ARISTOTLE
UNIVERSITY
OF THESSALONIKI

Economic Growth: Theoretical and Empirical Evaluation of Alternative Methodologies

Doctoral Thesis

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Doctoral Thesis – Διδακτορική Διατριβή

Economic Growth: Theoretical and Empirical Evaluation of Alternative Methodologies – Οικονομική Μεγέθυνση: Θεωρητική και Εμπειρική Αξιολόγηση Εναλλακτικών Μεθοδολογιών

Η υλοποίηση της διδακτορικής διατριβής συγχρηματοδοτήθηκε μέσω της Πράξης «Πρόγραμμα Χορήγησης Υποτροφιών για Μεταπτυχιακές Σπουδές Δεύτερου Κύκλου Σπουδών» του Επιχειρησιακού Προγράμματος «Ανάπτυξη Ανθρώπινου Δυναμικού, Εκπαίδευση και Διά Βίου Μάθηση», του ΕΣΠΑ 2014 - 2020 με τη συγχρηματοδότηση του Ευρωπαϊκού Κοινωνικού Ταμείου.

Ευχαριστίες

Ξεκινώντας, θα ήθελα να εκφράσω τις θερμότερες ευχαριστίες μου στην επιβλέπουσα καθηγήτριά μου, Δεσλή Ευαγγελία, για την αμέριστη στήριξη και ώθηση, την υπομονή και τις γνώσεις που μου προσέφερε καθ᾽ όλη τη διάρκεια εκπόνησης της διδακτορικής μου διατριβής. Υπήρξε εξαίρετη μέντορας και η καθοδήγησή της ήταν καθοριστική σε όλη αυτή τη πορεία. Θα ήθελα να ευχαριστήσω επίσης, τα μέλη της συμβουλευτικής μου επιτροπής, τον καθηγητή Κατρακυλίδη Κωνσταντίνο, ο οποίος με παρότρυνε και μου έδωσε το θάρρος να ξεκινήσω αυτή τη διαδρομή, καθώς και τον καθηγητή Παναγιωτίδη Θεόδωρο. Υπήρξαν και οι δύο σημαντικοί αρωγοί μέσα από τα εποικοδομητικά τους σχόλια και την ενθάρρυνσή τους καθ' όλη τη διάρκεια της διατριβής.

Ένα τεράστιο ευχαριστώ προς τον σύζυγό μου, Άγγελο, για την ανεκτίμητη στήριξη, αγάπη και υπομονή του σε όλα τα χρόνια εκπόνησης της διδακτορικής μου διατριβής, και στα πολλά χρόνια που προηγήθηκαν αυτής. Θα ήθελα επίσης, να ευχαριστήσω βαθύτατα τους γονείς μου, Τάσο και Ντίνα, και τον αδερφό μου, Χρήστο, για την πολύτιμη υποστήριξη τους.

Ευχαριστώ τους διδάκτορες Βικτωράτο Ιωσήφ, Γρηγοριάδη Βασίλη και τη διδάκτορα Τρέμμα Ουρανία για τη συνεργασία και τη φιλία που αναπτύξαμε τα τελευταία χρόνια. Τέλος, ευχαριστώ από καρδιάς την υποψήφια διδάκτορα Σδρόλια Ευαγγελία, και τη διδάκτορα Παρασκευοπούλου Χριστίνα για τη στήριξη που μου προσφέρουν απλόχερα όλα αυτά τα χρόνια.

Κλείνοντας, αν και δεν είθισται, θα ήθελα να αφιερώσω αυτή τη διατριβή στην κυρά Λένη, που είχε παιδεία, κι ας έλεγε ότι δεν ξέρει πολλά γράμματα.

Σύνοψη

Η οικονομική μεγέθυνση παίζει σημαντικό ρόλο στην επιστήμη των οικονομικών ενώ παράλληλα αποτελεί σημαντικό οικονομικό στόχο για τις περισσότερες οικονομίες. Οι πιο σημαντικές κατευθύνσεις στην εμπειρική προσέγγιση της οικονομικής μεγέθυνσης αφορούν τη διερεύνηση σχέσεων πιθανών παραγόντων και της οικονομικής μεγέθυνσης, καθώς και την έρευνα ύπαρξης οικονομικής σύγκλισης. Η διατριβή εμπεριέχει βιβλιογραφική επισκόπηση των θεμάτων αυτών, των υποκείμενων θεωριών και των σχετικών οικονομετρικών μεθοδολογιών για δεδομένα πάνελ. Ο σκοπός της διατριβής είναι να διερευνήσει πως η χρήση διαφορετικών οικονομετρικών μεθοδολογιών, κρατώντας το δείγμα σταθερό, επιδρά στα αποτελέσματα της έρευνας.

Η εμπειρική ανάλυση ξεκινάει με την εξέταση σχέσεων αλληλεπίδρασης αξιοποιώντας δημοφιλείς μεθοδολογίες, οι οποίες έχουν εδραιωθεί ως οι βασικές μεθοδολογίες και δίνουν τη πληροφόρηση για το εάν υπάρχει ή όχι σχέση μεταξύ δύο παραγόντων, και σε κάποιες περιπτώσεις τη κατεύθυνση αυτής (έλεγχοι συνολοκλήρωσης Pedroni, Kao, Maddala-Wu και Westerlund, έλεγχος αιτιότητας κατά Granger), καθώς και μεθοδολογίες που επιπλέον επιτρέπουν την ποσοτικοποίηση μίας τέτοιας σχέσης (εκτιμητές δεδομένων πάνελ Pooled Mean Group, Dynamic OLS, Fully Modified OLS). Η εφαρμογή αυτών των μεθοδολογιών χρησιμοποιεί τον παράγοντα των στρατιωτικών δαπανών, για τον οποίο η τωρινή βιβλιογραφία δίνει ασαφή εικόνα της σχετικής αιτιότητας, με συχνά αντικρουόμενες ενδείξεις. Η έρευνα καλύπτει 138 χώρες, κατά την περίοδο 1988-2013, χωρίς να κάνει παραδοχές σχετικά με τους θεωρητικούς διαύλους επιρροής και την κατεύθυνση αυτών, καθώς συχνά απαιτούν δεσμευτικές υποθέσεις. Επιπλέον, η έρευνα διεξάγεται και σε τρεις ομάδες χωρών με βάση το εισόδημα και το αναπτυξιακό τους στάδιο. Η ανάλυση δείχνει μια ανομοιομορφία στα αποτελέσματα που προκύπτουν από τις διαφορετικές μεθοδολογίες, η οποία δε μπορεί να συνδεθεί με κάποιο κοινό χαρακτηριστικό των χωρών του δείγματος. Πιο συγκεκριμένα, στη σχέση της οικονομικής μεγέθυνσης με τις στρατιωτικές δαπάνες, αιτιότητα από αυτές προς την οικονομική μεγέθυνση φαίνεται μόνο στις αναπτυσσόμενες χώρες (θετική μακροχρόνια), ενώ από την οικονομική μεγέθυνση προς τις στρατιωτικές δαπάνες, φαίνεται να υπάρχει θετική επίδραση για όλες τις ομάδες χωρών, εκτός από τις λιγότερο ανεπτυγμένες χώρες. Επιπλέον, η αλληλεπίδραση ήταν πιο έντονη πριν από την έναρξη της οικονομικής κρίσης.

Η εμπειρική ανάλυση συνεχίζει με την εξέταση τριών μεθοδολογιών εξέτασης οικονομικής σύγκλισης (β- σύγκλιση, log(t) σύγκλιση, και pairwise σύγκλιση), οι οποίες υποθέτουν ντετερμινιστική, στοχαστική ή συνδυαστική τάση στα δεδομένα, και επιτρέπουν ελέγχους σύγκλισης ανά ομάδες, οι οποίες είτε ορίζονται από το χρήστη είτε ενδογενώς από τα δεδομένα. Το δείγμα αποτελείται από οικονομίες χωρών που έχουν αναλυθεί ελάχιστα μέχρι σήμερα, με ασαφή αποτελέσματα, και πιο συγκεκριμένα, προσδιορίζονται ως οι πλουσιότερες οικονομίες παγκοσμίως. Επιπλέον, το δείγμα περιλαμβάνει χώρες μέλη του ΟΟΣΑ, («αναπτυγμένες»), αλλά και μη-μέλη, κάποια από τα οποία είναι πιο πλούσιες χώρες από τις «αναπτυγμένες». Όλες οι μέθοδοι συμφωνούν ότι η ομάδα των πλουσιότερων παγκοσμίως οικονομιών συμμετέχει σε μια συνεχιζόμενη διαδικασία σύγκλισης, αν και η χρηματοπιστωτική κρίση την έχει διαταράξει. Οι ενδείξεις οικονομικής σύγκλισης τείνουν να εξασθενούν όταν η υπόθεση της ντετερμινιστικής υποκείμενης τάσης εμπλουτίζεται με μια στοχαστική τάση και τελικά εγκαταλείπεται. Κάτι το οποίο θα έπρεπε να είναι αναμενόμενο – αν και συχνά η ερευνητική βιβλιογραφία το αγνοεί – καθώς οι περισσότερες οικονομίες χωρών έχουν κάποιο μακροχρόνιο προγραμματισμό.

Συμπερασματικά, η διερεύνηση των σχετικών οικονομετρικών μεθοδολογιών για τη μελέτη θεμάτων της οικονομικής μεγέθυνσης υποδεικνύει τη σημαντικότητα των θεωρητικών υποθέσεων, και των αντίστοιχων οικονομετρικών μεθοδολογιών, επηρεάζουν καθοριστικά τα αποτελέσματα. Προτείνεται ένας νέος δείκτης για την ανάλυση των αποτελεσμάτων στοχαστικής σύγκλισης. Τέλος, η επιλογή των οικονομετρικών μεθοδολογιών δεν πρέπει να επισκιάζεται από τη δημοφιλία, αλλά απαιτείται η εμπεριστατωμένη επιλογή καθώς και ο μη περιορισμός της εμπειρικής ανάλυσης σε μόνο μία μεθοδολογική προσέγγιση.

Abstract

Economic growth plays an important role in the field of economics, whilst at the same time it is the main economic objective for most of the world's economies. The most important directions in the empirical exploration of economic growth concern the investigation of relations between potential influential economic factors and economic growth and the examination of economic convergence. The thesis includes an overview of the relevant literature, the underlying theories and the corresponding econometric methodologies for panel data. The purpose of this thesis is to investigate how the use of different econometric methodologies, whilst keeping the sample constant, can influence the research outcome.

The empirical analysis begins with an examination of the interaction relationships utilizing popular methodologies that have been established as those that inform on the existence or not of a relationship between two factors, and in some cases on the direction of that relationship (cointegration tests of Pedroni, Kao, Maddala-Wu and Westerlund, Granger causality tests), along with methodologies that allow for the quantification of such a relationship (panel data estimators Pooled Mean Group, Dynamic OLS, Fully Modified OLS). The application of these methodologies utilizes the factor of military expenditure, for which the current bibliography provides an ambiguous picture about the potential causality, with often conflicting evidence. The research covers 138 countries, for the period 1988-2013, without making assumptions about the theoretical channels of influence or its direction, as they often require constricting assumptions. Additionally, the analysis is carried out in three groups of countries based on their income and developmental stage. The analysis shows a diversity in the results obtained from the different methodologies, which cannot be linked to any common country characteristics. In particular, military spending's causality to economic growth appears only in developing countries (positive long-term), while from economic growth towards military spending, there seems to be a positive effect for all groups of countries, except for the least developed countries. Also, the interaction seems more pronounced before the onset of the economic crisis.

The empirical analysis continues with the study of three economic convergence econometric methodologies (beta convergence, log(t) convergence, and pairwise convergence), which assume deterministic, stochastic or combinatorial trends in data, and allow convergence testing by groups, which are either user-defined or data-driven, on a common sample. The sample consists of the scarcely analyzed economies, with no clear picture about their economic convergence, that are identified as the world's top-income economies. The sample includes OECD member countries ("developed"), but also non-OECD members, most of which are richer countries than some of the "developed" ones. All methods agree that the group of the world's top-income economies is participating in an ongoing convergence process, though the financial crisis might have disturbed it. The convergence evidence tends to grow weaker when the assumption of the deterministic underlying trend is enriched with a stochastic trend and finally abandoned. Something that should be expected – although the research literature often ignores it – as most national-economies have some long-term planning.

