2 + \alpha_4} \left(\frac{\beta_2^*}{\beta_1}\right) e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta} \right] \qquad \text{for } \omega \in A_t^*$$

where C_t and C_t^* are some possible constants. Since $h_0(\omega)$ is fixed at date $t = 0$, it is obtained that [see, Lemma 2 from Karni and Zilcha (1994)] $\frac{\beta_2^*}{\beta_1} > \frac{\beta_2^*}{\beta_1}$ imply that $y_1^*(\omega)$ is more equal to $y_1(\omega)$. It is also derived that $h_1(\omega)$ are lower than $h_1^*(\omega)$ for all ω, and hence, $\overline{h}_1 < \overline{h}_1^*$. This inequality reinforces the result when $\mu(A_0) > 0$.

By (4.23), $h_1^{*v}(\omega)$ is more equal than $h_1^v(\omega)$ and $4\left(\frac{\beta_2^*}{\beta_1}\right) e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta} + \left(\frac{\beta_2^*}{\beta_1}\right)^2 \frac{(e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta})^2}{h_t^{*v}(\omega)} >$ $4\left(\frac{\beta_2}{\beta_1}\right) e_{gt}\bar{l}_t\overline{h}_t^{\eta} + \left(\frac{\beta_2}{\beta_1}\right)^2 \frac{(e_{gt}\bar{l}_t\overline{h}_t^{\eta})^2}{h_t^v(\omega)}$, hence $h_2^*(\omega)$ is more equal than $h_2(\omega)$.

This same argument can be continued for all dates $t = 3, 4, 5, \cdots$ Also note that $A_t \subset A_t^*$ (where A_t^* is the set of families in G_t^* who choose $e_t(\omega) = 0$) since $4\left(\frac{\beta_2^*}{\beta_1}\right) e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta} + \left(\frac{\beta_2^*}{\beta_1}\right)^2 \frac{(e_{gt}\bar{l}_t^*\overline{h}_t^{*\eta})^2}{h_t^{*v}(\omega)} > 4\left(\frac{\beta_2}{\beta_1}\right) e_{gt}\bar{l}_t\overline{h}_t^{\eta} + \left(\frac{\beta_2}{\beta_1}\right)^2 \frac{(e_{gt}\bar{l}_t\overline{h}_t^{\eta})^2}{h_t^v(\omega)}$ for all t. This only contributes to the more equal distribution of $y_{t+1}^*(\omega)$ since the left hand tail has been increased and equalized compared to the $y_{t+1}(\omega)$ case.

To complete the explanation, one considers the case where one increases η. When one increases the value of η, keeping other parameters constant, one is basically increasing the second term in (4.23), $\overline{h}_0^{\eta}$ while $h_0^v(\omega)$ remains unchanged. Again by Lemma 2 in Karni and Zilcha (1994), one obtains that the distribution of $h_1(\omega)$ becomes more equal. Taking into account the families $\omega \in G_1$ who belong to A_0 (i.e., the lower tail of the distribution of income) only reinforces the higher equality since their incomes are uniformly increased, while for all other $\omega \in G_1$, $\omega \notin A_0$, the proportional raise in their income is smaller. This can be continued for $t = 2$ as well since it is easy to verify that $\overline{h}_1^{\eta}$ increases while $h_1^v(\omega)$ becomes more equal. Now this process can be extended to $t = 2, 3, \cdots$.

More efficient provision of private education and income distribution under endogenous labor regime

When one consider improvements in the production process of human capital and if the provision of private education becomes more efficient, then the inequality in intragenerational distribution of income increases in all periods.

This follows from the same types of arguments using the fact that if $\beta_1 < \beta_1^*$ then $\frac{\beta_2}{\beta_1} > \frac{\beta_2}{\beta_1^*}$, and hence $h_1(\omega)$ is more equal then $h_1^*(\omega)$ and $\overline{h}_1 > \overline{h}_1^*$. This process leads, using similar arguments as before, to $y_t(\omega)$ more equal than $y_t^*(\omega)$ for all periods t. To complete the explanation, one compares two economies which differ only in parameter v. The economy with higher v will have more inequality in the intragenerational income distribution in all periods.

This can be seen as follows. Since the two economies have the same initial distribution of human capital $h_0(\omega)$, the process that determines $h_1(\omega)$ differs only in the parameter v. Denote by $v^* < v \leq 1$ the parameters, then it is clear that $[h_0(\omega)]^{v^*}$ is more equal than $[h_0(\omega)]^v$ since it is attained by a strictly concave transformation [see, Shaked and Shanthikumar (1994)].

Likewise, the human capital distribution $h_1^*(\omega)$ is more equal than the distribution $h_1(\omega)$. This implies that $y_1^*(\omega)$ is more equal than $y_1(\omega)$. Now one can apply the same argument to date 1: the distribution of $[h_1^*(\omega)]^{v^*}$ is more equal than that of $[h_1(\omega)]^{v^*}$, and hence, using (4.23) and the above reference, one derives that the distribution of $[h_2^*(\omega)]^{\upsilon^*}$ is more equal than that of $[h_2(\omega)]^{\upsilon^*}$. The process can be continued for all t.

Neutral technological improvement under endogenous labor regime

When one consider improvements in the production process of human capital and if the the technological improvement is neutral, then the inequality continues unchanged at period 1 but declines for all periods afterwards.

From (4.23) one notices that inequality in the distribution of $h_1(\omega)$ remains unchanged even though all levels of $h_1(\omega)$ increase due to this technological improvement. In particular, $\overline{h}_1$ increases. Now, since inequality of $h_1^{\upsilon}(\omega)$ did not vary but the second term in the right hand side of (4.23) has increased due to the higher value of $\overline{h}_1$, one obtains more equal distribution of $h_2(\omega)$. When $\mu(A_0) > 0$, the higher $\overline{h}_1$ results in higher income to all $\omega \in G_1$ who belong to A_0, which only reinforces the more equality in $y_2^*(\omega)$. Now, this argument can be used again at dates $3, 4, \cdots$.

Chapter 5

Monetary integration and exchange rates dynamics: the euro introduction and non-euro currencies

Chapter 5 is based on Van Dijk, Hafner and Munandar (2005).

5.1 Introduction

The advent of the euro has generated a substantial body of research investigating the consequences and effects of the introduction of the common currency in Europe.[1] Topics of particular interest include integration and co-movement of bond and stock markets (Kool, 2000; Morana and Beltratti, 2002; Guiso *et al.*, 2004; Pagano and von Thadden, 2004; Baele, 2005; Bartram *et al.*, 2005; Kim *et al.*, 2005), interdependence between U.S. and euro area money markets (Ehrmann and Fratzscher, 2005), convergence of real exchange rates (Lopez and Papell, 2003) and of inflation rates (Honohan and Lane, 2003), trade effects (Micco *et al.*, 2003; Bun and Klaassen, 2004), product market integration (Engel and Rogers, 2004), foreign exchange rate risk exposure of individual firms (Bartram and Karolyi, 2003), the behavior of nominal exchange rates of euro-zone countries in the run-up to the common currency (Frömmel and Menkhoff, 2001; Bond and Najand, 2002; Wilfling, 2002), and the role of the euro in the foreign exchange market (Detken and Hartmann, 2002; Hau *et al.*, 2002). Not surprisingly, most of this research focuses on the effects for countries that have adopted the common currency. The exceptions include Barr

[1]Since January 1, 1999 the euro replaced the national currencies of 11 countries: Belgium, Germany, Spain, France, Ireland, Italy, Luxembourg, the Netherlands, Austria, Portugal and Finland. On January 1, 2001 it also replaced the national currency of Greece. These 12 countries are now known collectively as the euro area.

et al. (2003), Micco *et al.* (2003) and Guiso *et al.* (2004), who (also) examine the effects of the euro introduction on European countries that held on to their own currency. The analysis in these papers considers variables such as trade and foreign direct investment, which obviously are closely linked to the exchange rate. Only Fisher (2002) succintly considers the exchange rate itself, by exploring the volatility properties of the currencies of European countries outside the euro-zone before and after January 1999.

The first and main contribution of this chapter is to further understanding of the effects of the euro introduction on the properties of exchange rates for European countries outside the euro-zone. In particular, the behavior of daily exchange rates of the British pound, Norwegian krone, Swedish krona, and Swiss franc against the U.S. dollar over the period from January 1, 1994 until December 31, 2003 is considered.[2,3] The focus are on the volatility and correlation properties of these exchange rates, paying particular attention to the co-movement with the euro and changes therein.

The insights gained from this study would be beneficial to policy makers, particularly monetary authorities who routinely follow and analyze movements and properties of exchange rates, including volatilities and correlations, and decide, based on such analysis, whether some monetary policy interventions are deemed necessary. Specifically, the results offer a perspective concerning a unique behavior of multiple exchange rates which simultaneously observe an agenda of monetary integration in the neighborhood. Obviously, other economies who envisage engaging in a similar economic integration program can also reap the benefits. For general market participants, information on volatilities and correlations of exchange rates are considered crucial. Such information is required to construct and diversify portfolios in order to achieve the highest level of efficiency. By studying the findings, investors or portfolio managers would obtain an empirical knowledge on how markets would react if similar events will occur in the future.

Our second contribution is methodological, concerning the dynamic conditional correlation (DCC) model introduced by Engle (2002), which is the econometric framework used to perform the analysis. Here how to extend this model to accommodate structural changes in the unconditional correlations is demonstrated. A successful application of this new method, as evidenced by this study, would bring numerous opportunities to conduct other empirical works which possibly involve structural changes in the unconditional correlations, for instance in stock or bond markets.

[2]UK and Sweden are European Union (E.U.) members outside the euro area while Norway and Switzerland are European countries outside the E.U.

[3]Danish krone is not included in the analysis. Denmark, an E.U. member, decided not to adopt the euro upon its introduction already in December 1992, a decision that was confirmed in the national referendum held on September 28, 2000. Nevertheless, it turns out that the correlation of the Danish krone with the euro has been very close to perfect ever since the euro came into existence. Indeed, since 1 January 1999 Danish krone has been participating in ERM II with a rather narrow fluctuation and of 2.25%, and effectively has had an almost fixed exchange rate vis-à-vis the euro.

The main findings are as follows. Large breaks in the unconditional correlations among all exchange rates considered occurred both at the time the formal decision to proceed with the euro was made in December 1996 and at the time of the actual introduction of the euro in January 1999. In particular, unconditional correlations were substantially lower after December 1996. This is attributed to increased heterogeneity of expectation in the foreign exchange market due to uncertainty about the eventual success of the single currency. The correlations were then considerably higher after January 1999. Besides the more coherent expectation held by market participants, the ultimate existence of euro means greater policy coordination among many countries involved. Bollerslev (1990) finds the similar results during the introduction of the European Monetary System (EMS) in 1979. Breaks also occurred in the unconditional exchange rate volatilities, but these were of a much smaller magnitude comparatively.

An extensive sensitivity analysis is performed to examine the robustness of the results. It is found that allowing for two breaks in unconditional correlations is appropriate, while support is also found for the break dates of December 1996 and January 1999. In addition, modelling the changes in unconditional correlations as instantaneous rather than gradual is supported by the data, except for the currency pairs involving the British pound.

The plan of the chapter is as follows. Section 5.2 sketches the 'road to the euro', highlighting the most important exchange rate policy decisions made by the governments and central bank authorities of the outside countries. The daily exchange rate series are described in Section 5.3. In Section 5.4, the extended DCC model allowing for structural breaks in unconditional volatilities and correlations is developed. Section 5.5 discusses the empirical results while section 5.6 elaborates the sensitivity analysis of such results. Finally, Section 5.7 concludes.

5.2 The introduction of the euro

In this section an overview of the crucial decisions taken in the process towards the introduction of the euro on January 1, 1999 is provided. This includes the main actions taken by the governments and central bank authorities of not only the countries that adopted the common currency, but also European Union (E.U.) members that decided to stay outside 'euroland' (UK and Sweden) and countries that did not belong to the E.U. in the first place (Norway and Switzerland).[4]

[4]This section draws upon information available at the websites of the European Council (`http://ue.eu.int/`), the European Central Bank (`http://www.ecb.int/`), the Bank of England (`http://www.bankofengland.co.uk/`), the Swedish Riksbank (`http://www.riksbanken.se/`), the Norges Bank (`http://www.norgesbank.no/`), and the Swiss National Bank (`http://www.snb.ch/`), as well as speeches by central bank governors published in the BIS Review (`http://www.bis.org/review/`).

5.2.1 Monetary integration in Europe

Countries in Europe have long been passionate with the objective of reducing exchange rate variability by means of increased policy coordination. On March 13, 1979, a new process to achieve this goal was started with the creation of the European Monetary System (EMS). The key ingredient of the EMS was the exchange rate mechanism (ERM), specifying fixed central exchange rates for each currency vis-a-vis all other participating currencies, with a band around these central rates within which the exchange rates could fluctuate freely. Central bank interventions were used to keep the exchange rates within the band, while realignments of the central rates were permitted in case a particular parity could not be defended. The numeraire of the ERM was the European Currency Unit (ECU), defined as a 'basket' of fixed quantities of the currencies of the member states. The value of the ECU against the U.S. dollar was determined as a weighted average of the U.S. dollar exchange rates of the component currencies. The central ERM rates of the participating currencies were expressed in terms of the ECU.

The EMS was in fact much more than just an exchange rate mechanism. It also involved the adjustment of monetary and economic policies as tools for achieving exchange rate stability. Its participants were able to create a zone in which monetary stability increased and capital controls were gradually relaxed. It thus fostered a downward convergence of inflation rates and stimulated a high degree of exchange rate stability, which led to improved overall economic performance, for example through protecting intra-European trade and investment from excessive exchange rate uncertainty (but see Darby *et al.* (1998) for a critical perspective).

This gradual process of stabilization and economic integration received a new impulse in June 1988, when the European Council confirmed the objective of the progressive realization of Economic and Monetary Union (EMU). The Delors committee, which subsequently was mandated to study and propose concrete stages leading to this union, suggested that EMU should be achieved in three discrete but evolutionary steps. Stage One of EMU, which began on July 1, 1990, involved abolishing all restrictions on capital movements between member states, free use of the ECU, increased cooperation between central banks and further coordination of monetary policies of the member states with the aim of achieving price stability. The Treaty of Rome, establishing the European Economic Community, was revised in 1991 to enable Stages Two and Three of EMU. The resulting Treaty on European Union was signed in Maastricht in February 1992 and after a prolonged ratification process came into force in November 1993.

Stage Two of EMU was entered on January 1, 1994, with the establishment of the European Monetary Institute (EMI). The two main tasks of the EMI were to strengthen central bank cooperation and monetary policy coordination, and to make the necessary preparations for establishing the European System of Central Banks (ESCB), for the conduct of the single monetary policy and for the creation of a single currency in the third stage.[5] In December 1995, the European Council decided upon the name of 'euro' for the single European currency and confirmed that the start of Stage Three of EMU would take place on January 1, 1999.

At its meeting held in Dublin on December 13-14, 1996, the European Council made decisive progress towards the third stage of EMU. In particular, it agreed upon the structure of the new Exchange Rate Mechanism (ERM II) and upon the principles and main elements of the Stability and Growth Pact for ensuring budgetary discipline in EMU countries. Both decisions were largely based upon a report presented by the EMI at the meeting. Although the resulting resolutions on ERM II and the Stability and Growth Pact were formally adopted at the European Council meeting in Amsterdam in June 1997, the Dublin meeting in December 1996 can be regarded as the time the final decision to proceed towards Stage Three of EMU and the introduction of the euro on January 1, 1999 was actually made.[6]

On May 2, 1998, it was decided that 11 E.U. member states had fulfilled the conditions necessary for participation in the third stage of EMU and the adoption of the single currency on January 1, 1999. At the same time it was also agreed that the ERM bilateral central rates would be used for determining the conversion rates for the euro. Upon the start of the third and final stage of EMU on January 1, 1999, the exchange rates of the currencies of the participating countries were irrevocably fixed accordingly. The European Central Bank (ECB) took over responsibility for conducting the single monetary policy in the euro area. Both the intra-E.U. exchange rate mechanism (ERM II) and the Stability and Growth Pact entered into force, and the single common currency, the euro, was officially launched.

5.2.2 Non-euro countries

UK

The Maastricht Treaty, signed in 1992, provided a special clause for the UK on the implementation of economic and monetary union in progressive stages. The British Government accepted participation up to the preparatory Stage Two, but arranged an opt-out from Stage Three, when exchange rates would be irrevocably locked, the euro would come into existence and the national currencies would be abolished.