Overall, the investigation of important issues of economic growth and the evaluation of the relevant methodologies indicate the importance of theoretical assumptions, and the corresponding econometric assumptions which have a decisive impact on the results produced. A new index for the interpretation of the stochastic convergence results is proposed. Finally, the importance of an in-depth selection of the appropriate methodologies should not be overshadowed by popularity, and the empirical analysis should not be limited to only one methodological approach.

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Chapter
1. Introduction

1.1. Economic Growth

The economic growth concept dates back to classical economists such as Adam Smith, Thomas Malthus, and David Ricardo, and has been one of the main targets of any government policy for at least the last 300 years. Initially, modern economic growth research in the 1960s and 70s, was mainly limited to theoretical neoclassical models. However, with the development of the endogenous growth theory and the increasing feasibility of empirical research, quantitative analysis became popular and frequently utilized for the understanding of economic growth, and its channels, determinants, etc. In recent years, the econometric approaches are becoming more refined, allowing for more complexity in the analyzed models. However, the refinement also brings certain underlying, potentially problematic, assumptions, such as the distribution of stochastic terms. This thesis addresses the need to investigate the differences and similarities in the conclusions that can be drawn using different econometric methodologies.

Determining what contributes to economic growth is of great importance in economics as the implications concern improving individual standards of living and income (Barro and Sala-i-Martin, 2003). There is considerable debate on the various drivers of economic growth, as a long-term sustainable economic growth is the goal for many policymakers, as well as on economic convergence. The models analyzing the influence of various drivers on economic growth, are potentially subject to the reverse impact, the frequently ignored, regressor endogeneity, as there may be interdependencies between economic growth and its determinants (Dunne and Tian, 2013; Lenkoski et al., 2014; Chudik and Pesaran, 2015; León-González and Montolio, 2015). Additionally, endogeneity is even more likely to be an issue if the growth model under analysis is a dynamic one. The empirical analysis of the present thesis begins with an examination of a wide variety of econometric methodologies for panel data that examine the relationship between economic growth and a selected determinant whilst utilizing a common sample, and evaluates whether their outcome depends on the properties of these methodologies. However, a wide range of literature also suggests that the most significant determinant of economic growth, is its own transition path, for example Barro (2003) and Sala-i-Martin et al. (2004). Thus, the present analysis of economic growth continues with the examination of the existence of economic convergence, under a range of corresponding methodologies which leads to a discussion about the presence or not of economic convergence.

1.2. Motivation and Background

The purpose of this thesis is to investigate how the use of different econometric methodologies, whilst keeping the sample constant, can influence the research outcome. The examination of these two research approaches is conducted initially by applying and comparing methodologies of interaction and relationships, and then applying and comparing methodologies of economic convergence.

There are a few studies that extensively examine the determinants of economic growth, such as those of Barro (2003) or Sala-i-Martin et al. (2004), as suggested by or derived from theoretical growth models. Among those are the physical capital, the human capital, trade openness, savings rate, and other variables, such as proxies for health capital and democracy. The most important and commonly included in the empirical literature, however, are government spending, and the initial level of growth of per capita Gross Domestic Product (GDP). The latter cannot be omitted due to its strong interpretive power in growth models and will be discussed subsequently. The former, i.e. government spending, has its own significance in growth models, as it has separate theoretical backgrounds depicting potential negative and positive effects on growth, and because it can be utilized as a fiscal policy measure by policymakers.

The main theoretical backgrounds for the effects of government spending on economic growth are the following two contradicting views; the hypotheses known as Wagner’s law and the Keynesian hypothesis. On one hand, Wagner's (1958) model shows public expenditures as endogenous to economic growth, suggesting a causal relationship between economic growth and public spending, with the direction of the causality running from the former to the latter. In other words, Wagner’s law proposes that economic growth is the reason government spending increases. On the other hand, the Keynesian hypothesis views government expenditures as exogenous (Loizides and Vamvoukas, 2005), and suggests that increasing them promotes economic growth. Further, the hypothesis expands to all kinds of public expenditures, proposing that increasing any of them can positively affect economic growth. Apart from these two hypotheses, the growth model of Solow (1956) has great significance for economic growth and a strong presence in the relevant literature. Solow (1956) suggests there is no effect of government spending to growth in the long run, attributing growth increases to population and labor force growth, and the rate of technological progress. The endogenous growth model of Barro (1991) that follows Solow's finds negative links between government consumption expenditures and growth and suggests government expenditures on investment would promote economic growth. It is not easy, however, for empirical research to properly categorize such government expenditures, but perhaps consistent analysis can only be performed through classification.

Among the categories of public spending, the most significant concern health, education, and defense. Spending on health and education apart of being (national) necessities, do not encounter as much controversy in the literature concerning their benefits; for example, Churchill et al. (2017) find positive effects of education spending and Hatam et al. (2016) of health spending on growth. Furthermore, acquiring empirical data on either of the two can be challenging. Military spending, on the other hand, is a government expenditure whose contribution is currently one of the most debated, especially since the start of the economic crisis, along with the global geopolitical conditions and the periodic pressures that some countries face concerning this type of spending.

Considering the various interconnections between growth and each of the individual expenditures entailed in public spending, the contradictions in the relevant theoretical models and the empirical literature appear reasonable, especially if we consider the magnitude of public spending, at least in the developed countries. Most commonly, these types of analyses are regression-based, which in this case essentially means a pre-assumption of the direction of the relationship between economic growth and the type of public spending. Furthermore, as the literature suggests, in most growth models, there are interdependencies between growth and its determinants, as growth is very likely to also be a driver of any existing relationship, resulting in models with regressor endogeneity. Additionally, when examining panel models, some level of cross-sectional dependence will most likely be present. Therefore, it is essential to examine the methodologies involved with the analysis of such relationships on a common sample. To appropriately examine those, the analysis must be applied on a selected determinant which is characterized by a lack of consensus on its effect on economic growth, without making pre-assumptions about the direction of that relationship. The selected determinant is the military expenditures.

The literature on military spending and its relationship with economic growth is reasonably extensive as from a theoretical perspective; this issue has been involved in an ongoing debate for decades. It is mostly driven by the complexity of the channels involved in the relationship, but also, a methodological one, as the disparity of the relevant empirical results invites further investigation from alternative perspectives. Furthermore, this type of government spending, though controversial, has regained its appeal since the financial crisis and, along with the contradictions of the relevant literature, it is an appropriate determinant of economic growth that will also allow the evaluation of the role the related methodological tools play in the results. The mutual influence between military expenditure and economic growth has received considerable empirical attention, and while their relationship is far from established, the knowledge about this interaction is becoming more extensive. For example, Alptekin and Levine's (2012) meta-analysis on the effect of military spending on economic growth found only positive effect for the developing countries; Churchill and Yew (2018) also carried out a meta-analysis and found negative effects of military spending on economic growth, while the meta-analysis of Yesilyurt and Yesilyurt (2019) found that overall military spending has no significant effect on economic growth. A review of the relevant literature can be found in **section 2.2.1.** Overall, the divergence of the time span and the selected countries in the data samples, the underlying assumptions about the channels of influence between military spending and economic growth that result to different econometric specifications, as well as the variety and sometimes inadequate estimation methodologies, result to an unclear picture of their interaction.

Therefore, the empirical analysis begins with an examination of various methodologies that look into the dynamic interaction between military spending and economic growth during the period 1988–2013 and covers 138 countries. The application of a diverse set of econometric methodologies on a common sample allows the evaluation of those methodologies and their appropriateness. Furthermore, it is a robust setting for the examination of the interrelations of economic growth and one of its most controversial determinants.

Turning to the other crucial determinant of economic growth, its initial value and its path, leads to the concept of economic convergence. An important concept that is essential in an analysis of economic growth, for which there is also a lack of consensus. Economic convergence enables the exploration of less noticeable growth determinants, such as the existence of cross-country externalities that can occur from geographic, trade or other links between countries. Furthermore, the relevant literature on the interactions of economic growth and its determinants indicates the important potential for regressor endogeneity that arises from the fact that economic growth itself affects most of its determinants, and cause uncertainty of the results. The theoretical background of convergence is based on the neoclassical assumption of capital's diminishing returns in an economy's production function, and it predicts that the economies with lower per capita GDP will grow faster over time than their counterparts with higher per capita GDP.

However, there are several different, and often competing concepts of economic convergence and numerous corresponding convergence methodologies. The relevant literature has a great number of studies examining different country groups, mostly geographically based, by applying a single convergence methodology, in most cases, generating a heterogeneity in the results and the overall accord concerning its existence, as the results are also affected by the selections of countries and methodologies. The available methodologies can be characterized by the assumptions about deterministic or stochastic trends, the time-length of the sample that they can be utilized for, and their ability to identify potential clubs. For this reason, it is difficult to compare the findings from different studies. As a result, the examination of economic convergence and of the corresponding methodologies should be conducted using differently based convergence concepts that are utilized on a common sample that has not been extensively studied and that is an alternative form of grouping.

Empirical literature fails to find convergence at a global level (Gaulier et al., 1999; Kang and Lee, 2005) and rarely that convergence is extremely slow (Li at al. 2016), a fact that is mainly due to the heterogeneity across countries. Instead, researchers are studying groups of countries, that are considered to have similar economies and convergence is theoretically more likely. The most frequently used distinction is based on the development level, with the developed countries groups typically defined as the Organization for Economic Co-operation and Development (OECD) members. This distinction started as a necessity due to data availability when the first studies appeared, and hence, they focused on countries characterized as developed at the time for which a satisfactory data volume and quality existed.

In addition to the data availability as the main factor that led to the pattern of employing the distinction based on the development level, this distinction was a rational choice as the then OECD members, that started with 17 members, had close political, social, economic and mainly trade links between them and the initial OECD group was leading the world economy in terms of income level growth and development. Lately, a problem arises as there is a lack of a uniform definition of which countries can be considered as developed. The popular OECD classification fails as not all current OECD members are universally considered as developed; for example, the UN considers as developed economies all the EU members, including some of the new ones that are not members of the OECD, but they do not classify as developed some of the existing OECD members; similarly, the International Monetary Fund (IMF) considers as advanced economies several non-OECD members, while some OECD members are absent from this list. Furthermore, in the more recent years, the world economy is increasingly being influenced and, in some areas, dominated not only by the "developed" economies but also by other economies that might be richer than the OECD members regardless of their perceived lower level of development. Hence, the "developed" classification as a prerequisite for an economy to be part of a convergent group that leads the world economy is now obsolete. The literature that looked at the income level as the country grouping criterion for the examination of convergence is very limited; Morales-Zumaquero and Sosvilla-Rivero (2016) and Boyle and McCarthy (1999) classified countries into four income groups over the period 1979-2011 and 1960–92 respectively, where they found indications of β-, and σ-convergence of various degrees mostly for the higher income groups. An analytical literature review of economic convergence can be found in **section 2.3**.

Therefore, the empirical analysis continues with an examination of economic convergence methodologies on a selected common sample which overcomes both above mentioned limitations, as is comprised by the sparsely analyzed top-income world economies, as described by the World Bank, and includes both OECD and non-OECD members. The investigation involves three of the most popular, but also diverse convergence methodologies, applied on a common sample of forty (40) of the world's richest countries over the period 1980-2016. More specifically, the beta convergence (Barro and Sala-i-Martin, 1992) that is able to detect deterministic trends, user-defined clubs, and has direct links to the theory, the log(t) approach (Phillips and Sul, 2007; 2009) that can detect both deterministic and stochastic trends, can detect automatically generated clubs, and has indirect links to the theory, and finally, the Pesaran (2007) pairwise convergence approach, that finds stochastic trends, user-defined clubs but has no specific theoretical background. The analysis will provide with significant insight on the appropriateness of the examined convergence methodologies as well as on the important issue of economic convergence.

Overall, the thesis contributes to the discussion of the selection of an econometric methodology for the areas of growth determinants and economic convergence, whilst overlooking their popularity and the usual theoretical, and potentially restrictive, assumptions by comparatively analyzing alternative econometric methodologies on the same sample.

1.3. Structure of the Thesis

The next chapter of the thesis entails a literature review on the examined subjects, starting from economic growth and public expenditures, and focusing on military spending, before moving to economic growth. Chapter 3 presents all methodologies involved in the evaluation of the relationships between economic growth and its drivers, and those that examine economic convergence, along with the main underlying assumptions and requirements. Chapter 4 examines the possible relationships between economic growth and a selected determinant, namely military expenditure. Chapter 5 examines the impact of the assumed underlying deterministic, stochastic or combinatorial trends of three economic convergence econometric methodologies in the data, on a sample of the scarcely analyzed top-income economies. The final chapter summarizes and concludes the thesis.

Chapter
2. Literature Review

2.1. Introduction

This chapter starts with a brief discussion on economic growth and its determinants, then looks on the subject of public spending, whose part is military spending, in relation to economic growth, and finally presents a more in-depth analysis of defense spending. Also, there is a thorough analysis of the concept of economic convergence and the relevant literature.

For each subject, there is an extensive literature review, along with the relevant empirical bibliography in chronological order, presented in tables for an overview. Additionally, in alphabetical order, there is a more detailed report for each article. The relevant literature has been organized in subsections.

2.2. Economic Growth and its determinants

The empirical literature that might or not be supported by theoretical model analysis, investigates the relationship of economic growth with potential determinants either utilizing regression or causality approaches, as well as whether economic convergence occurs over time. In most empirical approaches, economic growth is presented as the difference in growth rates between periods or, increasingly in recent years, proxied as the difference of the logarithms of per capita GDP between periods to avoid negative values.

Barro (2003) extensively examines the growth determinants suggested by or derived from main growth models, starting from Solow's model. Among those, the most important and commonly used in the empirical literature are the physical capital, presented as the initial level in each cross-section, for which diminishing returns are assumed, accompanied by the human capital, most times proxied by the education or school attendance or enrollment levels, and in some cases its effectiveness. Trade openness is almost always included, and so does the share of government consumption, and the savings rate, which is most commonly approximated by the ratio of investment in GDP. Lastly, more extended models involve political conditions such as rule of law and a democracy score, health capital (proxied by the life expectancy), population growth (also proxied by fertility rates), and in some cases inflation is used as a measure of macroeconomic stability. In his analysis, Barro (2003), also examines economic convergence, as he finds a positive effect on growth (measured as the differences in per capita growth rates across countries), when the initial level of real per capita GDP is low. Sala-i-Martin et al. (2004) use different methodologies to examine 32 economic variables as determinants of economic growth, finding significant partial correlation with long-run growth for about a third of them. Among the most important ones are regional dummies, proxies for human capital (such as those discussed above), as well as certain measures of openness. Nonetheless, the strongest variable turned out to be the initial level of income, once again. A finding that was also supported by Barro (2003) and refers to the concept of economic convergence discussed in Barro and Sala-i-Martin (1992).

There are some other studies examining the determinants of economic growth, although the majority of recent works have more focused objectives, and besides the important individual implications, it is apparent that the subjects of growth determinants and of economic convergence are closely related. The following section briefly discusses another significant factor of economic growth; financial development.

2.2.1. Economic growth and Financial Development

Financial development, and its importance, were originally underlined by Schumpeter (1934), and later by McKinnon (1973) and Shaw (1973), and continue to be analyzed theoretically and empirically. Financial institutions and openness are incorporated in most endogenous growth models, such as those discussed in the previous chapter, and there is a large body of empirical studies that shows a positive influence from financial development on growth, as expected by Schumpeter; Levine et al. (2000) and McCaig and Stengos (2005), among others. The potential effects of financial development on economic growth have also been viewed in an non-linear framework, for example Rioja and Valev (2004) examine those effects on countries cahategorized by the level of their financial development, finding minor positive influence for the countries with well-developed financial systems, relatively larger positive effects for the intermidiate economies, and ambigious effects for the countries with less-developed financial systems. Similarly, Deidda and Fattouh (2002) found that there is a threshold of initial income, above which financial development has positive effects on economic growth. Financial development is most commonly measured by the log of domestic credit provided by banks and institutions to the private sector as percanatge of GDP.

A separate series of articles, examines the related effects of financial openness or financial integration (also noted as financial liberazation) to economic growth. Some of the relevant research used constracted measures of financial openness finding positive (Quinn, 1997; Eichengreen and Leblang, 2003), as well as no effect on growth (Rodrik, 1998; McKenzie, 2001), while some studies reached the no effect conclusion utilizing both their own and existing indices, for example Edison et al. (2002), who found no significant link between financial opneness and economic growth. However, similarly to most growth determinants, studies that account for endogeneity and the reverse causality (i.e. from economic growth) find mixed results. The most commonly used measure for financial openness is the stock of total flows of foreign assets and liabilities as percentage of GDP. A limited number of studies examines the effect of financial developemnt on economic growth whilst taking into account trade and financial openness, such as the paper of Chortareas et al. (2015). They also find that taking cross-sectional dependence into account leads to no effects in the long run, however, when economic openness is included, the relationship changes, showing a long run relationhsip from financial development to growth for the edvanced countries, and a bidirectional one for the developing ones.

In this general framework, there are also studies examining the effect of more specific aspects of the financial openeness process, such as institutions (Klein and Olivei, 2008), equity markets liberazation (Quinn and Toyoda, 2008), and to a greater extent foreign direct investment (Alfaro et al., 2004; Ang, 2009; Iamsiraroj, 2016), on economic growth, most of which find a positive influence.

The section that follows initially reviews the literature on economic growth and public spending, as it is a significant factor that can act as an implementation tool for many policy decisions and could not be omitted from the analysis. However, since government spending includes various and diverse types of expenditures, all of which have been found to affect economic growth differently, the focus is then narrowed to one of them, namely military spending. The reasoning on which this selection was based is presented in the next section.

2.2.2. Economic growth and Public Expenditures

The interaction of public expenditures and growth is a vast and wide issue in economics that has been studied in numerous aspects. It contains analyses on the role and effects of public spending overall, such as that of Laboure and Taugourdeau (2018), who review the level of public spending in relation to the countries' developmental stage, Le and Suruga (2005) that analyze the simultaneous impact of public expenditures and foreign direct investment, as well as examinations of the hypothesis of Wagner's law, for example Acikgoz and Cinar (2017) and Wahab (2004). Reasonably, to perform an in-depth analysis not only on the effect but on the magnitude of that effect as well, in most cases the research-focus needs to be more specific (i.e., a particular type government spending). For example, Perović et al. (2018), Churchill et al. (2017), and Gamlath and Lahiri (2018), among others, studied the effects of government education expenditures on economic growth. Ye and Zhang (2018), Nghiem and Connelly (2017), and Hatam et al. (2016), among others, studied the effects of health spending on growth. While recently, the ongoing debate on defense spending and economic growth is reignited, for example, Miyamoto et al. (2019), George and Sandler (2018), Ortiz et al. (2019).

Military spending is a government expenditure whose contribution is currently one of the most debated, especially since the start of the economic crisis, along with the global geopolitical conditions and the periodic pressures that some countries face concerning their military spending. Apart from being one of the most controversial types of government spending, it is also the one with the broadest existing data samples, which always improves the validity of any econometric analysis. Any advantage is of great importance in the specific subject, as the relationship of military spending and economic growth is very complex, which also applies to most growth determinants, as there are numerous channels involved linking them from each direction, making the overall effect hard to identify. It is also an interesting subject form a methodological perspective as the relevant assumptions form the model under examination, influencing the results considerably. This is apparent in the review of the related literature that follows, as there is considerable variation in the relevant results.

2.2.3. Economic growth and Military Spending

The level of military spending, also referred to as defense spending, is influenced by international factors and events, like foreign policy objectives, exogenous real or perceived threats, armed conflict or military alliances and policies to contribute to multilateral peace-keeping operation as well as domestic reasons. The decision to authorize spending for national defense is the result of the central government's allocation process of public spending among competing objectives that are served by the government. Hence, military spending is expected to influence a country's economic growth via a variety of channels. On one hand, the military expenditure is frequently viewed as an unproductive public expenditure or "crowding out" other public spending that is considered to be more effectively contributing to economic development. Military spending could also be competing with civilian activities for labor, capital, and other production-related resources and subsequently distorting the demand and the resulting market price for them, and hence, it is expected to undermine economic growth. On the other hand, military spending could promote economic growth by stimulating aggregate demand for goods and services and reducing excess capacity ("military Keynesianism"), or through "spillover effects" from military research and development (R&D) of technologically advanced products to civilian spin-off products.

The mutual influence between military expenditure and economic growth has received considerable empirical attention, and while their relationship is far from established, the knowledge about this interaction is becoming more extensive. During the period 1969–1981, that was characterized by a more relaxed tension relative to the previous years in the global power confrontation arena, the military expenditure increased by 2.9% for members in the Warsaw Pact and by 0.5% for Organization for Economic Co-operation and Development (OECD) countries while by 11.2% for developing countries (Looney, 1988). Hence, the initial question in the literature was whether public spending in the defense area has a positive impact on economic growth, especially for the developing and less-developed countries. The first notable attempts to investigate this was by Benoit (1973, 1978), who found a positive impact of defense spending on economic growth for a group of less-developed countries and was later referred as the "Benoit Hypothesis". However, the applied econometric techniques were not satisfactory, and that spurred a broad interest in the area. Most of the studies that followed, focused on studying the 1960s and 1970s and in general, found that military spending was more beneficial for the wealthiest countries with no significant impact and even negative impact for the less-privileged countries, as the per capita income was reduced (Feder, 1983; Frederiksen and Looney, 1983; Lim, 1983; Biswas and Ram, 1986). However, the results did not hold if other factors are taken into account (Deger and Smith, 1983; Faini at el., 1984; Deger, 1986; Joerding, 1986).

Subsequent studies that used more years in their sample offered a diversity of findings while the assumed channels of influence between military spending and economic growth and the assumed underlying school of thought (neoclassical, Keynesian, institutionalist, Marxist) steered the outcome of the studies. The neoclassical approach sees military spending as a public good, and the economic effects of the military expenditure will be determined by its opportunity cost and the effectiveness of spending on alternative causes. The Keynesian approach views military spending as an aspect of state spending that increases output through a multiplier effect, in the presence of ineffective aggregate demand. The institutionalist approach combines the Keynesian perspective with the viewpoint of military spending spurring industrial inefficiencies as well as maintaining a powerful interest group composed of individuals, firms, and organizations that benefit from defense spending regardless of the country's actual needs. Finally, the Marxist approach sees the role of military spending as necessary for capitalist development and prevention of stagnation, and at the same time a wasteful way for lack of creating any further output in the society and for enhancing class struggle through the presence of the interest group mentioned by the institutionalists. Positive effects of military expenditure on economic growth through human capital accumulation or spin-off technologies were found by Weede (1983), Deger and Sen (1983), Deger (1986) and Yakovlev (2007), while through the process of enhancing infrastructure, promoting full employment and increasing a Keynesian-type aggregate demand was found by Kennedy (1983), DeGrasse (1983) and Mueller and Atesoglu (1993). Adverse effects of military expenditure on economic growth were found when alternative channels were investigated, like through reducing the savings rate, crowding out investment in new capital stock, health and education and increasing tax burden with more significant impact on resource restraint countries (see e.g., Smith, 1980; Cappelen et al., 1984; Mintz and Huang, 1990; Huang and Mintz, 1991; Ward and Davis, 1992; Batchelor et al., 2000; Dunne et al., 2001). Finally, there is another group of studies that imply that there is no relationship between the two variables mainly when the military expenditures are low (see, e.g., Alexander, 1990; Kinsella, 1990; Payne and Ross, 1992; DeRouen, 1994; Pieroni, 2009; Dritsakis, 2004). It should be noted that almost all articles were researching only the influence of military spending on economic growth and not the potential reverse causality.