In October 1997, the UK government set five economic tests that must be passed before it will recommend that the UK joins the euro, see Rollo (2002) for discussion. In

[5]The EMI itself had no responsibility for the conduct of monetary policy nor had it any competence for carrying out foreign exchange interventions.

[6]Coincidentally, at the Dublin meeting the EMI also presented the winning designs for the euro banknotes.

theory, passing these tests is distinct from any political decision to join. The tests are (i) Are business cycles and economic structures compatible with European interest rates on a permanent basis? (ii) If problems emerge, is there sufficient flexibility to deal with them? (iii) Would joining the euro create better conditions for firms making long-term decisions to invest in the UK? (iv) What impact would entry into the euro have on the UK's financial services industry? (v) Would joining the euro promote higher growth, stability and a lasting increase in jobs? The UK government assessed these tests in October 1997 and June 2003, and decided on both occasions that they had not all been passed.

These decisions are not surprising given the positive track record of the Bank of England in its conduct of monetary policy. Although the UK adopted a formal inflation target already in 1992, only in 1997 the responsibility for setting interest rates was transferred from the Treasury to the Bank, see Bean (1998) for an interesting analysis. The operational independence, which the Bank was granted at the same time, further enhanced the credibility of inflation targeting. According to the institutional framework laid down in the 1998 Bank of England Act, the Bank is required to set interest rates so as to maintain price stability and subject to that to support the economic policy of the Government, including its objectives for growth and employment. On the other hand, the Government should specify what its economic objectives are, including what is meant by price stability. If inflation deviates from target by more than 1 percentage point, the Governor of the Bank is required to write to the Treasury explaining the circumstances and setting out what action its Monetary Policy Committee (MPC) considers necessary to return to target. Against the target of 2.5% annual inflation for the RPIX (Retail Price Index exclusive of interest payments) which ran from 1997 until December 2003, average inflation was 2.4%. For 68 out of the 79 months, inflation was within 0.5 percentage point of the target - below it for 42 months, above it for 30, and on target for the remaining seven. Clements (2004) provides an in-depth evaluation of the inflation forecasts that play an important role in the MPC's decisions on interest rates.

Sweden

On November 19, 1992, the Sveriges Riksbank (Swedish Central Bank) abandoned its policy of pegging the krona to a trade-weighted average of foreign currencies. At the time, Sweden was neither a member of the E.U. nor participating in the European system of pegged exchange rates, and therefore entering the ERM was not feasible in the near future.

On January 15, 1993 the Riksbank decided to declare that the flexible exchange rate policy would be combined with an explicit target for inflation, defined in terms of the consumer price index (CPI). Specifically, the Riksbank decided that from 1994 onwards there would be a target for CPI inflation of 2 percent per year, accompanied by a 'tolerance interval' of 1 percentage point.

In late 1998, the Riksdag (Swedish Parliament) approved changes to the Riksbank Act making the central bank legally more independent and formalizing objectives towards an inflation-targeting regime. The Riksbank had to be made more independent in order to comply with the Maastricht Treaty, which Sweden in effect had signed when deciding to become an E.U. member in December 1994. Although Sweden was not a full participant in the EMU as it did not plan to adopt the euro upon its inception, there was broad political support in Sweden for the idea that technical and practical preparations should be made for a possible future full membership. The parliament's decision to make the Riksbank more independent had effectively been taken already before the government's decision to postpone membership in the EMU in December 1997. This timing was probably not co-incidental; legal independence for the Riksbank was viewed as useful to maintain credibility for the inflation target as long as Sweden is not a full member of the EMU.

Unlike the UK and Denmark, Sweden does not have a formal opt-out from the monetary union and therefore must (at least in theory) convert to the euro at some point. Notwithstanding this, on September 14, 2003 a referendum on the euro was held. The euro opponents claimed that adopting the common currency could damage the country's strong economic performance and generous welfare system, especially since Sweden's trade pattern and industrial structure deviate from the European average. On the other hand, the euro advocates argued that trade and future growth would be enhanced by becoming an EMU member. The result of the referendum was a rejection of the common currency by a 14 percentage point margin (56 to 42 percent, with 2 percent voting 'blank'). Despite the lack of an opt-out option, the Swedish government argued that complying with the referendum result is possible given that one of the requirements for adopting the euro is a prior two-year participation in the ERM II. By simply choosing to stay outside the exchange rate mechanism, the Swedish government was provided a formal loophole avoiding the theoretical requirement of adopting the euro.

Norway

For almost the entire post-World War II period monetary policy in Norway has been oriented towards maintaining exchange rate stability, with fiscal policy bearing the main responsibility for stabilising the economy. When the European Monetary System (EMS) was set up in 1979 Norway chose to link its krone to a trade-weighted basket of currencies. Despite the objective of a fixed exchange rate, several adjustments to the international value of the krone were made during the 1970s and 1980s to compensate for high wage and price inflation. From the mid-1980s the focus of monetary policy was increasingly shifted towards the role of a stable exchange rate as a nominal anchor, against the backdrop of high inflation and relatively high domestic interest rates following the devaluation in 1986. The E.U. countries' track record of low inflation was used as an argument for pegging the krone rate to the ECU in 1990. The currency turmoil in Europe in 1992-93 prompted Norway to abandon the fixed rate against the ECU in favor of a 'managed float', aiming to keep the exchange rate 'stable' against European currencies, but without explicit fluctuation margins. This objective for monetary policy was formalized in the Exchange Rate Regulation, the mandate assigned to Norges Bank (the Norwegian Central Bank) by the political authorities in May 1994.

At the end of 1996 and beginning of 1997 the Norwegian krone appreciated considerably, mainly due to higher oil prices and insufficiently tight fiscal policy. Norges bank reacted by lowering key interest rates between October 1996 and January 1997 by 1.25 percentage points while also purchasing large amounts of foreign exchange. Initially the Norwegian currency continued to appreciate, but fell back later during the spring to end 1997 at about the same level as it started the year. Importantly, on January 10, 1997 Norges Bank also declared that it would no longer intervene in the foreign exchange market to any significant extent. As a consequence, the krone became much more susceptible to turbulence in international financial markets, leading to a substantial increase in its volatility, see Bernhardsen and Røisland (2000).

Early 1999 the new governor of Norges Bank reinterpreted the monetary policy guidelines laid down in the Exchange Rate Regulation. In particular, it was recognized that targeting the exchange rate directly was no longer an appropriate operational goal of monetary policy. Instead, low and stable inflation was put forward as the essential condition for exchange rate stability. Monetary policy was therefore reoriented towards reducing inflation to the ECB target (two percent). This can be interpreted as the beginning of a period of *partial inflation targeting*, see e.g. Bauwens, Rime and Sucarrat (2006). The disappointing experiences with extensive exchange rate interventions further strengthened the position of the interest rate as the most important monetary policy instrument.

On March 29, 2001, the Government officially approved the new guidelines for monetary policy. Norges Bank sets the key interest rate with a view to maintaining low and stable inflation, with a specific annual CPI inflation target of 2.5 percentage points. Under the inflation targeting regime, Norges Bank no longer has a specific exchange rate target for the Norwegian krone.

Switzerland

Monetary policy in Switzerland has a long history of being autonomous, with the objective to preserve long-term price stability ever since the collapse of the Bretton Woods system. Convinced that inflation is a monetary phenomenon, the Swiss National Bank (SNB) opted for a strategy aimed at a steady growth of the money stock in line with the potential growth rate of the economy, see Rich (1997). Only in 2000 this was changed to inflation targeting.

Since 1973, the Swiss franc has been floating against all major currencies. Despite the flexible exchange rate regime, the Swiss franc has been remarkably stable against other European currencies ever since the early 1980s. Given that the SNB refrained from intervening in the foreign exchange market, this quasi-fixed exchange rate was achieved by market forces alone.

In the run-up towards the introduction of the euro, the SNB expressed concerns about the stability of the Swiss franc, about the ability of the Swiss to conduct an independent monetary policy, about the exchange rate sensitivity of the Swiss economy, and about the position of the Swiss franc as a transaction currency (even in Switzerland itself), see Fisher (2002) for discussion. The SNB implemented a pragmatic monetary policy aimed towards granting the Swiss economy the monetary flexibility necessary for handling these risks and uncertainties. After the launch of the euro, it soon appeared that the Swiss' fears did not materialize: The Swiss franc remained very stable against the euro, the SNB managed to hold on to its monetary independence, and the Swiss franc was not crowded out by the euro as a vehicle currency.

Summarizing the above, the main conclusion is that the two most important events in the run-up towards Stage Three of EMU were the agreement on the structure of the new Exchange Rate Mechanism (ERM II) and on the principles and main elements of the Stability and Growth Pact at the meeting of the European Council in Dublin on December 13-14, 1996, and the actual introduction of the euro on January 1, 1999. In the empirical analysis below, how these events affected the currencies of the outside countries is examined. Such effects may be expected given their close links with the Eurozone countries. In addition, changes in the exchange rate properties of the Norges krone may also have occurred due to the changes Norges Bank made in its exchange rate policy and monetary policy at the same time.

5.3 Data description

Table 5.1 displays summary statistics of the daily exchange rate returns. The complete explanation of the series is relegated to the appendix of this thesis. In addition to the full sample period, these statistics are also reported for the three relevant subperiods that are distinguished. The first period runs from January 1, 1994 until December 15, 1996, when the formal decision to proceed with ERM II and the euro was made at the European Summit in Dublin. The second subperiod comprises the period between this decision and the actual introduction of the euro on January 1, 1999. The third and final subperiod covers the remainder of the sample period until December 31, 2003.

Table 5.1: Exchange rate returns - summary statistics

					Correlations				
Currency	Mean	StD	Skew	Kurt	CHF	EUR	GBP	NOK	SEK
January 1, 1994-December 31, 2003									
CHF	−1.845	10.70	−0.225	4.817	1.000	0.926	0.581	0.752	0.646
EUR	−1.073	9.73	−0.104	4.264		1.000	0.607	0.812	0.713
GBP	−1.892	7.56	0.080	4.510			1.000	0.534	0.483
NOK	−1.225	9.73	−0.104	5.900				1.000	0.731
SEK	−1.481	9.88	−0.019	4.282					1.000
January 1, 1994-December 15, 1996									
CHF	−4.148	11.18	−0.369	6.718	1.000	0.942	0.621	0.887	0.531
EUR	−4.004	9.48	−0.060	5.686		1.000	0.658	0.945	0.559
GBP	−3.956	7.09	0.396	6.380			1.000	0.674	0.470
NOK	−5.165	8.30	−0.036	5.462				1.000	0.626
SEK	−6.969	8.92	0.186	4.334					1.000
December 16, 1996-December 31, 1998									
CHF	2.071	10.49	−0.380	4.003	1.000	0.886	0.416	0.565	0.585
EUR	3.701	9.16	−0.237	3.559		1.000	0.447	0.680	0.662
GBP	−0.074	8.00	−0.040	4.454			1.000	0.348	0.377
NOK	7.778	11.47	−0.333	7.993				1.000	0.706
SEK	8.660	10.02	−0.568	5.590					1.000
January 1, 1999-December 31, 2003									
CHF	−2.086	10.50	−0.056	3.666	1.000	0.935	0.631	0.784	0.737
EUR	−1.292	10.10	−0.081	3.767		1.000	0.646	0.821	0.806
GBP	−1.415	7.64	−0.019	3.668			1.000	0.565	0.533
NOK	−2.580	9.72	−0.012	3.806				1.000	0.793
SEK	−2.386	10.34	0.098	3.758					1.000

Note: The table reports summary statistics of daily exchange rate returns. StD denotes standard deviation, Skew is skewness and Kurt is kurtosis. Mean returns and standard deviations are given in annualized percentage points.

Apart from the important economic events that took place at the end of 1996 and 1998, the choice for these three subperiods is also motivated by the results from the following nonparametric analysis of volatilities and correlations. Let r_t denote the $(N \times 1)$ vector time series of daily exchange rate returns, where in this case $N = 5$. A nonparametric estimate of the correlation matrix R_t at $t = \tau$ can be obtained as

$$\widehat{R}(\tau) = \widehat{Q}^*(\tau)^{-1}\widehat{Q}(\tau)\widehat{Q}^*(\tau)^{-1} \tag{5.1}$$

where $\widehat{Q}(\tau)$ is the Nadaraya-Watson kernel estimator

$$\widehat{Q}(\tau) = \frac{\sum_{t=1}^{T}(r_t - \overline{r})(r_t - \overline{r})' K_h(t-\tau)}{\sum_{t=1}^{T} K_h(t-\tau)} \tag{5.2}$$

where $\overline{r} = \frac{1}{T}\sum_{t=1}^{T} r_t$, $K_h(u) = (1/h)K(u)$, $K(u)$ is a kernel density function (Fan and Gijbels, 1996)[7] and h a bandwidth parameter (a nonnegative number controlling the size of the local neighborhood) and where $\widehat{Q}^*(\tau)$ is diagonal matrix with the square roots of the diagonal elements of $\widehat{Q}(\tau)$ on its diagonal.[8] These also provide nonparametric estimates of the volatilities of the exchange rate returns at $t = \tau$.[9] A quartic kernel function with bandwidth $h = 1$ is employed.[10] The resulting volatility and correlation estimates, shown in Figure 5.1, are used in the discussion below.

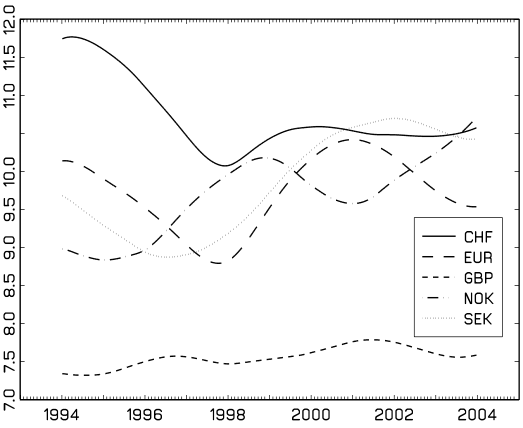
Concerning the univariate statistics (mean, standard deviation, skewness and kurtosis), it is first noted that the mean exchange rate returns varied considerably. Specifically, during the middle period from December 16, 1996 until December 31, 1998 the U.S. dollar depreciated against all currencies (except the British pound), while the first and third subperiods are characterized by an appreciation of the U.S. dollar. The standard deviation of exchange rate returns remained relatively stable across subperiods, although the Norwegian krone experienced higher volatility in 1997-98 and towards the end of the sample period, see also panel (a) in Figure 5.1. More variation is observed in skewness and kurtosis. Skewness is negative for all exchange rates and subperiods, except for the British pound and the Swedish krona before December 1996 and for the Swedish krona

[7]The kernel function is a real valued weight function, and in practice it is most often assigned a symmetric density function.

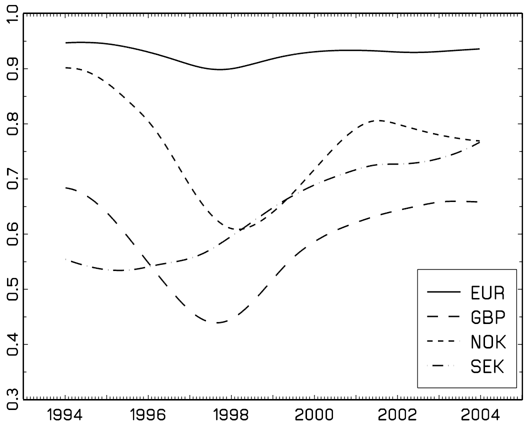
[8]In spite of the presence of other general types of estimators, the Nadaraya-Watson type estimator still stands out for two reasons. First, it brought about the notion of a kernel function. One early interpretation of the term 'kernel regression' referred to any nonparametric regression utilizing a kernel function. Second, by recognizing the Nadaraya-Watson estimator as a local constant fit one might extend the idea to local polynomial fitting.

[9]A detailed discussion of this nonparametric volatility and correlation estimator can be found in Hafner *et al.* (2006).