Even the oldest analyses provide with some approximation of the magnitude of the impact through the coefficient. However, most assume that the relationship is one-sided. Certain causality type models do not make this assumption, and there are also recently available econometric methodologies that can give information about the magnitude of the impact, although they are not always directly comparable. These econometric methodologies are presented in Chapter 3.

As Mintz and Stevenson (1995) first argued, the diversity of results is mainly a result of the use of alternative channels of interaction between the two magnitudes and the research methodology. On that front, there are studies that focus on one country (e.g., d'Agostino et al. (2011) and Kollias and Paleologou (2013) studied the USA) or a small group of countries (e.g. Dritsakis (2004) studied Greece and Turkey; Abu-Bader and Abu-Qarn (2003) reviewed Egypt, Israel, and Syria), or a specific geographical region with homogeneous countries (e.g., Dunne and Mohammed (1995) selected 13 sub-Saharan countries; Landau (1996) focused on 17 wealthy OECD countries; Dakurah et al. (2001) investigated 62 developing countries; Wijeweera and Webb (2011) looked into the case of South Asia). Additionally, the vast majority of studies use cross-country sectional data that limits the validity of the findings to the period under study as well as they might introduce bias owing to the heterogeneity of the countries when the sample contains diverse countries. The studies that used time series models also have problems with the low power of estimation as the data period was rather small. The first study to avoid these problems and utilize panel data was by Mintz and Stevenson (1995) who found that military expenditure leads to positive economic growth in less than 10% of the 103 countries in their sample. However, only a small volume of the recent literature has been using panel data: Ram (2006) used a sample of 119 countries, Yildirim et al. (2005) focused on Middle Eastern countries, Kollias, et al. (2007) investigated 15 EU members, Chang et al., (2011) utilized a dataset of 90 countries, Chen et al. (2014) analyzed 137 countries. There have been only a few studies that look into the short-run relationship using Granger causality tests (e.g., Joerding, 1986; Dunne and Perlo-Freeman, 2003; Chang et al., 2011), but they have been criticized for their contribution being limited to the period under study as well as for difficulty in interpreting their results as they were not connected with any theory. Finally, there have been arguments about the nonlinearity of the relationship between the two magnitudes, but the complexity of these models did not make them popular among researchers, and when they were applied, they focused on a small number of states (e.g., Barro, 1990; Cuaresma and Reitschuler, 2004).

As it is not possible to cover all areas of the extensive existing literature, more thorough military-growth literature surveys can be found in Ram (2006), Dunne and Uye (2010) and Dunne and Tian (2013). Dunne and Tian (2013) cover almost 170 studies, and they argue that the more recent studies that are focusing on the post-Cold War era provide stronger evidence of an adverse effect of military expenditure on economic growth with the developing countries to benefit the most if their military expenditure is reduced. More specifically they state that 53% of the post-Cold War cross-country studies find a negative relationship, 19% a positive relationship and 28% have unclear results while most of the case studies find a positive impact when conflict pairs such as Greece–Turkey, and India– Pakistan are in focus. Alptekin and Levine (2012) perform a meta-analysis of 32 works and find no support of a negative relationship and a positive one in developing countries. In their view, the controversy in the results is due to differences in the sample, periods involved, and functional forms. Churchill and Yew (2018) carry out a meta-analysis on 42 primary studies and find negative effects of military spending on economic growth, suggesting country and time samples, underlying models and econometric specifications cause variations in the size of the effects, while any positive effects are more pronounced in the developed world. The most recent meta-analysis of Yesilyurt and Yesilyurt (2019) extends the work of Alptekin and Levine (2012) to include 91 works (and a more diverse sample of studies) and find that overall military spending has no significant effect on economic growth. It should be noted that meta-analyses do not present a balanced view of the world, but a balanced view of the existing literature.

2.2.4. Economic growth and Military Spending – List of Empirical Literature

The following tables include the empirical articles from those discussed above that examine the effects of military spending on economic growth, presented in chronological order.

Table 2. 1 Empirical literature on the effects of military Spending on Economic growth

Author(s)	**Countries**	**Time Period**	**Model/ Methodology**	**Main Findings**
Benoit (1973, 1978)	44 LDCs	1950-1965	correlations between MSP and growth rates	positive correlation
Smith (1980)	14 OECD countries	1954-1973	OLS regressions	negative effect of MSP on investment, with a coefficient on MSP not significantly different from -1
Frederiksen and Looney (1983)	90 developing countries	1970-1978	cluster analysis and linear regressions	MSP has a positive effect on resource-rich countries and a neutral effect on developing countries
Lim (1983)	54 LDCs	1965-1973	OLS regressions	MSP was detrimental to economic growth
Cappelen, Gleditsch, and Bjerkholt (1984)	17 OECD countries	1960-1980	comparisons & longitudinal data analysis	net effect of MSP negative on economic growth (whole sample & subgroups), except for the Mediterranean countries.
Faini, Annez, and Taylor (1984)	22 countries (developed & developing)	1950-1970	OLS regressions	negative effect of MSP on growth rates in most cases – increasing MSP has economic costs in lost investment, reduced growth rates and lagged agricultural supply
Deger (1986)	50 LDCs	1965-1973	OLS estimates system equations	overall, MSP will reduce growth rate and retard development
Alexander (1990)	Belgium, Denmark, The Netherlands, Canada, Finland, Sweden, Austria, Australia, and New Zealand	1974-1985	cross-sectionally heteroskedastic and time-wise autoregressive model as described in Kmenta (1971)	MSP has no significant impact on economic growth the defense sector has relatively low productivity
Kinsella (1990)	the US	1943-1989	vector autoregression	no substantial causal relationship between MSP and growth
Mintz and Huang (1990)	the US	1953-1987	a two-equation model	indirect, lagged effect of MSP on growth, with lower MSP encouraging investment in the long run, which in turn promotes economic growth
Ward and Davis (1992)	the US	1948-1990	OLS regressions	MSP is a significant drain on the economy
Mintz and Stevenson (1995)	103 countries	1950-1985	based on the neoclassical growth theory OLS time-series regressions	only about 10% of the cases show a significant positive effect of MSP on growth
Dunne and Mohammed (1995)	13 Sub-Saharan countries	1967-1988	cross-sectional analysis of country averages, pooled data analysis	negative effect of MSP on economic development in some countries - no significant positive effect of MSP on economic growth
Batchelor, Dunne, and Saal (2000)	South Africa	1964-1995	neoclassical model ARDL	no significant impact of MSP on growth

LDCs: Least Developed countries, MSP: Military Spending, OLS: Ordinary Least Squares; OECD: Organization for Economic Cooperation and Development; ARDL: Autoregressive Distributed Lag

Table 2. 2 Empirical literature on the effects of military Spending on Economic growth				
Author(s)	**Countries**	**Time Period**	**Model/ Methodology**	**Main Findings**
Dakurah, Davies, and Sampath (2001)	62 developing countries	1975-1995	Granger causality extended to incorporate non-stationarity and cointegration	causation from MSP to economic growth in 13 countries, from growth to MSP in 10, and a feedback relation in 7
Dunne, Nikolaidou, and Vougas (2001)	Greece & Turkey	1964-1996	Granger causality techniques vector autoregressive (VAR) methodology	causality results suggest a positive effect of changing MSP on growth for Greece, but this is not sustained Granger causality negative impact of MSP on growth in Turkey
Abu-Bader and Abu-Qarn (2003)	Egypt, Israel, and Syria	1967-1998	multivariate cointegration and variance decomposition	MSP negatively affected economic growth - civilian government spending positively affected economic growth in Israel and Egypt
Cuaresma and Reitschuler (2004)	the US	1929-1999	threshold regressions	positive externalities of MSP are greater for relatively lower levels of defense and negative for higher levels
Dritsakis (2004)	Greece & Turkey	1960-2001	Johansen cointegration	no cointegrated relationship, Granger causality indicates a unidirectional causal relationship for both countries- there is a bilateral causal relationship between the MSP of the two countries
Yildirim, Sezgin, and Öcal (2005)	Middle Eastern countries and Turkey	1989-1999	cross-section and dynamic panel estimations	MSP enhances economic growth
Kollias, Mylonidis, and Paleologou (2007)	EU15	1961-2000	Fixed effects, Heteroscedasticity-Consistent Fixed effects & cointegration	positive feedback between growth and MSP in the long run and a positive impact of the latter on growth in the short run
Yakovlev (2007)	28 countries	1965-2000	augmented Solow growth model - fixed and random effects, and Arellano–Bond GMM estimators	higher MSP and net arms exports separately lead to lower economic growth, but higher MSP is less detrimental to growth for net arms exporters
Chang, Huang, and Yang (2011)	90 countries	1992-2006	GMM (Arellano and Bond, 1991)	MSP leads negatively economic growth for the panels of low-income countries negative causal relationship from MSP to economic growth for Europe and the Middle East–South Asia
Wiieweera and Webb (2011)	India, Pakistan, Nepal, Sri Lanka, and Bangladesh	1988-2007	panel cointegration	MSP in these countries has a negligible effect on economic growth
Kollias and Paleologou (2013)	the US	1956-2004	linear and non-linear causality tests	not causality for MSP
Chen, Lee, and Chiu (2014)	137 countries	1988-2005	two-step GMM	Short-run causality running from MSP in lower- middle- and high-income countries. From growth in low-income countries. Bidirectional short-run causality in Asia, Europe, Latin America & Caribbean, & Middle East & North Africa
LDCs: Least Developed countries, MSP: Military Spending, OLS: Ordinary Least Squares; GMM: Generalized Method of Moments				

2.2.5. Economic growth and Military Spending – Theoretical and Empirical Literature by Article

The current section presents more analytically the articles discussed in this chapter so far. The studies are presented in alphabetical order.

Abu-Bader and Abu-Qarn (2003) investigate the causality between government spending and economic growth in three countries, namely Egypt, Israel, and Syria. They use multivariate cointegration and variance decomposition techniques, from 1967 to 1998. They find a negative long-term relationship from government spending to economic growth. However, military spending, still, negatively affects economic growth in all three countries when the share of government civilian expenditures in GDP is also included in the system, although civilian government spending had positive effects on the economic growth of Israel and Egypt.

Alexander (1990) specified four sectoral production functions to model the effect of military spending on economic growth, which allowed the generation of externality effects of certain sectors to others as well as the possibility of productivity differentials within sectors. The model is applied to a group of developed countries, with the results showing that the overall effect of military spending on growth is neither significantly positive nor negative; however, the defense sector is substantially less productive than the "rest" of the economy.

Alptekin and Levine (2012) conduct a meta-analysis of 32 empirical studies examining the effect of military expenditure on economic growth, considering four hypotheses. They find no support for the hypothesis of a negative relationship between military expenditure and growth, for the LDCs or in general, while in the developed countries, there is support for a positive effect of military expenditure on economic growth. They also confirm the hypothesis of a non-linearity in the relationship, while they attribute the variations in the existing literature to differences in the sample, periods, and functional forms.

Churchill and Yew (2014) performed a meta-analysis of the empirical literature examining the impact of military expenditure on economic growth. They used 243 meta-observations from 42 studies and discovered indications of negative effects from military expenditure to economic growth. Their analysis suggests the assumed theoretical models, econometric specifications, the type of the data, as well as the examined period, mainly explain the differences in the military expenditure-growth literature. Finally, positive effects on economic growth from military expenditure are more evident for developed countries than less developed.

Barro (1990) includes with tax-financed government services that affect production or utility to the strand of endogenous-growth models that assume constant returns to a broad concept of capital. This results to the rise of growth and saving rates, at first, with productive government expenditures, but subsequently decline with an increase in utility-type expenditures. The decentralized choices of growth and saving have now reduced too much with the introduction of an income tax. However, with a Cobb-Douglas production function, the optimizing government nonetheless satisfies a natural condition for productive efficiency. The study includes an empirical cross-country analysis that supports some of the hypotheses concerning government and growth.

Batchelor, Dunne, and Saal (2000) empirically assess the economic effects of military spending in South Africa. They estimate a common neoclassical macroeconomic model, that is also analyzed at the level of the manufacturing sector. They use an ARDL procedure to allow for a data-driven dynamic structure of the model to improve it. In total, they find that military spending has no significant impact, except for the manufacturing sector where the effect is negative, suggesting that the reductions in domestic military spending could help improve the country's economic performance through the manufacturing sector.

Benoit (1973, 1978) analyzed the correlations between defense spending and growth rates in 44 least developed countries from 1950 to 1965. He finds a positive correlation between them with countries with high defense burden showing high growth rates and countries with low defense spending having low growth rates.

Biswas and Ram (1986) adapted Feder's model to study the effects and externalities of the military sector. They conclude that the findings at the time showed part of the process. They find some differences across low and middle income least developed countries as well as between the 1960s and 70s. They also find differences when the variable used is military expenditures and when it is divided by GDP. The paper discusses the conclusion of many studies, that positive and negative effects of military spending result in no aggregate effect, and point to the possible effects on other dimensions, besides income growth.

Cappelen, Gleditsch, and Bjerkholt (1984) compare cross-sectional data from industrialized countries and observe lower growth rates in countries with high defense spending than in those with low defense spending. At the same time, longitudinal data analysis shows that economic growth is higher in periods with high military expenditures. The analysis is then performed on pooled cross-sectional and longitudinal data from 17 OECD countries from 1960 to 1980, and geographical subgroups. In general, they find a positive impact of defense spending on manufacturing output, but a negative on investment. The whole samples, as well as the subgroups show a negative net effect on economic growth, with the exception of the Mediterranean countries.

Chang, Huang, and Yang (2011) apply GMM (Arellano and Bond, 1991) to data of 90 countries to examine the relationship between military spending and economic growth, for the period 1992–2006. They also examine the countries by income group, covering three groups, and find negative effects of military spending on growth in low-income countries. They also test four geographical groups and find stronger negative effects of military spending on growth in Europe and the Middle East–South Asia regions.

Chen, Lee, and Chiu (2014) utilize a sample of 137 countries to investigate the causality between the defense burden and real GDP. They use a two-step Generalized Method of Moments (GMM), and the differentiation of the results between regions show that one size does not fit all. They find a short-run causal relationship from military spending to GDP in two of the four income groups of countries (lower-middle- and high-income), while in low-income countries the relationship runs from GDP to military spending. Bidirectional short-run causality is found in Asia, Europe, Latin America & the Caribbean and the Middle East & North Africa. Lastly, they find no causality in the upper-middle-income group, or the European & Central Asian and Sub-Saharan African groups. They also discuss some important implications for the countries' defense policy.

Churchill and Yew (2018) conduct a meta-analysis on a sample of 272 meta-observations from 48 studies that examine the impact of military expenditure on economic growth. Overall, they find that negative effects of military expenditure from the existing literature. Their results indicate that the effect size estimate is strongly influenced by study variations, the existing differences in the results is attributed to the theoretical models, econometric specifications, and types of data, as well as the examined periods. Finally, their results suggest that developed countries are more likely to experience positive effects of military expenditure on growth.

Cuaresma and Reitschuler (2004) use time series data for the U.S. to investigate the relationship between military spending and growth, while allowing the effect of military spending on growth to be non-linear. They use threshold regressions in their analysis, and they find a level-dependent effect of military expenditure on GDP growth. They find that lower levels of military spending have larger positive externalities, and the effect becomes negative in higher levels of spending.

d'Agostino, Dunne, and Pieroni (2011) study the ideal size of government spending, using nested functional decompositions of defense spending into consumption and investment. They use semi-parametric methods to examine nested non-linear models of growth, using post World War II US data. Concerning private production investment expenditure is found to be productive, including both investment in military and in non-military. They find little evidence pointing to a negative effect from military spending to economic growth currently in the U.S., and only a low impact from civilian consumption. They conclude that there would be no economic benefits from increases in military spending.

Dakurah, Davies, and Sampath (2001) investigated the inter-relationships between military spending and economic growth in a sample of 62 developing countries. They use Granger causality tests, which they extend in order to incorporate cointegration and non-stationarity. A unidirectional causal relationship is found in 23 countries, from either direction (i.e., from economic growth to military spending or vice versa), and a bidirectional causal relationship is found in 7 countries (i.e., from both directions). Out of the 18 countries that were integrated of the same order none exhibited causality, while in 14 countries the data were integrated of differing orders. Results were differentiated between long-run effects and short-run causality when cointegration existed. They also discuss some of the limitations of the methods and results.

Deger (1986) studies the interrelationship of defense and development in least developed countries (LDCs), trying to consider the simultaneous nature of the interrelationships that underline the growth defense structure. His results contradict those of Benoit (1978), and others, that find positive effects of defense on growth in LDCs. In his view, this differentiation is due to a less complete picture analyzed by the previous studies, as defense spending may have a positive impact on structural processes, through "modernization", but it has negative effects on resource-based processes, by depressing domestic savings.

Deger and Sen (1983) use a formal optimizing model to analyze the strategic causes, such as security and threat, and the economic spin-off effects of military expenditure in less developed countries. Strategic factors are found to be relatively autonomous of economic factors, and the analysis then focuses on the widely held belief that the potential for positive externalities from defense spending are substantial (through technological progress, R&D, skill creation, effective demand), and from those there will also be positive effects in development. An empirical analysis for India shows that such claims are exaggerated, and positive economic effects from defense are weak.

Deger and Smith (1983) examined the relations between defense spending and economic growth, in emerging countries, in a macroeconomic statistical framework. Using cross-sectional data, they find that military spending impedes growth and thus hinders development, with a sensitivity analysis confirming their result.

DeGrasse (1983) examines the net economic impact of military spending. He considers the military budget in comparison to the whole economy of the U.S., as well as job creation comparatively to private and civilian government spending. The long-term effects of military spending during the Cold War are also considered. The technological costs and benefits of military spending in the U.S. are discussed. Overall, this book provides a first picture of the "opportunity cost" that society pays for a large military sector.

DeRouen (1994) examines the determinants and possible effects of Israeli military expenditures. Testing a three-sector production function model sensitive to the effects of increases in civilian technology and defense and non-defense externalities, he finds that short-term increases in defense spending diminished growth and non-defense spending fostered growth, as long as the model controlled for technological growth. The implications of these results for long-term Israeli defense planning include that eventual savings from peace would be best used for non-defense spending on infrastructure and private investment.

Dritsakis (2004) used the Johansen cointegration test and a vector error correction model to examine the relationship between defense spending and economic growth for two closely neighbored countries, that are both NATO members; Greece and Turkey. No cointegrated relationship is found between military spending and growth, while the Granger causality results show unidirectional causality between the two variables in both countries. Lastly, they find bilateral causality between the military expenditures of the two neighboring nations.

Dunne, Nikolaidou, and Vougas (2001) analyze the military spending of two countries, Greece and Turkey, which are interesting case studies in many aspects. They two countries have poor relations, they both have high military expenditures, and non-surprisingly, there is resulting unrest in the area. They use vector autoregressive (VAR) methodology and Granger causality tests, with the latter suggesting changing military expenditures would have a positive effect on the growth of Greece. However, when the cointegration between GDP and military spending is taken into account, the effect is not sustained. The only significant effects from the Granger causality tests, concern Turkey, and point to negative effects of military spending on economic growth.

Dunne and Mohammed (1995) studied thirteen Sub-Saharan African countries over the period from 1967 to 1988. They used data for the group of countries, a cross-sectional analysis of the country averages, and an analysis of the pooled country data. Regarding the determinants of military spending, economic factors appear to play an important role in determining the level of military burden across countries and through time. Strategic factors such as wars, the size of the army, as well as inertia are suggested by the pooled estimation results as important. Military spending is also found to hurt economic development in the time-series analysis, affecting it indirectly, through negative effects on human capital, investment distributions, and the balance of payments. This result is not uniformly found across economies, or in the pooled estimation, nonetheless, there are no significant positive effects of military expenditures on economic growth.

Dunne and Perlo-Freeman (2003) analyze the changed strategic environment after the end of the Cold War, and the potentially changed the behavior of the determinants, in developing countries, through cross-sectional demand functions, for the Cold War period and a little after its end. Their results, for both periods, indicate that military spending depended on neighbors' military spending and internal and external conflict. They find both democracy and population to be negatively related to spending on military. As for any potential change between periods in the underlying relationship, the two samples do not show any significant evidence of such.

Dunne and Tian (2013) analyze the large, complex, and growing literature on the effects of military expenditure on economic growth. There are several different aspects of the literature that make it difficult to summarize, such as the various theoretical approaches, the different empirical methods used, the sample covered, in terms of countries and periods, as well as the quality and statistical significance. Their article, covering nearly 170 studies, finds that current studies provide stronger evidence of negative effects of military spending on economic growth.

Dunne and Uve (2010) discuss military spending, which has influence beyond the resources it takes up, especially when it leads to or facilitates conflicts. Almost all countries have the need for defense expenditures, nonetheless, these can certainly have opportunity costs as they divert resources from other purposes that might improve the pace of development. Their empirical analysis examines developing countries, as those are the countries that are most likely affected and involved in war related events.

Faini, Annez, and Taylor (1984) study developed and developing countries for the period 1950-1970 roughly, and countries also grouped by region. In almost all cases, there is a negative effect of military spending on growth rates. Further analysis concludes that, except for developed countries, an increase in military expenditures has economic costs in lost investment, in reduced growth rates and lagged agricultural supply.

Feder (1983) studies a group of semi-industrialized less developed countries for the period 1964–1973 analyzing the sources of growth. The analytical framework developed, allowing for export and non-export sectors of the economy to have non-equal marginal factor productivities, finding marginal factor productivities to be considerably higher in the export sector. This is possibly due to inter-sectoral positive externalities created by the export sector, indicating that growth can be generated by the reallocation of existing resources from less efficient sectors (non-exporting), to the export sector that shows higher productivity, apart from increases in the aggregate levels of labor and capital.

Frederiksen and Looney (1983) examine the relationship between defense spending and economic growth under the hypothesis that the impact of added defense expenditures may vary between positive or negative, depending on the resource constraints that many developing countries face. They use a sample of 90 developing countries from 1970 to 1978 and, using cluster analysis and linear regressions, found that defense spending has a positive effect on resource-rich countries and a neutral effect on developing countries. In the latter group, investment variables were positive and statistically significant, while in relatively wealthy countries, only the growth rate of investment was statistically significant.

Huang and Mintz (1991) build on previous work and re-estimate their defense-growth model, which is based on a neoclassical production function, by isolating the externality component. They estimate the model using U.S. country-level data from 1950 to 1988 and compare their specifications and results to those of Atesoglu and Mueller (1990) and Alexander (1990).

Joerding (1986) tested the assumption of previous studies that military spending is exogenous relative to economic growth using Granger causality on two measures of military spending. The results consistently showed that military spending is not a strongly exogenous variable, implying flaws in previous work in this area.

Kinsella (1990) uses vector autoregression to investigate causality between military spending and economic performance in the U.S. during the period 1943-1989. No substantial causal relationship is found between military expenditures and the price level, the unemployment rate, or the interest rate, in either direction. Further, no significant lagged relationship is found between defense spending and output using annual data, concluding that these results offer no support to the link between defense spending and poor economic performance.

Kollias, Mylonidis, and Paleologou (2007) investigate the causal relationship between growth and military spending in panel data for the European Union (EU15) from 1961 to 2000. Their results indicate a positive feedback long-run relationship between growth and defense spending, and short-run positive effects of military spending on growth.

Kollias and Paleologou (2013) study the effects of military spending as well as spending on highways on economic growth, in the U.S. for the period 1956–2004. Using causality tests, both linear and non-linear, they find that spending on highways facilitates growth, but military spending does not.

Landau (1996) examines the effects of defense spending on economic growth in OECD economies. He tests and confirms the hypothesis that military expenditures non-linearly affect growth, with higher defense spending being associated with faster growth at low levels and slower growth at higher levels.

Lim (1983) extends the sample of Benoit (1978) to 54 least developed countries and studies them during a more recent, at the time, period (1965-73), as well as at a regional level, and finds that defense spending was detrimental to economic growth. However, this was not universally the case at a regional level, with Africa and the Western Hemisphere experiencing this adverse effect, but not Asia, the Middle East or southern Europe.