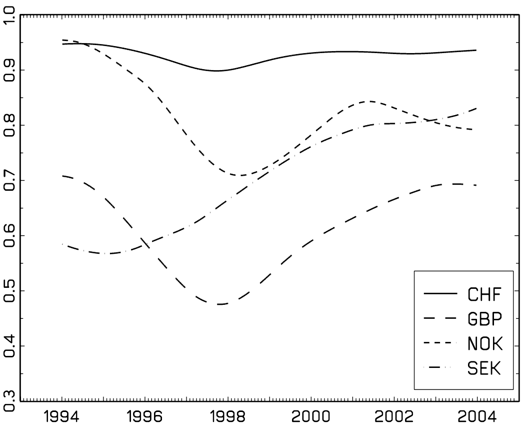
[10]The quartic kernel takes the following form: $K(u) = \frac{15}{16}(1-u^2)^2 I(|u| \leq 1)$. For practical purposes the choice of the kernel function is almost irrelevant for the efficiency of the estimate (Fan and Gijbels, 1996).



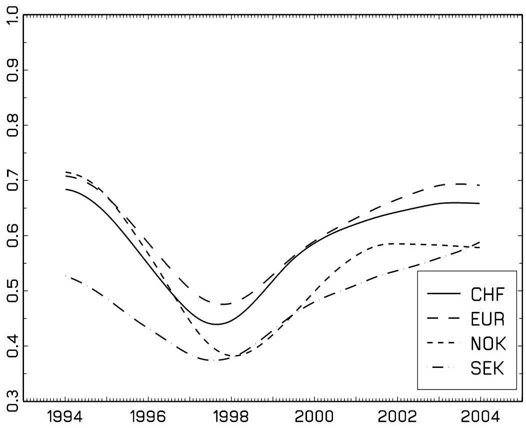
(a) Volatilities



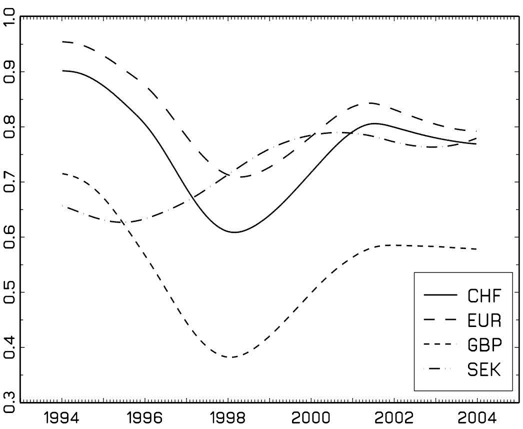
(b) CHF



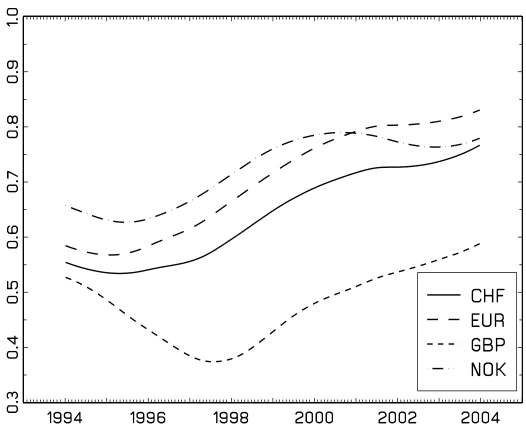
(c) EUR



(d) GBP



(e) NOK



(f) SEK

Figure 5.1: Nonparametric volatility estimates (panel (a)) and correlation estimates (panels (b)-(f)) for daily exchange rate returns over the period January 1, 1994-December 31, 2003, obtained from (5.1) using a quartic kernel function with bandwidth $h = 1$.

after January 1999. For the CHF and GBP, the (absolute) magnitude of the skewness declined substantially after January 1999 and December 1996, respectively. For the EUR, NOK and SEK, skewness was considerably larger (in absolute value) during the second subperiod. Similar patterns are found for the kurtosis.

Turning to the correlations, when computed over the full sample period these are quite high, ranging from 0.483 for the British pound and the Swedish krona to 0.926 for the Swiss franc and the euro. Comparing the correlations during the three subperiods and inspecting panels (b)-(f) of Figure 5.1, all correlations among CHF, EUR, GBP and NOK decreased around the end of 1996, when the formal decision concerning the euro was taken and Norway changed its exchange rate intervention policy. These correlations increased again around the time of the actual introduction of the euro and the change in Norway's monetary policy to (partial) inflation targeting in January 1999. For the CHF, EUR and GBP, correlations in fact appear to have returned to their pre-1997 levels, while correlations of these currencies with the NOK remained somewhat below this initial level. Correlations of the Swedish krona with the other currencies show a different pattern, in the sense that they steadily and monotonically became higher in consecutive subperiods (except for the GBP-SEK correlation, which was lower between December 1996 and January 1999).

In the next section, the framework of dynamic conditional correlation models is described. In particular, the model is extended to allow for the possibility of structural breaks in the unconditional correlations, in order to accommodate the substantial differences in co-movement of the exchange rates documented above.

5.4 Dynamic conditional correlation models

Let r_t denote the $(N \times 1)$ vector time series of daily exchange rate returns. Assuming that r_t is conditionally normal with mean $\mu_t = (\mu_{1t}, \ldots, \mu_{Nt})'$ and covariance matrix H_t, the generic model is defined as follows:

$$r_t | \mathcal{F}_{t-1} \sim N(\mu_t, H_t), \tag{5.3}$$

where $\mathcal{F}_t$ is the information set that includes all information up to and including time t. The conditional covariance matrix H_t can be decomposed as

$$H_t = S_t R_t S_t, \tag{5.4}$$

where $S_t = \mathsf{diag}(\sigma_{1t}, \ldots, \sigma_{Nt})$ is a diagonal matrix with the conditional standard deviations σ_{it}, $i = 1, \ldots, N$, on the diagonal. The matrix R_t, with the (i,j)-th element denoted as ρ_{ijt}, is the possibly time-varying conditional correlation matrix.

It is assumed that σ_{it}^2 can be adequately described by a univariate GARCH(1,1) model (see Bollerslev, 1986), such that

$$\sigma_{it}^2 = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \beta_i \sigma_{i,t-1}^2, \tag{5.5}$$

where $\varepsilon_{it} \equiv r_{it} - \mu_{it}$, $\omega_i > 0$, $\alpha_i > 0$, $\beta_i \geq 0$ and $\alpha_i + \beta_i < 1$, for $i = 1, \ldots, N$. The unconditional volatility of the unexpected returns ε_{it} implied by the GARCH(1,1) model is equal to $\omega_i/(1 - \alpha_i - \beta_i) \equiv \overline{\sigma}_i^2$. Hence, (5.5) can be rewritten as

$$\sigma_{it}^2 = (1 - \alpha_i - \beta_i)\overline{\sigma}_i^2 + \alpha_i \varepsilon_{i,t-1}^2 + \beta_i \sigma_{i,t-1}^2. \tag{5.6}$$

For the matrix R_t the dynamic conditional correlation (DCC) model introduced by Engle (2002) is employed. A similar model has been proposed by Tse and Tsui (2002). Defining the standarized shock $z_t = S_t^{-1}\varepsilon_t$, R_t is assumed to vary according to a GARCH-type process,[11]

$$Q_t = (1 - \gamma - \delta)\overline{Q} + \gamma z_{t-1} z_{t-1}' + \delta Q_{t-1}, \tag{5.7}$$
$$R_t = Q_t^{*\,-1} Q_t Q_t^{*\,-1}, \tag{5.8}$$

where Q_t^* is a diagonal matrix composed of the square roots of the diagonal elements of Q_t, γ and δ are scalars, and $\overline{Q} = \mathsf{E}[z_t z_t']$ is the unconditional covariance matrix of standardized shocks z_t.

In order to allow for structural changes in the unconditional volatilities and unconditional correlations, it is tempting (and in fact common practice) to replace $\overline{\sigma}_i^2$ in (5.6) and $\overline{Q}$ in (5.7) by $\overline{\sigma}_{it}^2$ and $\overline{Q}_t$, respectively, and specify these in a certain (parametric) way to allow for the types of changes desired. For example, the most general model considered in the next section allows for two instantaneous breaks in both the unconditional volatilities and unconditional correlations. This might be obtained by defining $\overline{\sigma}_{it}^2$ and $\overline{Q}_t$ as

$$\overline{\sigma}_{it}^2 = \overline{\sigma}_{i1}^2 \mathtt{I}[t \leq \tau_1] + \overline{\sigma}_{i2}^2 \mathtt{I}[\tau_1 < t \leq \tau_2] + \overline{\sigma}_{i3}^2 \mathtt{I}[\tau_2 < t], \tag{5.9}$$
$$\overline{Q}_t = \overline{Q}_1 \mathtt{I}[t \leq \tau_1] + \overline{Q}_2 \mathtt{I}[\tau_1 < t \leq \tau_2] + \overline{Q}_3 \mathtt{I}[\tau_2 < t], \tag{5.10}$$

where $\mathtt{I}[A]$ is the indicator function for the event A, and τ_1 and τ_2 denote the break-points with $\tau_1 < \tau_2$. These change-points can be either fixed *a priori* or left unspecified and estimated along with the other parameters in the model.

[11] Alternative models that allow for time-varying correlations are developed in Pelletier (2006) and Silvennoinen and Teräsvirta (2005), assuming that the correlations switch back and forth between a limited number of values, according to an unobserved Markov-Switching process or according to the value of observed exogenous variables, respectively. Hafner *et al.* (2006) generalize the latter approach by combining (5.1)-(5.2) with univariate GARCH models for the conditional volatility. For a comprehensive survey of multivariate GARCH models please see Bauwens, Laurent and Rombouts (2005). An interesting alternative approach to modelling dependence and changes therein is by means of copulas, see Patton (2006) for an application to exchange rate returns.

However, it turns out that in this case $\overline{\sigma}_{it}^2$ and $\overline{Q}_t$ do not represent the unconditional volatility and unconditional correlations at time t. For example, for the unconditional volatility, this can be seen from recursive substitution for $\sigma_{i,t-1}^2$ in (5.6) with $\overline{\sigma}_i^2$ replaced by $\overline{\sigma}_{it}^2$, which renders

$$\sigma_{it}^2 = (1 - \alpha_i - \beta_i) \sum_{j=0}^{\infty} \left(\prod_{k=1}^{j} (\alpha_i z_{i,t-k}^2 + \beta_i) \right) \overline{\sigma}_{i,t-j}^2,$$

such that the unconditional volatility at time t is equal to

$$\mathsf{E}[\sigma_{it}^2] = (1 - \alpha_i - \beta_i) \sum_{j=0}^{\infty} (\alpha_i + \beta_i)^j \overline{\sigma}_{i,t-j}^2 \neq \overline{\sigma}_{it}^2.$$

In case $\overline{\sigma}_{it}^2$ is specified as in (5.9), for example, the unconditional volatility changes gradually from $\overline{\sigma}_{i1}^2$ via $\overline{\sigma}_{i2}^2$ to $\overline{\sigma}_{i3}^2$ instead of instantaneously. This can be remedied by first rewriting (5.6) as

$$\sigma_{it}^2 = \overline{\sigma}_i^2 + \alpha_i(\varepsilon_{i,t-1}^2 - \overline{\sigma}_i^2) + \beta_i(\sigma_{i,t-1}^2 - \overline{\sigma}_i^2),$$

and then generalizing this as

$$\sigma_{it}^2 = \overline{\sigma}_{it}^2 + \alpha_i(\varepsilon_{i,t-1}^2 - \overline{\sigma}_{i,t-1}^2) + \beta_i(\sigma_{i,t-1}^2 - \overline{\sigma}_{i,t-1}^2). \tag{5.11}$$

It is straightforward to see that $\overline{\sigma}_{it}^2$ in this specification indeed can be interpreted as the unconditional volatility at time t. Thus, in case $\overline{\sigma}_{it}^2$ is specified as in (5.9), for example, the unconditional volatility does exhibit instantaneous jumps at $t = \tau_1$ and τ_2. It is remarked that (5.11) effectively is an alternative representation of the Spline GARCH model developed by Engle and Gonzalo Rangel (2004).

A similar line of reasoning applies to the DCC model. Here (5.7) is first rewritten as

$$Q_t = \overline{Q} + \gamma(z_{t-1}z_{t-1}' - \overline{Q}) + \delta(Q_{t-1} - \overline{Q}),$$

and then allow for changes in the unconditional correlations by generalizing this as

$$Q_t = \overline{Q}_t + \gamma(z_{t-1}z_{t-1}' - \overline{Q}_{t-1}) + \delta(Q_{t-1} - \overline{Q}_{t-1}), \tag{5.12}$$

such that $\overline{Q}_t$ represents the unconditional correlation matrix at time t (up to scaling as in (5.8)).

The attractive feature of the DCC model is that parameter estimation can be done sequentially in three steps. First, estimate the (univariate) models for the conditional means μ_{it} for the individual series r_{it}, $i = 1, \ldots, N$. Second, use the first-step residuals $\hat{\varepsilon}_{it} \equiv r_{it} - \hat{\mu}_{it}$ to estimate the parameters in the univariate GARCH(1,1) models and to obtain estimates of the conditional variances σ_{it}^2. Third, use the standardized residuals $\hat{z}_t \equiv \hat{S}_t^{-1}\hat{\varepsilon}_t$, with $\hat{S}_t = \mathsf{diag}(\hat{\sigma}_{1t}, \ldots, \hat{\sigma}_{Nt})$, to estimate the parameters in the model for R_t.

The complete DCC model (5.6)-(5.8) contains $3N + N(N+1)/2 + 2$ unknown parameters. This number can be reduced to $2N + 2$, however, by employing volatility targeting and correlation targeting. Volatility targeting, introduced by Engle and Mezrich (1996), essentially means that $\overline{\sigma}_i^2$ in (5.6) is not treated as an unknown parameter, but is replaced by its sample analogue $\widehat{\overline{\sigma}}_i^2 = \frac{1}{T}\sum_{t=1}^{T} \hat{\varepsilon}_{it}^2$, with T denoting the sample size, in the estimation of the remaining GARCH parameters α_i and β_i in the second step. This ensures that the unconditional volatility as implied by the GARCH model equals the sample variance of the first-step residuals. Similarly, correlation targeting involves replacing $\overline{Q}$ in (5.7) with the sample covariance matrix $\frac{1}{T}\sum_{t=1}^{T} \hat{z}_t \hat{z}_t'$. This imposes the restriction that the unconditional correlations as implied by the DCC model equal the unconditional sample correlations of the standardized residuals, and reduces the number of parameters to be estimated in the third step to two, namely γ and δ. Whether or not volatility and correlation targeting can still be employed in the DCC model with breaks, as given in (5.11) and (5.12), depends on the specification of $\overline{\sigma}_{it}^2$ and $\overline{Q}_t$. In case instantaneous breaks are allowed for, as in (5.9) and (5.10), targeting is possible by replacing $\overline{\sigma}_{ij}^2$ and $\overline{Q}_j$, $j = 1, 2, 3$, with their sample analogues.

Engle and Sheppard (2001) analyse the properties of the three-step estimation procedure for the standard DCC model without breaks in the unconditional correlations. Due to the sequential estimation of the model parameters, inference becomes a nontrivial issue, as the standard errors of the correlation parameters depend on the estimates of the conditional means and variances. Engle (2002) provides general expressions for the necessary adjustments to the third step covariance matrix to take into account the uncertainty of the first and second steps. However, this does not allow for computation of quasi-maximum likelihood (QML) standard errors that are robust to the violation of the assumption of normality in (5.3), as developed in Bollerslev and Wooldridge (1992). Given that this may be relevant for the exchange rate series considered, it is decided to estimate all parameters in the model jointly, such that QML standard errors can be obtained. This is not problematic given that the dimension of exchange rate series considered is reasonably small ($N = 5$), that one can use simple models for the conditional mean μ_t, and that both volatility targeting and correlation targeting are employed whenever possible.[12,13]

[12]Note that in this case $\hat{\varepsilon}_{it}$ and $\hat{z}_t$ change at each iteration of the nonlinear optimization procedure such that the unconditional sample volatilities and correlations need to be updated during the estimation process.

[13]The derivation of standard errors of the unconditional covariance matrix that is used for correlation targeting has not been worked out yet, at least not in analytic form. In the univariate context of volatility targeting in a GARCH(1,1) model, Kristensen and Linton (2004) propose to use a Newey-West type estimator; it is conjectured that such estimator could also be used in the multivariate context, although its convergence rate is quite slow. Improvement of this approach is left open for future research.