Mintz and Huang (1990) present and estimate a two-equation model to assess the direct and indirect, as well as the immediate and lagged effects that changes in military spending have on economic growth in the U.S. from 1953 to 1987. The analysis finds an indirect, lagged effect of military spending on growth, with lower military spending encouraging investment in the long run, which in turn promotes economic growth. Thus, this effect is not immediate; they find that it takes around five years for it to begin to manifest.

Mintz and Stevenson (1995) study the effects of defense expenditures on economic growth using a model based on the neoclassical growth theory. They use time-series data for the estimation of the model that is tested on 103 countries, while they account for the possible externality effects of military expenditures by employing a multisectoral model. They find that only around 10% of the countries show significant positive effects of defense spending on growth. This result is robust to the specification of the models and is in contrast to the finds of most cross-national studies.

Mueller and Atesoglu (1993) present a two-sector model, based on the neoclassical model. The model includes a civilian and a military sector, that both have technological change, and the military sector acts as an externality in the private sector. They include technological change in order to separate the effects of military expenditures between the change in the rate of military expenditures and the relative size of the military sector. They find that a change in military expenditures has significant positive effects on growth, and both military effects appear significant on their own.

Payne and Ross (1992) follow Kinsella's (1990) suggestion and use sub-annual level of data to examine the effect of defense spending on real output, price level and unemployment and interest rates. Their use they unrestricted vector autoregression analysis on a quarterly sample during the period 1960-1988. Their results indicate no causality between military spending and economic growth, in either direction.

Pieroni (2009) empirically examines the relationship between defense spending and economic growth, considering non-linear effects of defense spending. This is achieved with the inclusion of the effects of the share of military and civilian government spending, while the model also includes endogenous technology. The theory predicts a negative relationship between defense spending and growth when military spending is high, however, it is only found to be significant when a proxy for reallocation effects is included.

Smith (1980), examined the hypothesis that decreased investment was a significant opportunity cost of defense spending during the post-war period (1954-1973). He creates a function for the share of investment in potential income using the share of defense spending, demand pressure, and the growth rate. The analysis is performed on a sample of 14 OECD countries, and the results show strong negative effects of military spending. Results are robust to data treatment (cross-sections, time series, or pooled), and several assumptions concerning model and error structure.

Ward and Davis (1992) investigate the relationship between defense spending and economic growth in the U.S. during the period 1948-1990. They find that military spending significantly impedes economic growth. The analysis also considers a new universal system for the defense spending of the U.S., along with the relevant implications, and possible effects on economic growth in the 1990s. Proposed reductions of military spending are simulated, and the results imply strong positive effects in economic output during the 1993–96 period (from 2.5% up to 4.5%).

Weede (1983) uses the military participation ration of the labor force as an indicator of discipline-related human capital formation. Using cross-national regression analysis of economic growth rates, he shows that countries with higher skill levels, which were based on school enrollment ratios, grew faster, and countries with better social discipline, which was proxied by military participation ratios, also grew faster than others.

Wiieweera and Webb (2011) examine the relationship between military spending and economic growth in the five South Asian countries of India, Pakistan, Nepal, Sri Lanka, and Bangladesh throughout 1988–2007 using panel cointegration. They find that a 1% increase in military spending increases real GDP by only 0.04%. This implies an almost insignificant economic effect from the considerable volume of government spending being allocated towards defense purposes in these countries.

Yakovlev (2007) examines the non-linear relationship of military expenditures and economic growth, using Solow- and Barro-type growth models, as Dunne et al. (2005) suggested. He investigates the effects of military spending and arms trade on economic growth, by implementing fixed and random effects, as well as the Arellano–Bond (GMM) estimators. He examined those interaction in a panel of 28 countries during the period 1965-2000. He finds that the augmented Solow growth model, as it was specified by Dunne et al. (2005), produces more robust results than the reformulated Barro model. The results show that increased defense expenditures and net arms exports, disjointedly lead to lower economic growth. However, that increased defense expenditures is less harmful to growth when examining arms exporting countries.

Yesilyurt and Yesilyurt (2019) extend the well-known work of Alptekin and Levine (2012) to include 91 works (and a more diverse sample of studies) in a meta-analysis and find that overall military spending has no significant effect on economic growth. The average effect across all studies is found to be close to zero, while some study characteristics seem to be significant determinants of the effect of military expenditure on growth, but it cannot be described by a simple pattern.

Yildirim, Sezgin, and Öcal (2005) empirically investigate the effects of defense spending on economic growth in Turkey and a few other Middle Eastern countries. The period under analysis is from 1989 to 1999, and they use cross-section as well as dynamic panel estimations. The results show that military spending facilitates economic growth overall.

Here, the literature review of economic growth and public spending is concluded. The section that follows analyzes the concept of economic convergence, with a focus on the relevant empirical research.

2.3. Economic convergence

The first appearance of the concept of economic convergence, formulated as the idea that less advanced economies are growing faster than those with stronger economies, dates back to the 50s. Among the first were in the work of Kuznets (1955), who emphasized the importance of understanding growth and using this understanding to aid economic growth in other countries, particularly in less advanced economies, essentially describing economic convergence as the eventual goal of the study of economic growth. The most groundbreaking articles, at the time, were those of Solow (1956) and Swan (1956), who published on the same year and created what has become known as the Solow-Swan or the Solow model. Solow was recently awarded the Nobel prize in economics for his contribution to the theory of economic growth, as along with his following contributions (e.g., Solow, 1957), laid the foundations of what is known as “growth accounting”. Among the notable contributions is also the work of Rostow (1990) (original document Rostow (1960)), who presented an “impressionistic definition” of the stages of growth, and considered the patterns of growth from an economic historian’s perspective. From a historical perspective, as well, Gerschenkron (1962), describes economic backwardness, through the analysis of industrial development in the 19th century in Europe and Soviet Russia.

The work of Gomulka (1971), also belongs in this category, as he made the first step in building out a dynamic theory of growth, involving technology and labor productivity.

Among the first empirical examinations of economic convergence was that of Baumol (1986), however, it was not directly linked to theoretical models. Barro and Sala-i-Martin (1992) established a connection of an economic convergence concept, that assumes a deterministic trend, to the neoclassical growth model (β-convergence), followed by the related sigma-convergence (σ-convergence). The former was later enhanced to the concept of conditional convergence, with a deterministic trend assumption as well. A significant concept is also that of stochastic convergence that has no particular theoretical background but has an important presence in the relevant literature. In recent years there has been a development of alternative methodologies, such as that of Phillips and Sul (20017), (the log(t) convergence) that does not restrict the nature of the underlying trend, allowing it to be either deterministic or stochastic.

The estimation methodologies for the econometric analysis of these types of convergence are presented in Chapter 3, whilst the section that follows presents the concepts and the relevant findings where they have been applied. The section begins with the most well-known concept of beta-convergence (β-convergence), followed by the related sigma-convergence (σ-convergence). Next, the concept of stochastic convergence is described, with a special focus to the pairwise stochastic convergence of Pesaran (2007) that is studied in Chapter 5. The section that follows it covers the most important literature on the remaining convergence concepts, with a focus on the log(t) convergence that is also studied in Chapter 5. Following that, all relevant empirical research is presented in tables with the most important information regarding each analysis in chronological order. The last section contains a summary paragraph for each of the articles discussed, presented in alphabetical order.

2.3.1. β-convergence

The economic convergence literature is rich in volume as well as debate, which began a concept described by Barro (1984, chapter 12); Baumol (1986); De Long (1988); Barro (1991); Barro, Sala-i-Martin, Blanchard, & Hall (1991); Barro & Sala-i-Martin (1992a, 1992b), that is based on diminishing returns to capital and predicts that poor countries tend to grow faster than rich ones, giving them the opportunity to catch up to them, in terms of per capita (or per worker) income or product. This concept was formally described by Barro and Sala-i-Martin (1992) and became known as "absolute convergence" or "β-convergence".

The first empirical articles that followed searched for the existence of economic convergence, mainly in developed countries as the availability of data was limited. One of the first empirical studies was that of Baumol (1986) and was quite consequential. Baumol (1986) used Maddison's (1982) data to test for the existence of convergence within 16 industrialized countries and found evidence of convergence, especially after World War II. However, De Long (1988) found an error in his calculations and concluded that there was no evidence supporting absolute convergence unless one takes "an optimistic reading of the data". Baumol realized the error pointed out by De Long (1988) and Romer (1986), and in his article Baumol and Wolff (1988) retested for convergence in 72 countries using segmented linear and quadratic regressions, finding convergence for the top 15 countries. All countries exhibited some convergence except for the least developed ones (LDCs), and because of this heterogeneous behavior of the LDCs, longer samples showed no evidence of convergence. Nonetheless, all this correspondence ignited more research on the subject. Baumol, Blackman, and Wolff (1991) tested for and found evidence for convergence in 103 countries from 1960 to 1981. Dowrick and Nguyen (1989), created an extension of the neoclassical model, not with human capital but with a technological catch-up effect, through which the coefficient measures the speed of technological diffusion, instead of convergence.

A series of articles by Barro and Sala-i-Martin followed, where they empirically tested their concepts. Barro and Sala-i-Martin (1990) tested for convergence in 48 US states and the 20 original members of the OECD and found convergence, as was the case in Barro et al. (1991) where they found convergence in 73 European regions from 7 European countries. In contrast, Barro (1991) finds a lack of absolute convergence when testing for it in 98 countries. Sala-i-Martin (1996a) investigates the existence of absolute convergence in a variety of regions spanning over 110 countries. The cross-section of countries exhibited sigma, which will be discussed in the following section, and conditional beta-convergence, nevertheless, when examined in subgroups, all groups exhibited sigma and absolute beta-convergence; 22 OECD countries, 48 US states, 47 Japan regions and 90 European regions from 7 European countries.

There are a few studies during that period that review the empirical findings on convergence, such as the study of De la Fuente (1997), that conducts a selective survey of the empirical research on growth and convergence, focusing on various extensions of the neoclassical model, and reviews stylized facts, results, and implications. Also, the studies of Quah (1996a) and Sala-i-Martin (1996b) parallel each other in reviewing empirical findings on convergence, however, their emphases, interpretations, and criticisms differ sufficiently. Outstanding surveys of the convergence literature are also those of Temple (1999), who summarizes the evidence and some of the implications that the convergence literature has produced, Durlauf and Quah (1999), who provide with some stylized facts (different from Kaldor's, 1961), a presentation of the theoretical growth models and their implications. More recently, Islam (2003), surveys the convergence literature while showing the link between the concept of convergence and the growth theory debate. Easterly and Levine (2001) also document and discuss stylized facts of economic growth while paying attention to Total Factor Productivity (TFP). Abreu et al. (2005) conducted a meta-analysis on convergence in a cross-country or panel data setting, from research that uses growth or the level of income per capita as dependent variables, concluding that results from different growth regressions that are performed on different samples create a misleading picture for the existence of global convergence.

Cole and Neumayer (2003) tested for absolute beta-convergence on 110 countries, using weighted income levels and found strong evidence for it. Andreano et al., (2013) strongly confirm the hypothesis of conditional convergence of per capita GDPs for 26 Middle East and North Africa (MENA) countries over the last 60 years, using several environmental, and economic covariates to condition the model. Young et al. (2013) also tested for conditional beta-convergence, on US county-level data for 22 individual states, using Ordinary Least Squares (OLS) with Fixed Effects and a Generalized Method of Moments (GMM) model, and confirm it, while convergence speeds among states showed significant heterogeneity. Matkowski et al. (2016) examined real income convergence between the Central Eastern European countries that have joined the European Union (EU11) and 15 countries of Western Europe (EU15), using the evolution of the income gap between the two groups, β- and σ-convergence tested and confirmed a clear tendency towards income convergence over the analyzed period. However, the catching-up process was not continuous, exhibiting some breaks and divergence episodes, with the most intensive convergence period being from 2000 to 2007.

2.3.2. σ-convergence

This concept, described by Easterlin (1960); Borts and Stein (1965, chapter 2); Streissler (1979); Barro (1984, chapter 12); Baumol (1986); Dowrick and Nguyen (1989); Barro, Sala-I-Martin, Blanchard, & Hall (1991); Barro & Sala-i-Martin (1992a, 1992b), is based on cross-sectional dispersion. This type of convergence, known as "σ-convergence", occurs when dispersion between countries or regions, measured (usually) by the standard deviation of the logarithm of per capita or per worker income or product, declines over time. This type of convergence is almost always accompanied by β-convergence, as the latter is a necessary but not a sufficient condition for sigma convergence (Barro and Sala-i-Martin, 1992; Sala-i-Martin, 1994, 1996a).

In this context, Rapacki and Próchniak (2009) test for convergence between the 11 Central and Eastern European Countries and the EU-15, using beta- and sigma-convergence, confirming that the EU enlargement contributed significantly to the economic growth of the CEE-11 countries and their catching-up process. Simionescu (2014), on the other hand, tests the EU28, for sigma-convergence, and finds a decrease in divergence, but no clear evidence of convergence. Sigma convergence has also been tested for with unit root tests, for example, Drennan et al. (2004) who used this methodology to test the per capita personal income of metropolitan cities in the US and found that divergence is not decreasing. An alternative approach was presented by Pfaffermayr (2009) who tested for sigma convergence in a spatial context, among 212 EU regions, finding pronounced heterogeneity in the speed of convergence with a relatively slow average of 0.4-0.6%. In more recent literature, Bolea et al. (2018) analyzed the evolution of sigma convergence in Europe, extended to a multi-regional input-output framework, finding that convergence was driven mainly by trade and technological sectors, with the financial crisis reducing its power.

2.3.3. Stochastic convergence

Quah has presented an alternative framework for studying the dynamics of a panel of cross-economy incomes. In his paper in 1993 Quah (1993), produced interesting, robust descriptions of the tendency towards a two-camp world, divided between haves and have-nots, where an escape from the poverty trap has a low probability in both the long- and short- run. In his 1996 paper Quah (1996b), presents new findings - on various issues, such as persistence and stratification, convergence clubs, and the dividing distribution into twin peaks of rich and poor. He suggests the relevance of a class of theoretical ideas, different from the production-function accounting traditionally favored.

Many researchers studied and showed the potential problems associated with the beta-convergence approach, see for example Quah (1993) and Evans (1998). Durlauf et al. (2005) explain that β_{ols} can be negative even when the sample includes countries associated with different steady states. Furthermore, as Bernard and Durlauf (1996) phrase it, "the cross-section tests can reject a no convergence null hypothesis for data generated by economies with different long-run steady states". Others opposed to the idea at a more fundamental aspect, for example, Durlauf and Quah (1999) disagree with the linear approximation of the growth equation since, in many growth models, it is profoundly nonlinear. They were not alone in this disagreement as Bernard and Durlauf (1991, 1995) and Bernard and Jones (1996) have supported the idea that convergence is by default a dynamic concept. In this direction, alternative approaches were proposed where convergence is tested in an explicitly *stochastic* framework. Carlino and Mills (1993) use time series techniques in testing for (stochastic) convergence, which is supported when the log of per capita income of an economy relative to a benchmark economy is stationary. As Evans (1998) explains, stochastic convergence implies that common technology shocks are what drives long-run movements in an economy's output, building on the idea that international differences between economies are temporary. Bernard and Durlauf (1995) test for cointegration between the output series of economies in a new version of stochastic convergence testing, while Evans and Karras (1996) form their alternative approach for stochastic convergence testing, consisting of 4 steps and involving stationarity testing. Their work has since been re-applied, see for example Liu and Ruiz (2006) who used a revised version of the methodology.

As the methodological approaches to the issue of convergence increased, some of the literature focused on examining this process, for example, Goddard and Wilson (2001) considered the relative merits of cross-sectional and panel estimation of convergence regressions. Through Monte Carlo methods, they confirmed that they are both underperformed by a panel estimator which is unaffected by heterogeneity. Allowing for heterogeneity is, for many, the necessary condition to support the cross-sectional notion of β-convergence, for example, Carlino and Mills (1993), and Islam (2003). Soukiazis (2000) attempted to distinguish the main approaches which explain the convergence or divergence phenomena, their results, and their weakness and presents examples of other models as alternative approaches to explain the complexity of the convergence issue.

The empirical literature on stochastic convergence is far from limited. Bernard and Durlauf (1991, 1995) used unit root and cointegration tests on 15 OECD countries and a European sub-sample and found no stochastic convergence for the OECD and some evidence of stochastic convergence in the EU with France. Carlino and Mills (1993) tested for stochastic convergence in the US regions and found some evidence in favor of it. Evans and Karras (1996) also tested the US states along with 54 countries and found evidence in favor of stochastic convergence. Lee et al. (1997) tested a stochastic Solow model on 102 countries and found that this model has quite different properties and substantially higher estimates of beta-convergence. Li and Papell (1999) found evidence of deterministic, as well as stochastic convergence when testing a group of 16 OECD countries, while Fleissig and Strauss (2001), who also tested a group of OECD members (15) and a European sub-sample, using unit root tests, found evidence in favor of stochastic convergence, but only after the World War II. Cellini and Scorcu (2000) analyzed the stochastic convergence of per capita income among the G7 countries, showing that when there are structural breaks, the condition of stationary pairwise differences between per capita GDP, which is a quite strong condition, holds in more cases than expected. However, convergence occurred more often in the first part of the time sample than in the second one.

Evans and Kim (2011) found evidence of stochastic convergence in Asia, when they examined 13 countries. However, that convergence did not hold when they allowed for multiple structural breaks and cross-sectional dependence. Charles, Darne, and Hoarau (2012) analyzed convergence of real per capita output, both absolute and conditional, in the countries of COMESA (Common Market for Eastern and Southern Africa). They used various panel unit root tests but found no evidence in favor of convergence. However, when they applied a condition for economic development, they found two convergence clubs that exhibited absolute convergence, and were such that supported poverty trap conditions being present. King and Ramlogan-Dobson (2015) used Fourier-type tests, to examine stochastic convergence in eighteen Latin American countries, finding that in almost all, growth is consistently related to the U.S. growth, but they had converged to a quite low income level. Chapsa et al. (2015) tested for stochastic convergence in the EU countries, using various unit root tests, with the Netherlands as the benchmark country. The unit root, and the convergence hypothesis were rejected in 6 out of 14 countries. However, they found stronger evidence in favor of convergence when accounting for one or two endogenous structural breaks in the intercept and slope of the trend function.

Stochastic convergence continues to be an essential part of the empirical literature of convergence; however, as Alexiadis (2013) notes; stochastic convergence does not have a clear theoretical background.

2.3.3.1. Pairwise convergence

There is a recent stochastic methodology that has attracted significant attention; the pair-wise convergence test of Pesaran (2007). The proposed approach to testing for output convergence considers all N(N-1)/2 possible pairs of log per-capita output gaps across N economies. All such output gap pairs must be stationary with a constant mean. Essentially, instead of using one of the countries as a benchmark like most of the stochastic empirical analyses, he suggests creating all possible pairs within the sample. The methodology can handle individual output series having unit-roots, or other non-stationary common factors, while it eliminated the choice of a reference country. Many researchers have utilized this methodology, for example, in the context of economic growth convergence is the study of Carrion-i-Silvestre and German-Soto (2009) who analyzed stochastic convergence amongst Mexican Federal entities and found evidence supporting it, after accounting for cross-section dependence and multiple structural breaks. Deckers and Hanck (2012) also employed the Pesaran (2007) definition for testing for output convergence across 51 economies. They extend this definition with testing techniques that allow them to bound the expected fraction of false rejections at a desired level; however, the empirical results showed that the data do not support the notion of output convergence after controlling for multiplicity.

Le Pen (2011) used Pesaran's pair-wise approach to test income convergence on 195 European regions and found little evidence in favor of it. However, they also used autocorrelation functions, and the results showed that shocks to output gaps seem to disappear as time passes.

2.3.4. Other convergence concepts

The traction of the convergence debate has led to the emergence of alternative definitions and accompanying tests of convergence across economies. Kang and Lee (2005) introduced the concept of *Q-convergence*, which is based on whether interquartile range shrinks (convergence) or expands (divergence). Despite being deterministic, it shows changes in both dispersion and clusters and is insensitive to outliers. It has, yet, only been applied by Liaskos and Papadas (2010) in the context of economic convergence.

Another concept of convergence, proposed by Lucke (2008) is ρ-convergence, which is equivalent to β-divergence in reverse time and implies bounds for convergence speed of merely σ-convergent economies. Empirically, the ρ-concept detects divergence earlier than the σ- or β-concept, and according to Lucke (2008), there is a clear ranking among the three concepts, with ρ-convergence being the strongest. For a given persistence of the initial income ranking, ρ-convergence implies faster convergence than σ-convergence, and the latter is faster than β-convergence. Furthermore, the absence of ρ-convergence may indicate long-run-divergence even if σ-convergence seems to be present. However, the concept has not yet been applied in the economic growth context.

A section of the empirical literature of convergence is filled by regional convergence studies; convergence across regions which could cover one or many countries. Unsurprisingly, most of them analyze European regions, as a political and economic union of countries. Azomahou et al. (2011) examined income convergence across 159 European regions, using a semiparametric partially linear model. Their estimation shows country heterogeneity and nonlinearity in the convergence process, and their findings are dependent on the income of the regions. Low-income regions, and new union countries in particular, exhibited divergence, while medium-income regions showed convergence and, finally, high-income regions exhibited no convergence.

2.3.4.1. Log t convergence

Another, recent, alternative for testing for convergence is the log-t convergence test of Phillips and Sul (2007, 2009). This panel methodology allows for the representation of the behavior of economies in transition paths, and allows for a wide range of possible time paths as well as for individual heterogeneity. The model has common as well as individual-specific components and is created as a nonlinear time-varying factor model. The heterogeneous time-varying idiosyncratic components converge over time to a constant, and this form of convergence is related to the concept of conditional sigma convergence. Essentially, it is a simple regression-based convergence test, which includes a new method of creating convergence clubs. The Phillips and Sul (2007, 2009) methodology is getting increasing attention; Monfort et al. (2013), analyzed real convergence in GDP per worker in the EU member, finding evidence of different economic growth rates within Europe, converging to different steady states, which implies divergence in the EU-14. Two convergence clubs emerge from the cluster analysis that are not related to the fact that some countries belong to the euro area, as well as two convergence clubs of Eastern European countries, where belonging to the eurozone appeared significant for club fromation. Borsi and Metiu (2015) investigated per capita income convergence in the European Union (EU), finding no overall income convergence. However, the club convergence analysis using the log-t method, suggested the existence of convergence clubs based, mainly, on geographic criteria, and not so much on EMU membership. A clear separation between the new and old EU members was also evident from the results in the long run, while there was also a division between the South-East vs. North-West dimension since the 1990s. The Phillips and Sul (2007, 2009) methodology was also utilized in the paper of Ghosh et al. (2013), who analyzed regional divergence in income between different states in India, and the results displayed considerable divergence in per capita income across states. Evidence of convergence clubs are also found, that variated, in terms of number and composition, across sectors. At the aggregate level, three clubs are found, while there were also some convergence clubs in the industrial, agriculture and services sectors.

Bartkowska and Riedl (2012) focused on Western European regions (206), and using the Phillips and Sul (2007, 2009) log-t test, they empirically tested the conditional convergence hypothesis. The results showed six per capita income convergence clubs, with estimates from an ordered logit model showing initial conditions explaining club convergence and controlling for its structural characteristics. Using the same methodology (log-t), Simionescu (2015) empirically examined convergence of GDP per capita in EU-28 members and the relevant European regions. They found that at a national level, there were considerable differences between original members and CEEC economies, while at regional level, they found five convergence clubs.

Recently, the log(t) methodology is also being utilized in other expressions of empirical research on economic growth. For example, Holmes et al. (2019) investigate the existence and form of convergence in local house prices using the methodology of Phillips and Sul (2009), Delgado et al. (2019) examine convergence in corporate income tax, while Barrios, et al. (2019) analyze convergence in innovation activity of European regions, providing an alternative methodological view in other strands of the empirical literature of economic growth.

2.3.5. Economic convergence – List of empirical literature

The following tables include the empirical articles from those discussed in the above sections that empirically examine income or output convergence, presented in chronological order.