5.5 Empirical results

The DCC model discussed in the previous section is estimated for the five-dimensional vector of daily exchange rate returns, $r_t = (\text{CHF}_t, \text{EUR}_t, \text{GBP}_t, \text{NOK}_t, \text{SEK}_t)'$.[14] To determine an appropriate specification for the conditional mean μ_t, the analysis start out with testing for cointegration among the exchange rates, but no evidence is found thereof. In addition, none of the exchange rate returns series exhibits significant autocorrelation, such that μ_t is set equal to a constant, that is $\mu_t = \mu$ for $t = 1, \ldots, T$.[15]

Ten different models with structural changes in volatilities and correlations are estimated, by varying the number, the type and the location of the breaks. First, the standard DCC model without breaks as given in (5.6)-(5.8) is estimated. Second, six models with a single break in the unconditional volatilities only, in the unconditional correlations only, or in both are estimated, with the change occurring either at December 15, 1996 or at January 1, 1999. That is, the model (5.8) with (5.11) and (5.12) are considered, where $\overline{\sigma}^2_{it}$ and $\overline{Q}_t$ are either constant or specified as $\overline{\sigma}^2_{it} = \overline{\sigma}^2_{i1}\mathtt{I}[t \leq \tau] + \overline{\sigma}^2_{i2}\mathtt{I}[\tau > t]$ and $\overline{Q}_t = \overline{Q}_1\mathtt{I}[t \leq \tau] + \overline{Q}_2\mathtt{I}[\tau > t]$. Third and finally, three models with two instantaneous breaks occurring at both these dates, and affecting only the unconditional volatilities as in (5.9), or only the unconditional correlations as in (5.10), or both, are estimated. For all ten specifications, the corresponding constant conditional correlation (CCC) model of Bollerslev (1990), which sets $Q_t = \overline{Q}_t$ for all t in (5.12) or, equivalently, $R_t = \overline{R}_t$ for all t in (5.4) are also estimated.

Table 5.2 summarizes the estimation results, by showing the log-likelihood values for the CCC and DCC models, together with the estimates of the parameters γ and δ governing the correlation dynamics in the DCC model (5.12).

The analyses lead to several interesting conclusions. First, conditional correlations are time-varying, given the very large differences between the log-likelihood values of the DCC models and their CCC counterparts, irrespective of the specification of the unconditional volatilities and correlations. For example, in the most general specification with two breaks in both $\overline{\sigma}^2_{it}$ and $\overline{Q}_t$, the log-likelihood increases by 170 points from –4962 to –4792, which, after applying a formal test using likelihood ratio statistics, is statistically significant.

Second, allowing for structural breaks in unconditional volatilities and correlations considerably improves the fit of the model. Comparing the log-likelihood values for models with a single break, it appears that for both unconditional volatilities and correlations the most important change occurred in December 1996. The log-likelihood values of

[14]The analysis was also performed using bivariate models for all possible exchange rate pairs. This led to qualitatively and quantitatively similar results.

[15]In all estimated models, as many structural changes in μ as there are breaks in the unconditional volatilities and correlations are allowed, which will be discussed below.

Table 5.2: Estimated DCC models for daily exchange rate returns

Model	$\mathcal{L}$(CCC)	$\mathcal{L}$(DCC)	γ	δ
NB	-5448.70	-4931.56	0.025	0.968
			(0.003)	(0.005)
SBV(12-15-1996)	-5426.94	-4907.17	0.025	0.967
			(0.003)	(0.005)
SBV(12-31-1998)	-5446.54	-4921.80	0.025	0.968
			(0.003)	(0.005)
SBC(12-15-1996)	-5112.37	-4850.85	0.024	0.956
			(0.004)	(0.009)
SBC(12-31-1998)	-5332.24	-4925.56	0.024	0.967
			(0.003)	(0.006)
SBVC(12-15-1996)	-5091.68	-4834.65	0.024	0.956
			(0.004)	(0.008)
SBVC(12-31-1998)	-5322.70	-4919.07	0.024	0.966
			(0.003)	(0.006)
TBV	-5422.66	-4899.00	0.025	0.967
			(0.003)	(0.005)
TBC	-4991.13	-4816.42	0.023	0.948
			(0.004)	(0.012)
TBVC	-4961.64	-4792.73	0.023	0.947
			(0.004)	(0.012)

Note: The table reports estimation results of of CCC and DCC models for daily exchange rate returns over the period January 1, 1994-December 31, 2003. NB denotes the model with no structural breaks; XBV (XBC) denotes models with structural breaks in the unconditional volatilities (correlations) and no breaks in the unconditional correlations (volatilities); XBVC denotes models with structural breaks in both the unconditional volatilities and in the unconditional correlations; X=S or T depending on whether a single (S) or two (T) structural breaks are allowed for. $\mathcal{L}$(CCC) and $\mathcal{L}$(DCC) denote the log-likelihood values of the CCC and DCC models, respectively. Point estimates of the parameters γ and δ in the DCC model (5.12) are given, with Bollerslev-Wooldridge type QML standard errors given in parentheses.

the models with two breaks in turn are considerably higher than those of the one-break models, suggesting that allowing for two structural changes is warranted.

A series of formal tests using likelihood ratio statistics are conducted. For instance, the log-likelihood of the DCC model with *two* structural breaks in both types of structural change is equal to –4792.73 compared to –4919.07 with *one* structural break in both types of structural change and –4931.56 with no structural break. It is remarked that all improvements in fit due to allowing for one and two structural breaks in both unconditional volatilities and correlations are statistically significant.

Third, based on the log-likelihood values, structural changes in unconditional correlations appear to be more important than breaks in unconditional volatilities. The log-likelihood of the DCC model with two breaks in $\overline{Q}_t$ is equal to –4816, compared to –4899 for the DCC model with two breaks in $\overline{\sigma}_{it}^2$. The same is suggested by the estimates of the GARCH parameters α and β given in Table 5.3, and the estimate of $\overline{\sigma}_{it}$ in the DCC model with two breaks in unconditional volatilities and correlations shown in Figure 5.2, together with the estimated conditional standard deviations (in annualized percentage points). The GARCH parameter estimates hardly change when incorporating volatility breaks in the model, while the changes in the unconditional volatility are relatively small. An exception is the unconditional volatility of the Norges krone, which increased by about 50% at the end of 1996 due to the change in the intervention policy of Norges Bank.

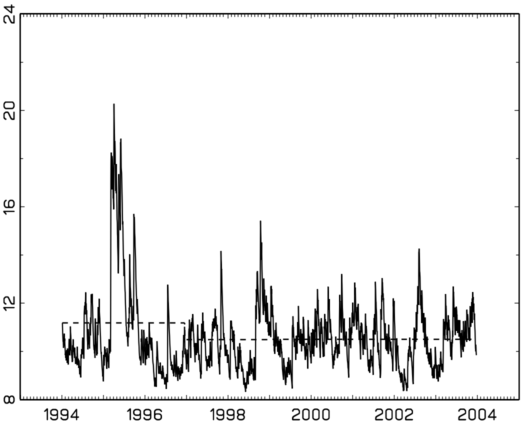
Another series of formal tests using likelihood ratio statistics are performed. As a result, both types of structural change appear to be relevant, as the model with break(s) in *both* unconditional volatilities and unconditional correlations substantially improves the fit compared to the models with break(s) in *just one of the two*. For instance, the log-likelihood of the DCC model with both types of structural change in December 12, 1998 is equal to –4919.07, compared to –4921.80 with structural change in volatilities only and –4925.56 in correlation only. Similarly, the log-likelihood of the DCC model with both types of structural change in December 15, 1996 is equal to –4834.65, compared to –4907.17 with structural change in volatilities only and –4850.85 in correlation only. It is again remarked that all improvements in fit due to allowing for breaks in unconditional volatilities and correlations mentioned above are statistically significant.

Fourth, allowing for structural breaks in correlations decreases the persistence of conditional correlations, as measured by $\gamma + \delta$. The estimate of δ declines if breaks are included, while the estimate of γ is virtually unchanged. The reduction in the estimate of δ from 0.968 in the standard DCC model to 0.947 in the model with two breaks in volatilities and in correlations may not appear to be all that large, but it does imply a substantial decline in persistence of shocks ε_t to the conditional correlations. Specifically, the half-life of shocks to the conditional correlations, computed as $\ln(0.5)/\ln(\hat{\gamma} + \hat{\delta})$, is reduced from 95 to 23 days.

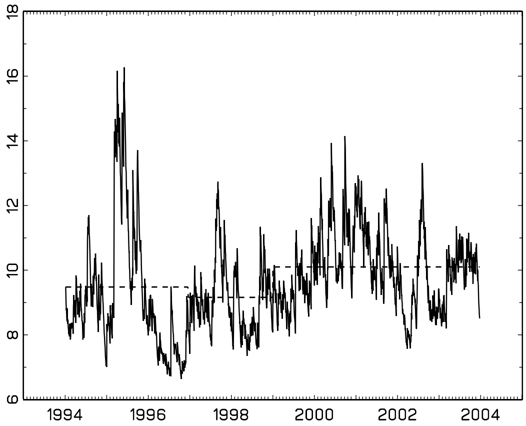
Table 5.3: Estimated GARCH(1,1) models for daily exchange rate returns

Currency	NB		SBVC(12-15-1996)		TBVC	
	α_i	β_i	α_i	β_i	α_i	β_i
CHF	0.047	0.928	0.046	0.922	0.044	0.922
	(0.009)	(0.016)	(0.010)	(0.020)	(0.009)	(0.022)
EUR	0.047	0.935	0.046	0.931	0.044	0.930
	(0.008)	(0.014)	(0.010)	(0.019)	(0.009)	(0.019)
GBP	0.046	0.919	0.048	0.910	0.049	0.904
	(0.011)	(0.024)	(0.012)	(0.026)	(0.011)	(0.027)
NOK	0.058	0.927	0.050	0.927	0.046	0.930
	(0.016)	(0.023)	(0.015)	(0.026)	(0.012)	(0.024)
SEK	0.038	0.949	0.034	0.952	0.033	0.955
	(0.007)	(0.012)	(0.014)	(0.014)	(0.007)	(0.013)

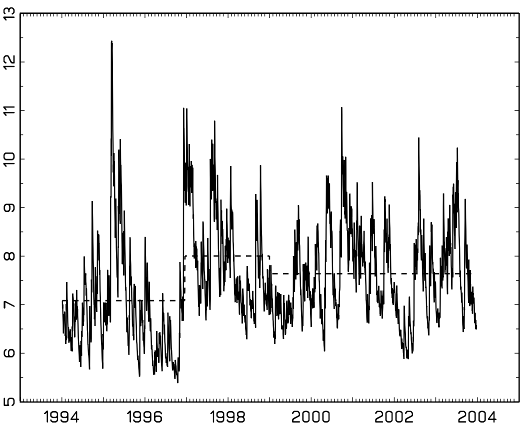
Note: The table reports estimates of the GARCH parameters α_i and β_i in the DCC model with no structural breaks (NB), and in the DCC models with a single and two structural breaks in the unconditional volatilities and unconditional correlations (SBVC and TBVC). Bollerslev-Wooldridge type QML standard errors are given in parentheses.



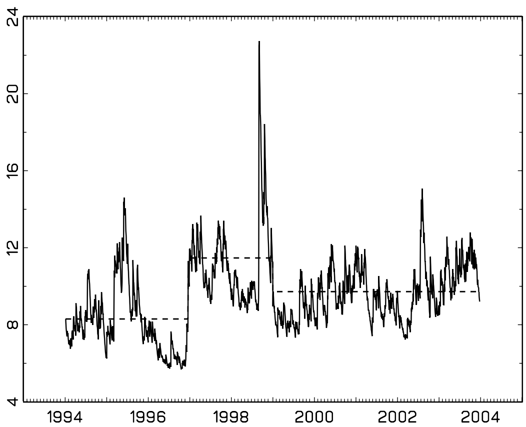
(a) CHF



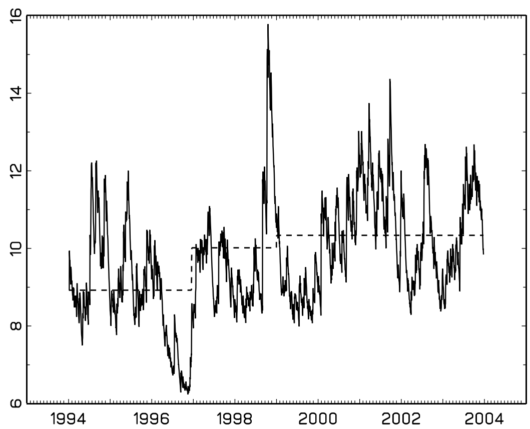
(b) EUR



(c) GBP



(d) NOK



(e) SEK

Figure 5.2: Conditional volatilities of daily exchange rate returns in GARCH(1,1) model with breaks in unconditional volatilities occurring at December 15, 1996 and January 1, 1999 (solid line). Dashed lines are unconditional variances.

Fifth, and perhaps most interesting, the DCC model with two breaks in unconditional volatilities and correlations confirms that the unconditional correlations were substantially lower between December 1996 and January 1999. This can be seen from Figures 5.3-5.5, displaying the estimated conditional correlations from this DCC model together with the corresponding elements of $\overline{Q}_t$.

A striking finding in this study is that lower exchange rate correlations between the formal decision to proceed with the euro and its actual introduction are found. An explanation is offered as follows. The Dublin meeting in December 1996 provided crucial information as to which countries committed themselves to take further steps towards economic and monetary unification. On the one hand, this event was perceived as a positive signal that the euro project was really moving towards success. According to the euro-advocates, the birth of the single currency was a matter of 'when', and not 'if'.

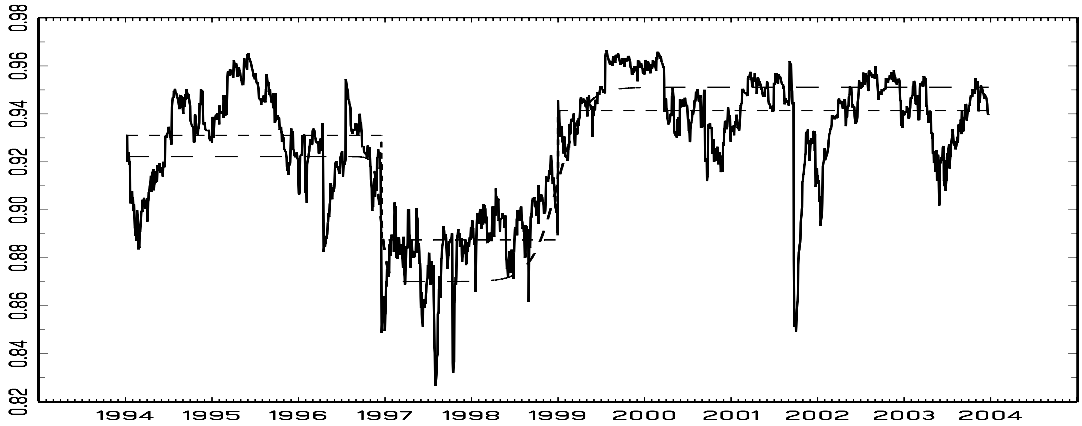
On the other hand, the exclusion of the UK, Sweden and Denmark with their relatively recent impressive economic and monetary records raised some doubts about the ultimate success of the euro project. This negative view was particularly shared by those already skeptical of the idea of a single currency, believing that joining euro would further constrain growth of the participating countries, and therefore the euro should and would never come into existence.

These two camps, the euro-advocates and the euro-skeptics, which had polarized already before the decision on ERM II, were then even more divided. This situation had resulted in more disparate expectations held by both policy makers, who regards exchange rates as among their tools in conducting monetary policy, and investors, who incorporates European currencies in their portfolios.

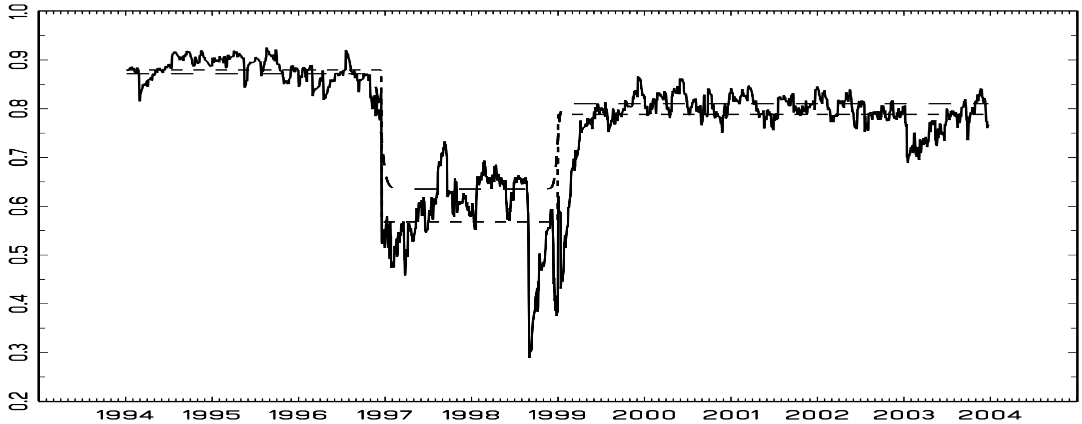
In turn, these dissenting opinions on the certainty of the birth of euro had led to more heterogeneity in the monetary decisions taken by governments/central banks and in the financial decisions by investors which related to exchange rates of European countries. Consequently, the correlations among currencies of European countries, regardless of whether they are in or out of ERM II, were weakened after the decisions made at the EC meeting in Dublin. Thus, in a nutshell, the increased heterogeneity of expectation of investors and policy-makers in foreign exchange markets during the intervening period, about whether euro would come into existence, is responsible for the breakdowns of exchange rates correlations.

More heterogenous expectations in the market are associated with lower correlations of exchange rates under consideration simply because various different expectations would lead to divergent exchange rates trading strategies by market participants and this would result in more random movements of the exchange rates, hence lower correlations among the exchange rates.

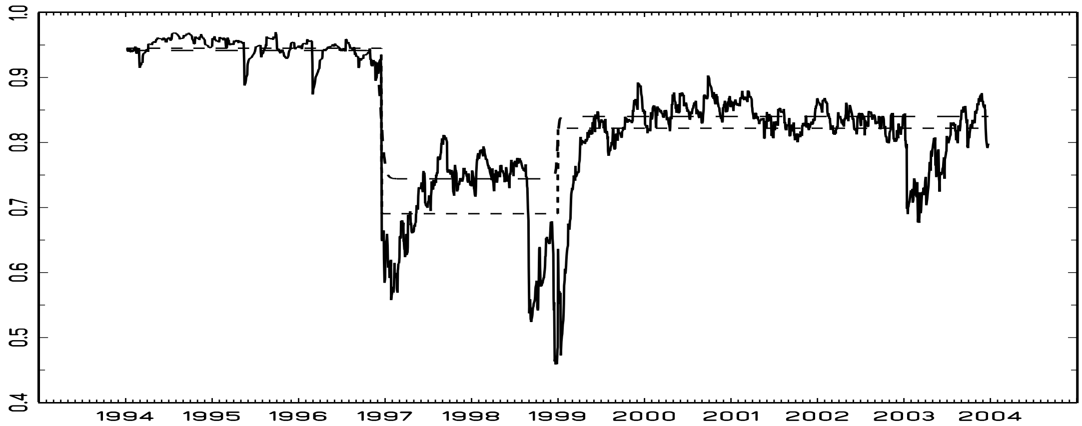
Ultimately, the formal euro introduction on January 1, 1999 confirmed that the EMU was indeed a viable project. After the euro launch, opinions among market participants



(a) CHF-EUR

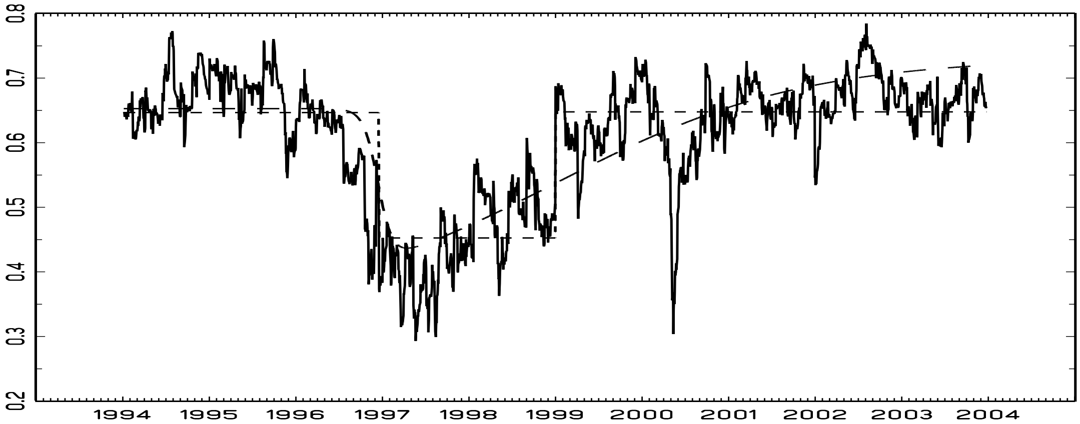


(b) CHF-NOK

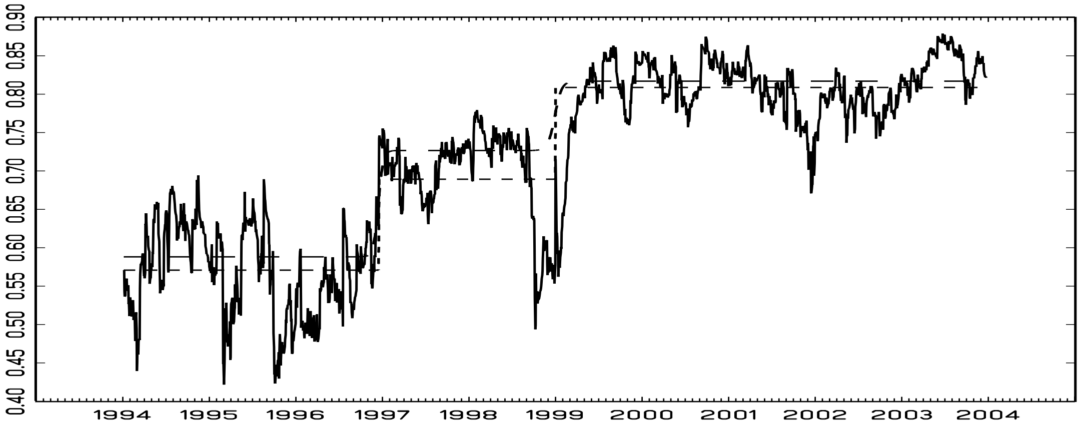


(c) EUR-NOK

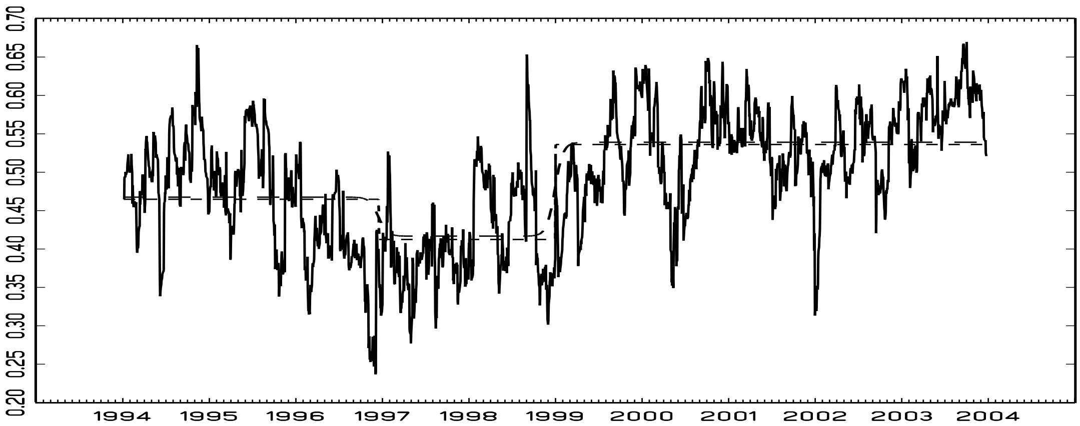
Figure 5.3: Dynamic conditional correlation between daily exchange rate returns in DCC model with breaks in unconditional volatilities and unconditional correlations occurring at December 15, 1996 and January 1, 1999 (solid line). Short-dashed lines are unconditional correlations. Long-dashed lines are unconditional correlations in bivariate smooth transition DCC models.



(a) EUR-GBP

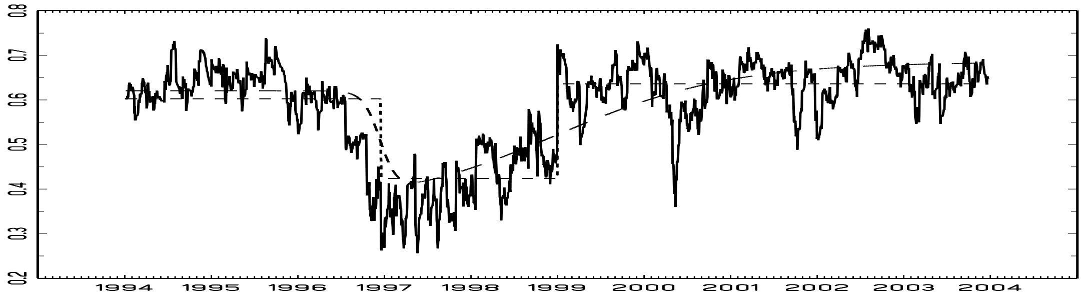


(b) EUR-SEK

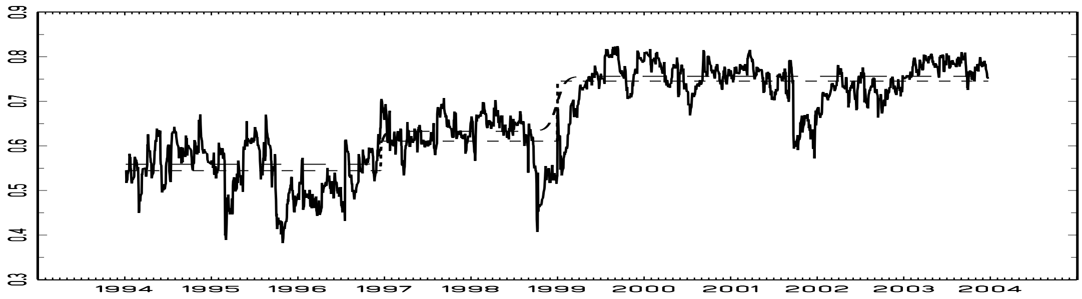


(c) GBP-SEK

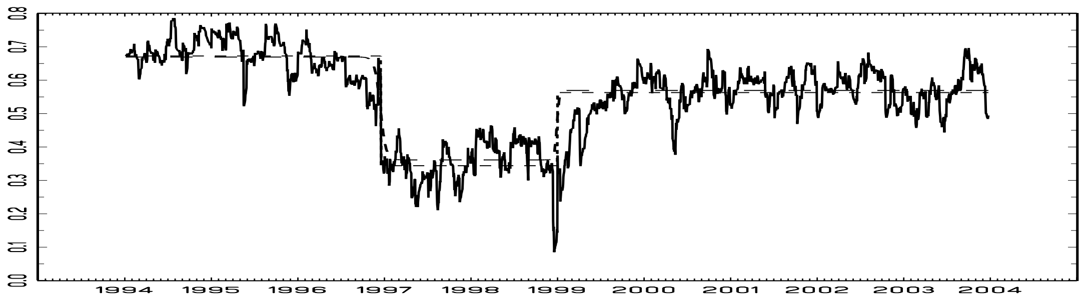
Figure 5.4: Dynamic conditional correlation between daily exchange rate returns in DCC model with breaks in unconditional volatilities and unconditional correlations occurring at December 15, 1996 and January 1, 1999 (solid line). Short-dashed lines are unconditional correlations. Long-dashed lines are unconditional correlations in bivariate smooth transition DCC models.



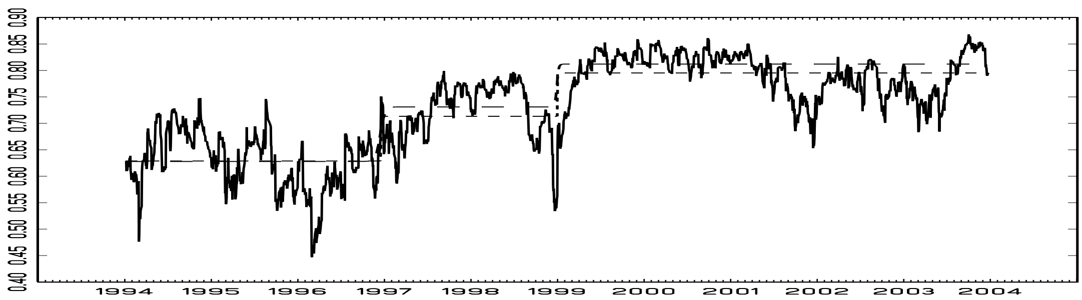
(a) CHF-GBP



(b) CHF-SEK



(c) GBP-NOK



(d) NOK-SEK

Figure 5.5: Dynamic conditional correlation between daily exchange rate returns in DCC model with breaks in unconditional volatilities and unconditional correlations occurring at December 15, 1996 and January 1, 1999 (solid line). Short-dashed lines are unconditional correlations. Long-dashed lines are unconditional correlations in bivariate smooth transition DCC models.

and policy makers on the euro became more homogenous as the uncertainty of the euro existence had been resolved. As a result of such more homogenous expectation, the monetary and financial decisions related to the euro and non-euro currencies taken by central banks and investors were more concerted compared to those taken during the intervening period. Therefore the correlations among euro and non-euro currencies were strengthened again.[16,17]

The results suggesting that all correlations are substantially increased upon the introduction of the euro may also be attributed to the expected benefits from increasing monetary and financial integration in the euro. These benefits are (at least) twofold. First, the elimination of exchange rate risk is expected to provide more certainty to manufacturing and exporting firms on imported material costs and on export revenues, respectively. This might be expected to increase aggregate production and trade within euro area countries.[18] Second, the single currency also ensures the existence of a stable monetary aggregate, which is vital for the ECB's success in monetary policy implementation. ECB's task is to optimally manage interest rates to influence real economic variables. Without a stable monetary aggregate, the ECB's monetary policy transmission mechanism will be ineffective. The euro introduction has created an integrated money market in the euro area and as a result, the existence of only one risk-free market rate stabilizes the monetary aggregate.[19] Having recognized the potential benefits of euro for countries adopting the currencies, countries outside the euro zone (e.g. Norway, Sweden, Switzerland and U.K) may wish to gain maximum positive spill-overs by keeping their currencies more in line with the euro, explaining the increased correlations after January 1999.

[16] On the importance of heterogeneity of expectation in foreign exchange markets, see Bollerslev (1990), Lyons (1991, 1996) and Taylor and Allen (1992). For other asset markets, see Easley and O'Hara (1992) and Loretan and English (2000).

[17] This study differs from a 'news' impact analysis, which is usually conducted using of an event study, in several respects. First, in this study the focus is on the second moment, namely, volatility and correlation while in a 'news' analysis the focus is on the first moment (e.g. an appreciation of a stock price). Second, here two closely related events are involved, one in December 1996 and another in December 1999 while a normal 'news' by definition consists of only *one* event. Third, although both events are closely related, reactions from market participants after the first event occured were not expected to be identical. The expectations of whether the second event would occur are heterogeneous. Such more heterogenous expectations then translated into *unconcerted* monetary and financial decision makings on exchange rates under consideration. On the contrary, in a normal 'news' one can expect homogeneous reactions from the market in the sense that the direction of movement of the market after the 'news' is revealed is predictable (e.g. an IPO announcement would lead to an appreciation of the stock price). In current study, only after the second event have occurred that the ultimate uniform responses can be concluded.

[18] See for instance Micco *et al.* (2003) and Bun and Klaassen (2004)

[19] See for instance Zestos (2005).

Another explanation of the uniform increase of correlations among the different exchange rates relates to cross-border contagion in the banking sector, that is the transmission of idiosyncratic shocks affecting one bank or a group of banks in a given country to other (groups of) banks in other countries. Gropp and Vesala (2004) provide empirical evidence that the euro introduction has increased the relevance of such contagion effects, both among euro-area countries as well as between euro-area and non-euro countries. The integrated money market denominated in the common currency stimulates international transactions, especially among major banks that have good information and low transaction costs. Cross-border links among banks in different (euro-area and outside) countries are therefore strengthened and hence contagion becomes more prevalent and significant. Such stronger contagion may well have resulted in the increased correlations among the euro and non-euro currencies.

In addition to the sizeable breaks in the unconditional correlations, several large swings in the conditional correlations stand out in Figures 5.3-5.5. For example, the CHF-EUR conditional correlation declined substantially during the third quarter of 1997. This might be related to the Asian financial crises, particularly the resulting massive capital flight from individuals in affected countries to Swiss bank accounts. Swiss banks of course have a strong reputation worldwide as a safe haven for capital, due to their strict customer secrecy policy, among others. The fact that these unique characteristics of Swiss banks are not shared by banks in euro countries might explain why countries in the euro area did not share the Swiss experience in attracting capital from Asia during the crisis, leading to the all-time low CHF-EUR conditional correlation. A similar downward jump in the CHF-EUR conditional correlation occurred in the third quarter of 2001, presumably linked to the WTC attack on September 11 and the subsequent war on terror.

The effective exchange rate of the British pound against the U.S. dollar fell by around 12.5% in May 2000, completely eliminating the gains made by the pound over the previous six months. Apart from the period when the British pound left the ERM in 1992, this was the largest one-month change in its exchange rate against the U.S. dollar since 1986. As this depreciation was not shared by other currencies, the correlations between the British pound and all other currencies dropped off substantially around that time.

Notable declines are also observed in the correlations involving the Norwegian krone in 1998. These declines are obviously related to the financial crises in Asia, Russia and Brazil, which severely affected Norway due to its heavy reliance on oil and gas exports. Weaker global demand contributed to a sharp fall in commodity prices including oil, which in turn worsened Norway's terms of trade and led to a substantial depreciation of the krone exchange rate; see also Akram (2004) for recent evidence on the sensitivity of the krone to the oil price. The Norwegian krone was down sharply from around 101 against the ECU at the beginning of 1998 to 115 in October, the weakest rate since the objective of exchange rate stability against the ECU was adopted. Norges Bank responded by raising its key interest rates in several steps in 1998. These rates were first raised in March after the krone weakened against the ECU during the first three months of the year. The krone then appreciated slightly and stabilized for a period, but pressure on the krone increased again during the summer. Norges Bank responded by raising interest rates on six further occasions. Following the last increase on August 25, the deposit rate and the overnight lending rate were 8% and 10%, respectively, or 4.5 percentage points higher than at the beginning of 1998. Norges Bank intervened to support the krone for the equivalent of NOK 29 billion in the period mid-October to mid-December. It was thought necessary to defend the krone through interventions in order to prevent a self-reinforcing and unnecessary weakening of the currency. Subsequently it was realized that the fluctuations in the exchange rate actually were amplified as a result of speculation, hedging and portfolio shifts in financial markets. These unfortunate events, together with Norway's unique economic characteristics compared to other European countries, made that all NOK correlations weakened to an unusual extent.

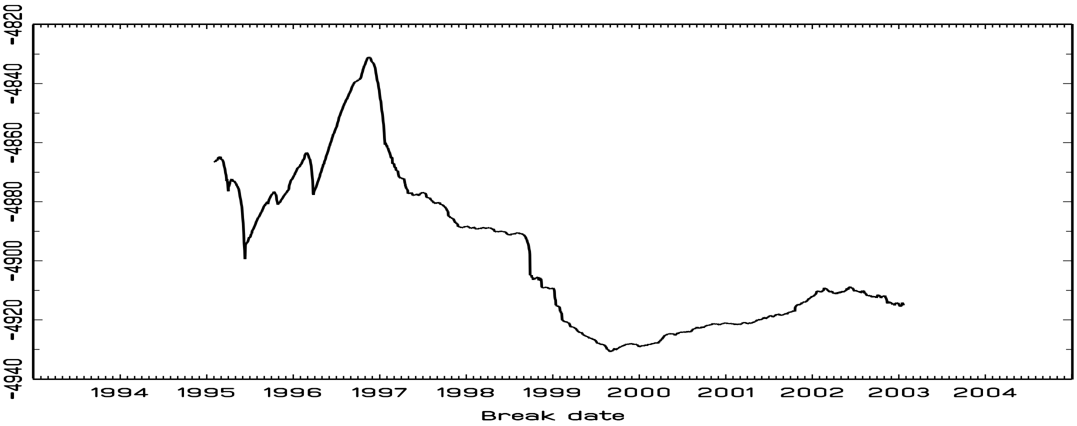
Finally, the Russian crisis and the ensuing unrest in international financial markets in the autumn of 1998 increased the risk aversion of investors and prompted a flight to safer assets and more secure currencies. This hit the Swedish krona (even though the economic fundamentals in Sweden were not bad in general), which explains the sharp declines in the correlations with the euro and Swiss franc observed in panels (b) of Figures 5.4 and 5.5.

5.6 Sensitivity analysis

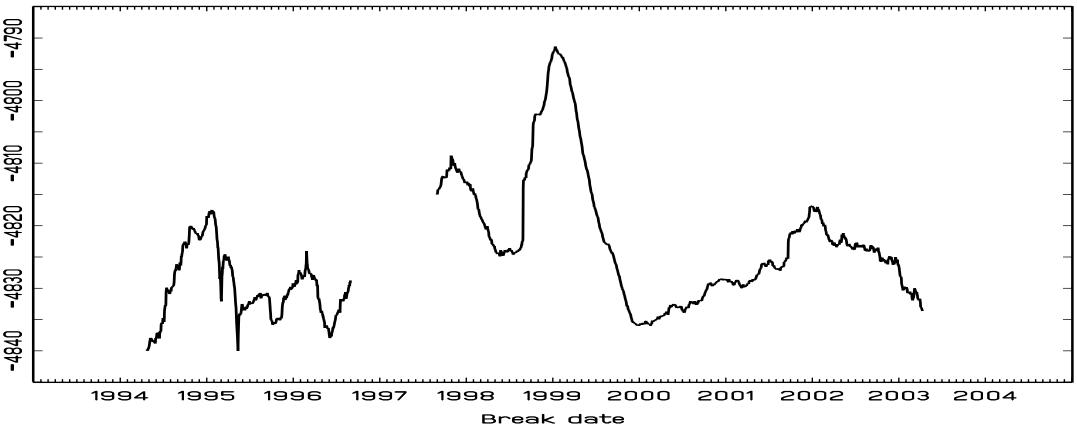
Four robustness checks are performed to validate and substantiate our empirical results as described above. First, it is examined whether *a priori* imposing the breaks in unconditional volatilities and correlations to occur at December 15, 1996 and January 1, 1999 was appropriate. On the one hand, they are obvious break date 'candidates' given the important economic events that took place at these dates. On the other hand, it may be that the volatility and correlation changes actually occurred at different points in time. In particular, the introduction of the euro was decided and announced well before January 1999 and financial market participants may have changed their behavior already before this date. An obvious alternative candidate break date is May 2, 1998, when the precise membership of the first wave of EMU was decided upon and made public. To address this issue, τ_1 and τ_2 in (5.9) and (5.10) are treated as unknown parameters or, put differently, the break dates are determined endogenously. Joint estimation of the two change-points can in principle be done by means of a two-dimensional grid search over τ_1 and τ_2, using a pre-determined set $\mathcal{T}$ of 'allowable' break dates. However, in this case this is computationally prohibitive given the complexity of the model and the length of the time series. The two break-points are therefore sequentially estimated as follows.[20] DCC models with a single break in the unconditional volatilities and correlations for all possible break-points in the inner 80% of the sample are estimated, that is between January 1, 1995 and December 31, 2002, approximately. Panel (a) of Figure 5.6 shows the resulting log likelihood values, from which it is observed that the maximum (which delivers the estimate of the break date) occurs just before December 15, 1996. Formal test statistics for a break in volatilities and correlations occurring at an unknown point in time can be constructed from this series of log likelihood values, see Andrews (1993), Andrews and Ploberger (1994), and Chu (1995). These convincingly reject the null hypothesis of no break. Next, DCC models with two breaks are estimated, fixing one of the breaks to occur at December 15, 1996 while the other break occurs at an unknown point in time, and requiring that at least 10% of the available subsamples are before and after each break. The resulting sequence of log-likelihood values in panel (b) of Figure 5.6 shows a clear maximum very close to January 1, 1999. Again, formal test statistics indicate that this second break is statistically significant. Based on the above analysis it is concluded that imposing the breaks in unconditional volatilities and correlations to occur at the time of the formal decision to proceed with the euro in December 1996 and at the time of the actual introduction in January 1999 was appropriate.

Second, one may question whether the appropriate number of breaks indeed is two, or whether more breaks should be allowed for. This issue is addressed by estimating DCC models with three breaks in unconditional volatilities and correlations. Two of the breaks are fixed to occur at December 15, 1996 and January 1, 1999, while the third break occurs at an unknown point in time, as described above. This results in the sequence of log-likelihood values shown in panel (c) of Figure 5.6. Several local maxima (and hence candidate break dates) are observed around July 1998, March 2000, and February 2002. The log-likelihood values at these points indicate a considerable improvement in fit relative to the model with two breaks. However, inspecting the resulting (un)conditional correlations, it appears that these potential third breaks are mostly currency-specific. As can also be seen from Figures 5.3-5.5, the break in July 1998 is relevant mostly for the Norwegian krone and to a lesser extent for the Swedish krona, as the correlations involving one of these two currencies experienced sharp declines. The probable cause for these large abrupt changes has been discussed before. The apparent break in March 2000 is caused by the substantial depreciation of the British pound leading to sharp but temporary declines in correlations with the other currencies, in particular with the euro and Swiss Franc. Similarly, increases in correlations of the British pound are responsible for the break in February 2002, although in addition a considerable reduction in the correlation between

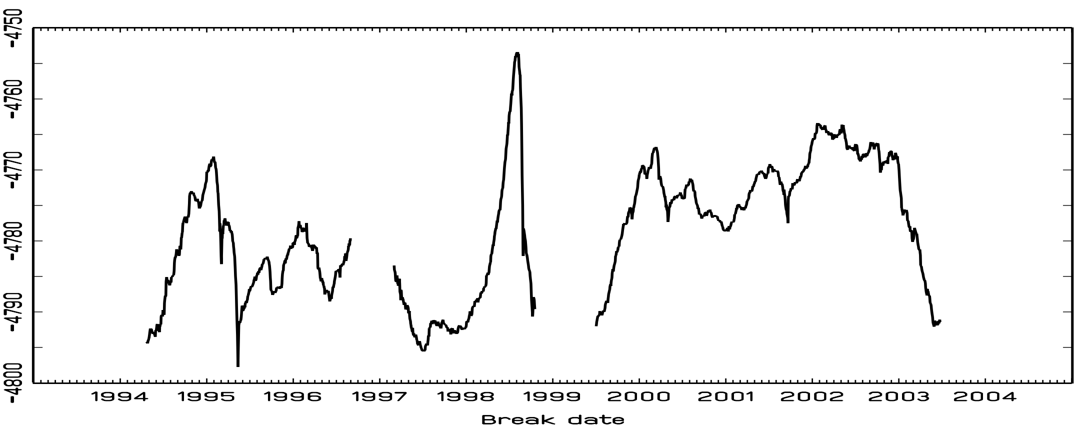
[20] Bai and Perron (1998) established the asymptotic properties of this sequential approach, demonstrating consistency and efficiency.



(a) Single break



(b) Two breaks



(c) Three breaks

Figure 5.6: Log-likelihood value for different break dates in DCC model with a single break (panel (a)), with two breaks where one of the breaks occurs at December 15, 1996 (panel (b)), and with three breaks where two of the breaks occur at December 15, 1996 and January 1, 1999 (panel (c)).

the Norwegian krone and the Swedish krona is observed around the same time. In sum, it seems that allowing for more breaks may be worthwhile, but that any such additional breaks are not common across all exchange rate pairs but rather currency-specific.

Third, it might be argued that a gradual change in unconditional volatilities and correlations may be more realistic than the instantaneous jumps that have been used so far. To explore this possibility, a DCC model with such gradual changes is estimated by specifying $\overline{\sigma}^2_{it}$ in (5.11) and $\overline{Q}_t$ in (5.12) as

$$\overline{\sigma}^2_{it} = \overline{\sigma}^2_{i1}(1 - G(t;\zeta_1,\tau_1)) + \overline{\sigma}^2_{i2}G(t;\zeta_1,\tau_1)(1 - G(t;\zeta_2,\tau_2)) + \overline{\sigma}^2_{i3}G(t;\zeta_1,\tau_1)G(t;\zeta_2,\tau_2), \tag{5.13}$$

$$\overline{Q}_t = \overline{Q}_1(1 - G(t;\zeta_1,\tau_1)) + \overline{Q}_2G(t;\zeta_1,\tau_1)(1 - G(t;\zeta_2,\tau_2)) + \overline{Q}_3G(t;\zeta_1,\tau_1)G(t;\zeta_2,\tau_2), \tag{5.14}$$

where

$$G(t;\zeta_j,\tau_j) = (1 + \exp(-\zeta_j(t - \tau_j)))^{-1}, \qquad \zeta_j > 0, \tag{5.15}$$

$j = 1, 2$, are logistic functions that change from 0 to 1 as t increases. The parameter ζ_j determines the smoothness of the change, with larger values of ζ_j implying faster transitions. Note that if $\zeta_j \to \infty$, the logistic function $G(t;\zeta_j,\tau_j)$ becomes indistinguishable from the indicator function $\mathtt{I}[t > \tau_j]$. Hence, the smooth transition DCC model nests the DCC model with discrete changes as a special case. For identification purposes, the restriction $\tau_1 < \tau_2$ is imposed, such that the unconditional correlations change from $\overline{Q}_1$ via $\overline{Q}_2$ to $\overline{Q}_3$ as time goes by.[21] An unfortunate feature of allowing for gradual changes is that volatility targeting and correlation targeting cannot be used to reduce the number of unknown parameters. Hence, the unconditional volatilities $\overline{\sigma}^2_{ij}$ for $i = 1, \ldots, N$ and $j = 1, 2, 3$ and the unconditional correlation matrices $\overline{Q}_j$, $j = 1, 2, 3$ are estimated, along with the other parameters in the model (giving a total of 57 parameters to be estimated).[22] Imposing the changes in volatilities and correlations to be centered around December 15, 1996 and January 1, 1999 as before, the resulting estimates of the smoothness parameters in the logistic transition functions (5.15) are quite large: $\hat{\zeta}_1 = 304$ and $\hat{\zeta}_2 = 165$.[23] These imply

[21]Multivariate GARCH models with smoothly changing unconditional correlations are also considered by Longin and Solnik (1995), Berben and Jansen (2005) and Silvennoinen and Teräsvirta (2005). However, in both studies, this model is developed as an extension of the CCC-model, that is DCC-type dynamics in the conditional correlations are not allowed for.

[22]In the estimation procedure, it is enforced that $\overline{Q}_t$ is a genuine correlation matrix by taking the Choleski decompositions of $\overline{Q}_j = P_jP_j'$, $j = 1, 2, 3$, where P_j is a lower triangular matrix and imposing constraints on the non-zero elements of P_j that lead to ones on the diagonal of $\overline{Q}_j$ and automatically give off-diagonal elements between –1 and 1; see Pelletier (2006) for details.

[23]The accompanying log-likelihood value is equal to −4767.56, compared to −4792.73 for the corresponding 'standard' DCC model with instantaneous changes in the unconditional volatilities and correlations.

that from start to finish the first and second changes take about three and six months, respectively. As a further check, bivariate DCC models with smooth structural changes are also estimated. For most currency pairs the changes occur quite rapidly, as can be seen from Figures 5.3-5.5 where the resulting unconditional correlations are shown. Exceptions include the correlations among the Swiss Franc, the euro and the British pound, for which the second change in unconditional correlation materializes rather gradually. Generalizing the smooth transition DCC model to allow for correlation-specific speeds of change is problematic however, as it becomes difficult to guarantee that the resulting unconditional correlation matrix $\overline{Q}_t$ in (5.14) is positive semi-definite for all t; see Silvennoinen and Teräsvirta (2005) for further discussion.

Fourth, the DCC model may be deemed restrictive in the sense that all conditional correlations among the exchange rates are assumed to follow the same dynamics as determined by the parameters γ and δ in (5.7). To examine whether this is relevant for daily exchange rate returns considered, a variant of the semi-generalized DCC (SGDCC) model developed by Hafner and Franses (2003) is estimated, which allows for asset-specific news impact parameters by replacing (5.12) with

$$Q_t = \overline{Q}_t + \gamma\gamma' \odot (z_{t-1}z'_{t-1} - \overline{Q}_{t-1}) + \delta(Q_{t-1} - \overline{Q}_{t-1}), \tag{5.16}$$

where $\odot$ denotes the Hadamard product and $\gamma = (\gamma_1, \gamma_2, \ldots, \gamma_N)'$ now is an $(N \times 1)$ vector. Hence, in this model the effect of the cross-product $z_{i,t-1}z_{j,t-1}$ on q_{ijt} (and this on the conditional correlation ρ_{ijt}) is given by $\gamma_i\gamma_j$.[24] Estimating the ten possible models with the different number, types and location of break(s), a modest improvement in the log-likelihood values and moderate differences in the coefficients γ_i are generally found across currencies. For example, allowing for two breaks in both unconditional volatilities and correlations, the log-likelihood value for the SGDCC model is equal to -4781.60, compared to -4792.73 for the corresponding 'standard' DCC model. Hence, a formal likelihood ratio statistic for testing the restrictions $\gamma_1 = \gamma_2 = \ldots = \gamma_5$ would allow rejection of the DCC model at conventional significance levels against the SGDCC alternative. The estimates of γ_i (with QML standard errors in parentheses) are equal to 0.175 (0.019), 0.181 (0.018), 0.113 (0.018), 0.171 (0.025) and 0.142 (0.019) for CHF, EUR, GBP, NOK and SEK, respectively.[25] Hence, it is concluded that there is some scope for generalizing the DCC model to allow for different dynamics in the conditional correlations, but that the standard model is sufficiently flexible to address the issue of breaks in unconditional correlations.

[24]See Cappiello *et al.* (2003) for other generalizations of the DCC model.

[25]These may be compared with the square root of the estimate of γ in the DCC model with two volatility and correlation breaks, which is equal to 0.152.

5.7 Concluding remarks

This chapter has provided convincing evidence for structural breaks in unconditional correlations between the U.S. dollar exchange rates of the British pound, Norwegian krone, Swedish krona, Swiss franc and the euro during the period 1994-2003.

Using an extension of the dynamic conditional correlation (DCC) model, this research finds that such breaks occurred both at the time the formal decision to proceed with the euro was made in December 1996 and at the time of the actual introduction in January 1999. Most correlations were substantially lower during the intervening period. The decline in correlations is attributed to increased heterogeneity of expectation in the foreign exchange markets due to diverging opinions about the viability of the euro. On the other hand, following the actual euro introduction, the strong and uniform increase of the correlations seems to have been caused by both the homogeneity of expectations among market participants concerning the involved currencies and the fact that non-euro countries recognized potential benefits related to the elimination of exchange rate risk due to the emergence of the single currency.

This study offers a new perspective concerning the behavior of multiple exchange rates which simultaneously experience an agenda of monetary integration. Other economies who may engage in a similar economic integration program can use this result to be more prepared with consequences. For general market participants, the information concerning such volatilities and correlations can be used to predict the behavior of exchange rates that follows from a similar event, and use such prediction to construct and diversify portfolios in such situation. The findings also have clear implications for financial decision making. For example, adequate currency risk management requires accurate modelling of volatility and correlation patterns of exchange rates. The analysis demonstrates that allowing for time-varying conditional volatilities and correlations by means of a standard DCC model may not be sufficient in this respect. Incorporating occasional structural breaks in unconditional volatilities and correlations may be necessary.

Chapter 6

Summary and further research

In this thesis a number of theoretical and empirical results concerning economic integration are introduced and analyzed. In this chapter the main findings of this thesis are summarized and some topics for further research are mentioned.

In Chapter 2, a specific relationship between output and factor shares is established. Such theoretical construct can be useful to describe the distribution of production among members of a presumably integrated economy. The general form of this relationship nests several relationships that relate to different assumptions concerning technology and factor mobility. If one considers identical production technology and free factor mobility, then the equal-share relationship emerges, stating that each member's share of total output of an integrated economy will equal its shares of stocks of productive factor of the integrated economy.

This result can be discussed and extended in the following ways. First, one may test the relationship using other alternative presumably integrated economies, such as among states or provinces within a particular country. In this direction, the possible issues may include availability and standardization of data, particularly the data of stocks of physical capital. Despite such issue of data quality and quantity, the equal-share relationship can always be viewed as a benchmark of an economic integration, in a sense that how close data of a group of economies are resembling such relationship can be regarded as the distance of these economies from achieving full integration.

Second, the equal-share relationship analyzed in Chapter 2 might be criticized for its lack of realism due to its assumption of constant return to scale. Many recent literatures of endogenous growth have departed from a constant return approach by considering an increasing return specification. In such study, analysis is usually performed at an industry level. However, when discussing an economy at state or national level, constant return is more plausible since one averages different scales in various industries. Nonetheless, generalizing the model to incorporate increasing return seems potentially useful.

Third, the empirical relevance of the equal-share relationship emphasizes the significance of investments in physical and human capital. However, institutional arrangements that determine such policies play a crucial role. Therefore, further research that investigates roles of institutions in characterizing the policy space of integrated economy members is called for.

Chapter 3 discusses the implication of observing the equal-share relationship on the distribution of output and factor shares among integrated economy members. Specifically, such distribution of output and factor shares would exhibit Zipf's law. This striking empirical evidence is demonstrated with respect to two presumably integrated economies: the 51 U.S. states and 14 E.U countries. The result is consistent with a model that assumes that the growth process of the shares of members of an integrated economy is random and homogeneous across members.

In Chapter 3, problems in parameter estimation together with their possible solutions are presented. On such estimation issue, Leamer and Levinsohn (1995) observe that, in the context of empirical research in international trade and factor mobility, researchers often spend much energy to see whether a theory fits perfectly. Leamer and Levinsohn argue instead that the real question should be how well a theory fits, rather than whether or not it fits exactly. Consistent with this suggestion, Chapter 3 shows that the data are typically well described by Zipf's law, and more importantly, a theoretical explanation of why this should be true is put forward.

One implication of the validity of Zipf's law is that shares of output and of any given factor across economies are proportional. And since the sum over shares of output or factor for an integrated economy is one, if the equal-share relationship holds for one economy then this relationship must also hold, in a statistical sense, for all other economies.

Although several explanations have been proposed concerning observed deviation between actual share values and their theoretical ones, further research is still required. Such research will aim to seek possible roles of various macroeconomic or institutional factors in explaining such deviation. On the other hand, more works are also needed to reconcile and to link these results with the literature on "border effect" or "home bias," for instance Engel and Rogers (1996) and Wolf (2000). Such works, claiming that intranational trade are excessive compared to international trade due to the apparent presence of formal and informal trade barriers might have certain implications on distribution of production.

In Chapter 4, the effects of capital markets integration on income inequality are analyzed. Specifically, capital markets integration alone does not seem to change the intragenerational income distribution in both capital exporting and capital importing countries. This result partly explains the seemingly persistent inequality observed in real data despite increasingly larger foreign direct investment and financial capital flow recorded. However, in the long run, intergenerational income inequality is expected to decline due to equalization of wage rate. This finding to some extent explains the reduction of income gaps in recent years between advanced countries and countries emerging from the ruins of the World War II.

Chapter 4 also discusses the significance of the process of human capital formation on social mobility in the economy. More precisely, by seriously taken into account elastic labor supply, conditions that allows for poverty trap and for positive growth of human capital to occur are derived. Such conditions turn out to depend on the time-varying levels of human capital in the economy.

Although the model in Chapter 4 has accommodated numerous important and realistic features in human capital formation and the model has also been successfully calibrated using the data of the Dutch economy, further extension is still possible. For instance, the current model assumes that labors have no specialization (i.e., perfect substitution). Although it is possible that teachers are selected randomly from the population as in this model, empirical evidence seems to suggest that the quality of instructors differ with the quality of average individuals.

In another front, recent research saw evidence that innate abilities are correlated across generations. More than half of the transfer of intergenerational ability is inherited (Plug and Vijverberg, 2003). This empirical finding clearly calls for an extension of the model that accommodates such intergenerational linkage.

Another interesting extension is to include the growing international trade in addition to capital markets integration when analyzing the consequence of various processes in human capital formation. A way to proceed is to try to enrich this model with some features from Bougheas and Riezman (2005), which analyze the effects of trade and the distribution of human capital on income distribution. Combining trades and capital mobility will surely make the model more realistic.

Chapter 5 studies the dynamics of exchange rates surrounding the introduction of euro as the common currency for the 12 E.U. countries. Large breaks in unconditional correlation among all exchange rates considered are convincingly found and such breaks occurred both at the time the formal decision to proceed with the euro was announced in December 1996 and at the time the euro was officially introduced in January 1999. Specifically, the unconditional correlations were substantially lower in the intermediate period.

The finding is attributed to increased heterogeneity in the foreign exchange markets during the intervening period and the lowering of such heterogeneity after euro was officially introduced. On the one hand, the Dublin meeting in December 1996 might have been perceived as a positive signal that the euro project was really moving toward success. On the other hand, the exclusion of the UK, Sweden and Denmark with their recent impressive economic records might have raised some doubts about the project.

This situation might have resulted in more disparate views held by both policy makers and investors. Since heterogeneity in expectations translated into divergent strategies observed in foreign exchange markets, correlations among currencies of European countries, regardless of whether they are in or out of the euro project, were weakened by the Dublin decision.

Eventually, the formal euro introduction on January 1, 1999 confirmed that the EMU was indeed a viable project. After the euro launch, opinions among market participants and policy makers on the euro became more homogenous as the uncertainty of the euro existence had been resolved. As a result of such more homogenous expectation, the monetary and financial decisions related to the euro and non-euro currencies taken by central banks and investors were more concerted compared to those taken during the intervening period. Therefore the correlations among euro and non-euro currencies were strengthened again.

From methodological point of view, the derivation of standard errors of the unconditional covariance matrix that is used for correlation targeting in this empirical work has not been established yet. As the 'solution', the approach by Kristensen and Linton (2004) who propose to use a Newey-West type of estimator in a univariate context is adopted. It is conjectured that this method can also be used in the multivariate context. Further research is required to improve this approach.

In Chapter 5 it is shown that incorporating occasional structural breaks in unconditional volatilities and correlations may be necessary in addition to allowing for time varying conditional volatilities and correlations by means of a standard DCC model. One may use this technique to investigate other interesting applications in international macroeconomics and finance, such as the 1997 Asian currency crisis involving the currencies of Indonesia, Malaysia, Philippines, Singapore, South Korea and Thailand.

Concerning the euro introduction itself, one may also be interested to expand the empirical analysis in Chapter 5 to include major stock market indices in Europe. It is generally acknowledged that both currency and stock markets can form appealing linkages, for example see Cumperayot *et al.* (2006). This topic is left for further research.

Appendix A

Data methods and sources

A.1 Data construction of output, physical capital and human capital

Both Chapter 2 and Chapter 3 use extensively data on shares of output, physical capital and human capital. For each of the 51 U.S. states, output is measured by real gross state product (GSP) as reported by the U.S. Bureau of Economic Analysis (BEA).[1] These data are available yearly from 1990 to 2000.

State physical capital stocks are estimated by multiplying estimates of the total U.S. physical capital stock per industry with an industry's contribution to the state's total income and then summing them across industries. Estimates of state physical capital stocks are derived from BEA (2002) estimates of the total U.S. physical capital stock in each of nine one-digit industrial sectors comprising all economic activity.[2] These national physical capital stocks in each industry are allocated to each state by multiplying an industry's total capital stock[3] by that industry's contribution to a state's total income.[4] These industry capital stock estimates are then summed, for each state, to obtain an estimate of a state's total stock of physical capital.[5] The calculation performed for each

[1]Data on gross state product available at `http://www.bea.doc.gov/bea/regional/gsp`.

[2]The sectors (BEA code) are Farming (81), Agricultural services, forestry, fishing & other (100); Mining (200); Construction (300); Manufacturing (400); Transportation(500); Wholesale and retail trade (610); Finance, insurance and real estate (700); and Services (800).

[3]Data on state physical capital stocks by industry were taken from U.S. Fixed Assets Tables, available at `http://www.bea.doc.gov/bea/dn/faweb`.

[4]Annual data on state value added available at `http://www.bea.doc.gov/bea/regional/spi`.

[5]This procedure follows that used by Munnel (1990) and Garofalo and Yamarik (2002).

state at each time t can be expressed algebraically as

$$k_m(t) = \sum_{j=1}^{9} \left[K_j(t) \frac{y_{mj}(t)}{Y_m(t)} \right].$$

In this equation, $k_m(t)$ is the stock of physical capital in state m, $y_{mj}(t)$ is value added by industry j in state m ($m = 1 \ldots 51$), $Y_m(t)$ is state m's total value added, and $K_j(t)$ is the national level stock of physical capital in industry j ($j = 1 \ldots 9$). This procedure assumes that the capital-to-output ratio within an industry j (i.e., $\frac{k_{mj}(t)}{y_{mj}(t)}$) is the same across U.S. states, that is, $\frac{k_{mj}(t)}{y_{mj}(t)} = \frac{K_m(t)}{Y_m(t)}$. In turn, this assumption implies that an industry is in a common steady state across all U.S. states.[6] For example, the agricultural sector in Texas is in the same steady state as its counterpart in Oregon, and the manufacturing sector in Pennsylvania is in the same steady state as its counterpart in Ohio.[7] The constructed physical capital data are from 1990 to 2000, on a yearly basis.

State human capital stocks are measured by the number of persons in the state with at least a secondary education. They are derived from data on state educational attainment taken from the U.S. Bureau of the Census.[8] Census data on educational attainment are available only every 10 years, which limited the construction of human capital stocks to two years: 1990, and 2000.

Due to missing data, complete data for U.S. states on all three variables (output, physical and human capital) are available only for 1990 and 2000, when U.S. Decennial Census were conducted. However, output and physical capital data are available for other years. Where appropriate (e.g., when computing rank correlations) we use these additional years of data.

We also consider three other economic groupings: (1) the E.U., consisting of 14 E.U. member countries (Luxembourg is excluded due to lack of data), (2) Developing Countries, consisting of 30 lower income countries and (3) the World, consisting of 55 countries for which the necessary data are available. Output of each country is derived from the data on real GDP per capita (base year = 1996) and population in Penn World Tables 6.1 (Heston, Summers and Aten, 2002). The output data are available annually from 1960 to 2000.

[6]If a sector is converging towards its steady state, the output-to-capital ratio would be below its steady-state value. This only poses a problem if the initial output-to-capital ratios vary across U.S. states. If the ratios do vary, the procedure would allocate too much to those states further from steady-state and too little to those states closer to their steady state.

[7]If a sector has a different steady state, and hence a different capital-to-output ratio, the procedure will allocate too much to states with lower ratios and too little to states with higher ratios. However, this possibility is unlikely if competition lead firms in all states to adopt the best available production technology.

[8]Decennial Census dataset available at `http://factfinder.census.gov`

Country physical capital stocks from 1965 to 1990 are those reported in the Penn World Tables 5.6 (Heston and Summers, 1991a; 1991b) which reports four data series for each country: (1) population, (2) physical capital stock per worker, (3) real GDP per capita and (4) real GDP per worker.[9] The physical capital stocks for each country are constructed as the product of the first three series divided by the last series. The data covers the period 1965-1990. Physical capital stock data for E.U. countries are also available from Timmer *et al.* (2003) covering period 1980-2000.[10,11] These two data sources are combined in order to obtain a capital stock series for E.U. countries covering 1965 to 2000.[12]

Country human capital stocks are constructed using data on secondary education attainment rate, as reported in Barro and Lee (1993, 1996, and 2000).[13] Each country's stock of human capital stock is measured by multiplying the percentage of a country's population having at least a secondary level of education with the country's total population. Data on a country's population are from Heston, Summers and Aten (2002). Since data on rates of educational attainment are only available every 5 years, the data sample was limited to five-year intervals from 1960 to 2000. Following this constraint, data on output and physical capital stocks are also restricted to the five-year intervals.

The countries comprising the World integrated economic area are: Argentina, Australia, Austria, Belgium, Bolivia, Botswana, Canada, Chile, Colombia, Denmark, Dominican Republic, Ecuador, Finland, France, Germany, Greece, Guatemala, Honduras, Hong Kong, Iceland, India, Iran, Ireland, Israel, Italy, Jamaica, Japan, Kenya, Republic of Korea, Malawi, Mauritius, Mexico, Netherlands, New Zealand, Norway, Panama, Paraguay, Peru, Philippines, Portugal, Sierra Leone, Spain, Sri Lanka, Swaziland, Sweden, Switzerland, Syria, Taiwan, Thailand, Turkey, United Kingdom, United States, Venezuela, Zambia and Zimbabwe.

The 14 E.U. countries are: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden and United Kingdom.[14] The set of 30 Developing Countries comprises: Argentina, Bolivia, Botswana, Chile, Colombia, Dominican Republic, Ecuador, Guatemala, Honduras, Hong Kong, India, Iran, Israel,

[9] At the time this chapter was written the Penn World Tables Version 6.1 did not report country physical capital stocks.

[10] Physical capital database available at `http://www.ggdc.net/dseries/growth-accounting.shtml`.

[11] The series forms the source of the OECD productivity database. See e.g., Schreyer et al. (2003).

[12] We performed estimation using both sets of data for E.U. countries and found no qualitative difference in results when data are available from both sources (1980, 1985 and 1990). The results using capital stock data from Timmer et al. (2003) will be reported during these three years.

[13] Other studies using the Barro-Lee data include Rajan and Zingales (1998), Ramey and Ramey (1995), Barro (1999), Easterly and Levine (1998), Hall and Jones (1999) and Sachs and Warner (1995).

[14] Luxembourg is excluded for lack of data on human capital. Given the small scale of Luxembourg's economy relative to other E.U. countries this omission is unlikely to affect the E.U. results.

Jamaica, Kenya, Malawi, Mauritius, Panama, Paraguay, Peru, Philippines, Sierra Leone, Sri Lanka, Swaziland, Syria, Taiwan, Thailand, Venezuela, Zambia and Zimbabwe.

A.2 Statistics of the Netherlands for simulation of the human capital formation model

In Chapter 4, a numerical simulation is performed to test the model. The deterministic equilibrium, that is, when random abilities are set to their mean, is calibrated on statistics from the Netherlands over the period 1975-2000. Data for the key variables are summarized in Table A.1.

Table A.1: Data of The Netherlands (1975-2000) taken as the baseline economy

Variable	Value
Gini coefficient, disposable income (2000)	0.325
Public education expenditure (% of GDP, 1999	5.1
Output level (1 trillion Euro, 2000)	401.089
Growth rate, real GDP per capita (%, 1975-2000)	56.94
Capital coefficient (Euro, 2000)	4.6
Employment (100 million, 2000)	69.17

Source: Central Bureau of Statistics of The Netherlands.

Table A.2: Parameters of the baseline economy

ϕ	A	β_1	β_2	υ	η
0.3	4.599	3.440	6.091	1	1
α_1	α_2	α_3	α_4	τ_{-1}	$\bar{l}_{-1}\bar{h}_{-1}$
2.537	2.537	1.3	1.6	0.051	89.61

To facilitate the analysis, the following assumptions have been made to compute the calibrated parameters which are presented in Table A.2:

Human capital. The stock of effective human capital at $t = -1$ is approximated in two steps. Total employment is first divided in 7 scholastic achievements ranging from primary school to university degree. Using the wage of each educational type relative to that of a worker with a primary school certificate as wight, the weighted sum over educational types provides proxy for the stock of effective human capital. While the actual employment in 2000 is 69.17 hundred thousand, the proxy $\bar{l}_t\bar{h}_t$ is 89.61 hundred thousand primary school equivalent workers.

Families. Thirteen heterogeneous families are considered with a human capital at $t = -1$ taking values 2.1, 2.4, 2.6, 3.0, 3.6, 4.4, 5.5, 7.3, 8.9, 11.1, 12.3, 12.7 and 13.8. Each family has an initial $\omega = A, B, ...L$ and M. These imaginary families are chosen with two criteria in mind. First, the sum of individual endowments of human capital is 89.61. Second, they have the Gini coefficient equal to 0.325, the observed Gini coefficient in 2000. The following formula for the Gini coefficient is used:

$$g_t = \frac{1}{2n(n-1)\overline{y}_t} \sum_{i=1}^{n} \sum_{j=1}^{n} |y_i - y_j| \tag{1.1}$$

where $n = 13$ represents the number of families, $\overline{y}_t$ is average income, y_i and y_j are individual incomes.

Preferences. Parameters α_1 and α_2 are selected to obtain net savinigs. Parameter α_3 is picked such that the poorest familiy A does not participate to the education process, namely $e_{-1} = 0$. Also, α_4 is chosen based on the available empirical evidence concerning leisure.

Human capital formation. Parameters β_1 and β_2 are created to obtain $e_{-1} = 0$ and to calibrate the observed growth rate of the economy.

A.3 Data explanation and sources of exchange rates

Chapter 5 studies the time-varying volatilities an correlations of various exchange rates in a multivariate framework. Specifically, daily U.S. dollar exchange rates of the Swiss franc (CHF), euro (EUR), British pound (GBP), Norwegian krone (NOK), and Swedish krona (SEK) over the period from January 1, 1994 (the start of Stage Two of EMU) until December 31, 2003 (2512 observations) are considered. Up to December 31, 1998, the euro series actually concerns the exchange rate of the German Deutschmark, while the euro is used as of January 1, 1999.

Although the German Deutschmark undoubtedly was the single most important currency in the Eurozone before 1999, it may not be completely representative of exchange rate developments in the euro countries. An alternative would be to use the ECU instead of the Deutschmark for the pre-euro period. This possibility is not considered, however, for the fact that the British pound and Swedish krona were part of the ECU. This obviously may influence results, in particular those pertaining to the correlations of these currencies with the "euro". The data is obtained from the Federal Reserve Bank of New York and concerns noon buying rates in New York.

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Nederlandse samenvatting (Summary in Dutch)

Het onderzoek in dit proefschrift kan ruwweg worden beschreven door drie kernbegrippen: economische integratie, de vorming van menselijk kapitaal en de dynamiek van wisselkoersen.

In Hoofdstuk 2 wordt een specifieke relatie tussen productie en factor aandelen aangetoond. Dit kan nuttig zijn om de verdeling van productie over leden van een verondersteld geïntegreerde economie te beschrijven. De algemene vorm van de relatie tussen productie en factor aandelen bevat verscheidene andere relaties die betrekking hebben op verschillende aannames over technologie en factor mobiliteit. Als men bijvoorbeeld uitgaat van een identieke productie technologie en vrije factor mobiliteit, dan verschijnt de "gelijk aandeel"relatie, die stelt dat het aandeel in totale productie van elk lid van een geïntegreerde economie gelijk zal zijn aan zijn aandeel in the voorraad productieve factor van de geïntegreerde economie.

Dit resultaat kan op de volgende manieren worden besproken en uitgebreid. Ter eerste kan men de bovenstaande relatie testen door gebruik te maken van een verondersteld geïntegreerde economie, zoals bijvoorbeeld het geval is tussen provincies van een land. Een probleem hierbij kan de beschikbaarheid en standaardisatie van data zijn, in het bijzonder data over de voorraad fysiek kapitaal. Ondanks deze mogelijke problemen betreffende de kwaliteit en kwantiteit van data kan de "gelijk aandeel" relatie altijd worden gezien als referentiepunt voor economische integratie, en hoe goed de data van een groep economische eenheden deze relatie weergeeft kan worden gezien als de afstand van deze economische eenheden tot volledige integratie.

Ter tweede kan de "gelijk aandeel" relatie die wordt geanalyseerd in Hoofdstuk 2 worden bekritiseerd vanwege het gebrek aan realisme dat veroorzaakt wordt door de aanname van constante schaalopbrengsten. Veel recente literatuur betreffend endogene groei is afgeweken van de constante schaalopbrengsten aanname en gebruikt in plaats daarvan de aanname van toenemende schaalopbrengsten. In deze literatuur wordt de analyse gewoonlijk uitgevoerd op het bedrijfstak niveau. Wanneer men echter een economie op provincie of nationaal niveau analyseert is de aanname van constante schaalopbrengsten meer aannemelijk aangezien men op zo'n niveau de schaalopbrengsten in verschillende bedrijfstakken middelt. Desalniettemin kan het nuttig zijn om het model te generaliseren zodat het ook toenemende schaalopbrengsten kan bevatten.

Ten derde benadrukt de empirische relevantie van de "gelijk aandeel" relatie het belang van investeringen in fysiek en menselijk kapitaal. Hier speelt de institutionele inrichting van een economie die deze investeringen bepaalt een cruciale rol. Daarom is verder onderzoek nodig naar de rol van deze institutionele inrichting in de leden van een geïntegreerde economie.

Hoofdstuk 3 bediscussieert de gevolgen van de "gelijk aandeel" relatie voor de verdeling van productie en factor aandelen onder leden van een geïntegreerde economie. Meer specifiek, zo'n verdeling van productie en factor aandelen in een volledig geïntegreerde economie zou moeten voldoen aan Zipf's wet. Dit opmerkelijke empirische feit wordt aangetoond voor twee verondersteld geïntegreerde economieën: de 51 staten van de VS en 14 EU landen. Het resultaat is consistent met een model dat aanneemt dat het groeiproces van de aandelen van leden van een geïntegreerde economie random is en homogeen over leden.

In Hoofdstuk 3 worden problemen met de schatting van parameters en mogelijke oplossingen behandeld. Met betrekking tot dit onderwerp observeren Leamer en Levinsohn (1995) dat in de context van empirisch onderzoek naar internationale handel en factor mobiliteit onderzoekers veel energie besteden aan het bepalen of een theorie precies passend is. Leamer and Levinshon beargumenteren dat de vraag die werkelijk gesteld zou moeten worden is hoe goed een theorie past, in plaats van of hij precies past of niet. In lijn met deze aanbeveling stelt Hoofdstuk 3 vast dat de data over het algemeen goed worden beschreven door Zipf's wet en nog belangrijker, een theoretische verklaring waarom dit zo is wordt gegeven.

Een gevolg van het opgaan van Zipf's wet is dat aandelen in productie en factoren proportioneel zijn. En aangezien de som over aandelen in productie of factoren voor een geïntegreerde economie gelijk is aan één, als de "gelijk aandeel" relatie geldt voor één economie dan moet deze relatie in statistisch opzicht ook gelden voor alle andere economieën.

Hoewel verschillende verklaringen worden voorgesteld betreffend geobserveerde verschillen tussen werkelijke en theoretische aandelen is verder onderzoek nodig. Dit onderzoek zou de verschillen kunnen proberen te verklaren met behulp van verschillende macro-economische of institutionele factoren. Aan de andere kant is verder werk nodig om de resultaten van Hoofdstuk 3 in overeenstemming te brengen met en te linken aan de literatuur over grenseffecten en thuisvoordeel, zie bijvoorbeeld Engel en Rogers (1996) en Wolf (2000). Deze literatuur, die claimt dat intranationale handel te omvangrijk is in vergelijking met internationale handel vanwege de aanwezigheid van formele en informele handelsbarrières, kan gevolgen hebben voor de verdeling van productie.

In Hoofdstuk 4 worden de effecten van kapitaalmarktintegratie op inkomensongelijkheid geanalyseerd. Kapitaalmarktintegratie alleen blijkt niets te veranderen aan de inkomensverdeling binnen een generatie, in zowel kapitaal exporterende als kapitaal importerende landen. Dit resultaat verklaart gedeeltelijk de aanhoudende ongelijkheid die ondanks toenemende buitenlandse directe investeringen en de toenemende stroom financieel kapitaal uit data blijkt. Op de lange termijn echter wordt verwacht dat inkomensongelijkheid bij iedere generatie zal afnemen door nivellering van de lonen. Dit resultaat verklaart in zekere mate de recente verkleining van de inkomenskloof tussen geavanceerde landen en landen die uit de tweede wereldoorlog komen.

Hoofdstuk 4 bespreekt ook het belang van de vorming van menselijk kapitaal voor sociale mobiliteit in de economie. Meer precies, rekening houdend met een elastisch aanbod van arbeid wordt een voorwaarde afgeleid die zowel een armoedeval als positieve groei van menselijk kapitaal toestaat. Deze voorwaarde blijkt af te hangen van de tijdsvariërende hoeveelheid menselijk kapitaal in de economie.

Hoewel het model in Hoofdstuk 4 meerdere belangrijke en realistische kenmerken van de vorming van menselijk kapitaal in beeld brengt en het succesvol is geijkt met behulp van data over de Nederlandse economie is verdere uitbreiding mogelijk. Het huidige model neemt bijvoorbeeld aan dat arbeid niet gespecialiseerd is (dat is, arbeid is perfect substitueerbaar). Het is mogelijk dat onderwijzers in elke generatie random worden geselecteerd uit de bevolking terwijl empirisch bewijs aangeeft dat de kwaliteit van onderwijzers afhangt van de kwaliteit van gemiddelde individuen.

Op een ander gebied geeft recente literatuur bewijs dat aangeboren bekwaamheid is gecorreleerd over generaties. Meer dan de helft van de overdracht van bekwaamheid tussen generaties blijkt erfelijk te zijn (Plug en Vijverberg, 2003). Deze empirische vondst vraagt duidelijk om een uitbreiding van het model dat zo'n verbinding tussen generaties mogelijk maakt.

Een andere interessante uitbreiding is om de groeiende internationale handel toe te voegen naast kapitaalmarktintegratie wanneer de gevolgen van verscheidene processen van de vorming van menselijk kapitaal voor ongelijkheid worden geanalyseerd. Een manier om dit te doen is om sommige kenmerken van Bougheas en Riezman (2005) toe te voegen aan het model. Bougheas en Riezman analyseren de gevolgen van handel en de verdeling van menselijk kapitaal op inkomensverdeling. Door handel en kapitaalmobiliteit te combineren ontstaat een zogenaamde fuzzy wereld, maar dit is zeker meer realistisch.

Hoofdstuk 5 bestudeert de dynamiek van wisselkoersen volgend op de introductie van de euro als de gezamenlijke munt van 12 EU landen. Er worden overtuigende grote omslagen gevonden in de onconditionele correlaties tussen alle bestudeerde wisselkoersen en deze omslagen kwamen zowel voor ter tijde van de formele beslissing om door de gaan met het euro project in december 1996 als ter tijde van de werkelijke introductie van de euro in januari 1999. De onconditionle correlaties waren aanzienlijk lager in de tussenliggende periode. Dit wordt veroorzaakt door toegenomen heterogeniteit in de internationale valutamarkt in de tussenliggende periode. Aan de ene kant kon de Dublin bijeenkomst in december 1996 worden opgevat als een positief signaal dat het euro project succes zou hebben. Aan de andere kant zal de uitsluiting van de UK, Zweden en Denemarken, met hun indrukwekkende economische successen, tot enige twijfel over het project hebben geleid. Deze situatie kan leiden tot verschillende visies van zowel beleidsmakers en investeerders. Aangezien heterogeniteit in verwachtingen vertaald zal worden in verschillende strategieën in de internationale valutamarkt zullen de correlaties tussen valuta van verschillende Europese landen, ongeacht of ze meedoen in het euro project of niet, verminderen door de Dublin beslissing.

Uit methodologisch gezichtspunt is de bepaling van standaardfouten van de onconditionele covariantiematrix die wordt gebruikt in dit empirische werk nog niet vastgesteld. Als oplossing wordt de methode van Kristensen en Linton (2004) gebruikt. Zij stellen voor om een Newey-West type schatter in een univariate context te gebruiken. Het wordt verondersteld dat deze methode ook in de multivariate context kan worden gebruikt. Verder onderzoek is nodig om deze aanpak te verbeteren.

In Hoofdstuk 5 wordt aangetoond dat het noodzakelijk kan zijn om incidentele structurele omslagen toe te voegen aan onconditionele volatiliteiten en correlaties, naast het toestaan van tijdsvariërende conditionele volatiliteiten en correlaties door middel van een standaard DCC model. Men kan deze techniek gebruiken om andere interessante toepassingen in internationale macro-economie en financiën te onderzoeken, zoals de Aziatische valutacrisis in 1997, die betrekking had op de valuta van Indonesië, Maleisië, de Filipijnen, Singapore, Zuid Korea en Thailand.

Met betrekking tot de introductie van de euro is het interessant om de empirische analyse in Hoofdstuk 5 uit te breiden naar de belangrijkste aandelenmarkten in Europa. Het wordt algemeen aangenomen dat valuta- en aandelenmarkten een aantrekkelijke koppeling hebben, zie bijvoorbeeld Cumperayot *et al.* (2006). Dit onderwerp wordt overgelaten voor verder onderzoek.

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