Table 2. 3 Empirical literature on economic convergence				
Author(s)	**Countries**	**Time Period**	**Model/ Methodology**	**Main Findings**
Abramovitz (1986)	16 countries	1870 - 1979	conditional convergence	strong potentiality for conv. of productivity levels, if countries have a "social capability" adequate to absorb more advanced technologies
Dowrick and Nguyen (1989)	16 OECD countries	1950-1985	non-parametric regression models	convergence that weakens after 1973
Barro and Sala-i-Martin, (1990)	48 US states & 98 countries	1840-1963 & 1960-1985	β- and σ-convergence	conv. for various periods for the US and only conditional conv. for the cross-country analysis
Barro & Sala-i-Martin (1992a)	47 Japan prefectures & 48 US states	1930-1987	β- and σ-convergence	evidence of convergence in both samples
Barro & Sala-i-Martin (1992b)	48 US states	1840-1963	conditional convergence	clear evidence of convergence
Carlino and Mills (1993)	U.S. regions	1929-1990	stochastic convergence β-convergence	evidence for stochastic Conv. for U.S. regional per-capita incomes but only after allowing for a break
Bernard and Durlauf (1995)	15 OECD countries	1900-1987	stochastic conv., trace and maximum eigenvalue statistics on Conv. and cointegration	very little evidence of Conv. - strong evidence of common stochastic elements in long-run economic fluctuations
Bernard and Jones (1996)	U.S. States	1963-1989	stochastic convergence	substantial evidence of catch-up and Conv. in aggregate labor productivity substantial heterogeneity in Conv. outcomes at the industry level
Evans and Karras (1996)	48 US states & 54 countries	1929-1991	stochastic convergence β-convergence	conditional Conv. in both samples from both methods
Quah (1996a)	118 countries	1948-1989	stochastic convergence	Conv. could arise for reasons unrelated to the dynamics of economic growth - some evidence supports Baumol's idea of 'convergence clubs'
Quah (1996b)	European Regions	1980-1989	absolute - Markov Chain	results highlight the importance of spatial and national spillovers in regional income distribution dynamics
Sala-i-Martin, (1996a)	110 countries, subgroups: OECD, US states, Japan pref. European countries	1880-1990	β- and σ-convergence	strong evidence of sigma and absolute beta-convergence in all datasets except for the 110 countries that shows sigma and conditional beta
Sala-i-Martin, (1996b)	US, Japan & 5 European countries	1950-1985	β- and σ-convergence	convergence at approximately 2% a year
Conv.: Convergence, OECD: Organization for Economic Cooperation and Development				

Table 2. 4 Empirical literature on economic convergence

Author(s)	Countries	Time Period	Model/ Methodology	Main Findings
Li and Papell (1999)	16 OECD countries	1870-1989	stochastic & deterministic convergence	evidence of deterministic Conv. for 10, and stochastic Conv. for 14, of the 16 OECD countries
Cellini and Scorcu (2000)	G7	1900-1987	stochastic convergence	stochastic Conv. holds in many cases after allowing for a structural break in the intercept and/or the slope parameters
Fleissig and Strauss (2001)	15 OECD	1900-1987	stochastic convergence	stochastic convergence occurs only in the period 1948–87
Rassekh, Panik & Kolluri (2001)	24 OECD countries	1950-1990	conditional convergence -ARMA process	modest support of conv., explained by patterns of investment, government consumption, and exports
Cole and Neumayer (2003)	110 countries	1960-1996 & 1980-1996	β-convergence	convincing evidence of income Conv. if the regressions are weighted by population
Liu and Ruiz (2006)	24 OECD countries	1953-2000	Absolute and Conditional	robust evidence of conditional convergence among OECD countries
Carrion-i-Silvestre and German-Soto, (2008)	Mexican Federal entities	1870-1994	stochastic convergence β-convergence	stochastic after accounting for cross-section dependence & structural breaks - no evidence of β-Conv.
Pfaffermayr, (2009)	212 EU regions	1980-2002	σ- & conditional spatial σ-convergence	pronounced heterogeneity in the conv. speeds - significant conditional σ- conv.
Rapacki and Prochniak, (2009)	CEE10 & EU15 countries	1996-2007	β- and σ-convergence	the EU enlargement has significantly contributed to the economic growth of the CEE-10 countries
Le Pen (2011)	195 regions of the oldest 15 EU members	1980 to 2006	stochastic convergence	not much evidence in favor of stochastic convergence
Azomahou, El ouardighi, Nguyen-Van, Pham (2011)	European Regions	1990–2005 & 1998-2007	semiparametric specification accounting for country heterogeneity	non-linearity and heterogeneity in the Conv. process - semiparametric models perform better
Evans & Kim (2011)	13 Asian countries	1960 - 2007	stochastic convergence	evidence of stochastic conv., that do not hold after accounting for structural breaks & cross-sectional dependence
Bartkowska & Riedl (2012)	206 European regions	1990 - 2002	two-step procedure endogenous convergence groups	support of Conv. clubs, European regions form six separate groups converging to their own steady-state paths

Conv.: Convergence, OECD: Organization for Economic Cooperation and Development, CEE: Central Eastern European, EU: European Union; ARMA: Autoregressive-moving-average model

Table 2. 5 Empirical literature on economic convergence				
Author(s)	**Countries**	**Time Period**	**Model/ Methodology**	**Main Findings**
Charles, Darne, and Hoarau (2012)	20 COMESA economies	1960 - 2003	stochastic convergence	rejected the presence of stochastic Conv. - a Conv. process towards the bottom is at work, except for the most four developed countries
Deckers and Hank (2012)	51 countries	1950-2003	stochastic convergence	no support for output convergence after controlling for multiplicity
Ghosh, Ghoshray & Malki (2012)	fifteen major states of India	1968–2008	stochastic & deterministic Conv. club conv.	considerable divergence in per capita income across states three endogenous Conv. clubs
Andreano, Laureti & Postiglione (2013)	26 MENA countries	1950-2007	conditional β-convergence	strongly confirm the hypothesis of conditional convergence
Monfort, Cuestas & Ordóñez (2013)	24 European countries	1980 - 2009 & 1990 - 2009	stochastic & deterministic conv. club Conv.	strong divergences within the EU - Eastern European countries seem to benefit from the process of transition & the desire to belong to the eurozone
Young, Higgins & Levy (2013)	US county level on 50 states	1970-2010	regressions - GMM estimations	conv. rates average 9.2% for 22 states, above 5% for 15 states, substantial heterogeneity in individual state conv. rates
Simionescu (2014)	EU28	2000-2012	σ-convergence	no Conv. is confirmed, but there is a decrease in divergence
Borsi and Metiu (2015)	27 of the enlarged EU	1995-2010 27 members 1970-2010 21 members	stochastic & deterministic conv. club Conv.	no overall income Conv. in the EU - mainly geographical Conv. clubs - clear separation between the CEE and the old EU members in the long run
Chapsa, Katrakilidis, and Tabakis (2015)	EU-15	1950–2010	stochastic convergence β-convergence	evidence of stochastic convergence for 6-8 out of 14 countries
King & Ramlogan-Dobson (2015)	18 Latin American countries	1950–2009	stochastic & deterministic convergence	almost half the countries show evidence of catching-up with the US - most of the remainder show evidence of recently achieving deterministic Conv.
Simionescu (2015)	regions of EU28	1995 – 2012	stochastic & determ. convergence club convergence	rejection of the hypothesis of overall Conv. - relative Conv. at country level (four conv. clubs) & at regional level (five conv. clubs)
Matkowski, Prochniak, and Ryszard (2016)	EU11 and EU15 countries	1993-2015	β- and σ-convergence	clear tendency to income Conv. between the two groups of countries, with many breaks & some episodes of divergence
Bolea, Duarte, and Choliz (2018)	28 EU members	2000-2014	σ- convergence	trend towards Conv. with a significant breakpoint in 2008
Conv.: Convergence, COMESA: Common Market for Eastern and Southern Africa, MENA: Middle East & North Africa, GMM: Generalized Method of Moments; CEE: Central Eastern European				

2.3.6. Economic convergence – Theoretical and Empirical Literature by Article

The current section presents more analytically the articles discussed in this chapter so far. The studies are presented in alphabetical order.

Abramovitz, (1986) analyses productivity growth rates of 16 industrialized countries and shows that a country's potential for rapid growth is strong not when it is backward without qualification, but when it is technologically lagging but socially advanced. He claims that a complete view of the catch-up process, does not lend itself to simple formulation, and its implications ramify and are hard to separate from the more general process of growth at large.

Abreu, De Groot & Florax (2005) analyze the results of the empirical literature on the rate of convergence and investigate potential sources of heterogeneity in the estimates. Their analysis reveals that significant differences in convergence rates exist for models deviating from the standard unconditional convergence model. Specifically, models using a standard Solow specification as well as models incorporating fiscal and financial variables typically lead to convergence rates that are significantly higher than the legendary 2% rate.

Andreano, Laureti & Postiglione (2013) use a conditional β-convergence approach to evaluate the economic growth of the Middle East and North Africa (MENA) countries. They use several environmental, and economic covariates to condition the model. They find strong evidence in favor of conditional convergence of per capita GDPs in 26 MENA countries over a period of 60 years.

Azomahou, El ouardighi, Nguyen-Van, Pham (2011) examine income convergence in European regions, using a semiparametric partially linear model. They find that the convergence process includes heterogeneity as well as nonlinearity. Low-income countries, and especially new members exhibit divergence, while medium-income regions are shown to be converging. Lastly, high-income regions exhibit no convergence.

Barro and Sala-i-Martin (1990) discuss convergence in the neoclassical growth model and formally describe and test the concepts of beta and sigma convergence on 48 U.S. states (1840-1963) and 98 countries (1960-1985). They find convergence for various periods for the U.S. and only conditional convergence for the cross-country analysis. Conditional convergence for the U.S. states yields a convergence speed of around 2%. The dynamics of the concepts are discussed as well as the individual effects being observed through beta-convergence, effects related to diminishing returns to capital, the mobility of labor and capital, and the diffusion of technological innovations.

Barro (1991) examines growth in 98 countries from 1960 to 1985. He finds a positive relationship between the growth rate of real per capita GDP and the initial human capital (proxied by school enrollment rates) as well as to measures of political stability. He finds a negative relationship between growth and initial level of per capita GDP and a proxy for market distortions. Furthermore, the results also suggest that higher human capital countries have higher ratios of investment to GDP and lower fertility rates. Finally, growth is found to be inversely related to the share of government consumption of GDP but is trivially related to the share of public investment.

Barro, Sala-i-Martin, Blanchard, & Hall (1991) created an extension of the empirical work of Barro and Sala-i-Martin, (1990) and examined growth and dispersion of per capita income in the U.S. from 1880, and 73 regions of Western Europe from 1950. Overall, the evidence points towards convergence as per capita income and product tend to grow faster in poor states than in rich ones. Similar is the result for the European regions; however, the inclusion of more regions would probably weaken the effects. They also examine the relationship between migration and economic growth and find it to be positive. The article closes with a discussion on the concepts of convergence, the implications arising as well as possible improvements to the models.

Barro & Sala-i-Martin (1992a) examine the new concept of beta convergence in two datasets; 47 prefectures in Japan and 48 states of the United States. Poor prefectures and states are growing faster, showing evidence of convergence is found in both. They analyze cross-sectional standard deviations across states and prefectures, as well, and describe another concept of convergence, related to sigma. Lastly, net in-migration rates' reaction to the log of initial income shows a slow, but important, speed of population adjustment to income differentials.

Barro & Sala-i-Martin (1992b) study the concept of economic convergence of per capita income and product over time, using a neoclassical growth model in 48 U.S. states for the period 1840-1963. They find strong evidence of convergence, but in order for the findings to be reconciled quantitatively with the neoclassical model, diminishing returns to capital have to set in very slowly. They find similar results for per capita GDP while using proxies to account for differences in steady-state characteristics.

Bartkowska and Riedl (2012) focused on Western European regions (206), and they empirically test the conditional convergence hypothesis using the Phillips and Sul (2007, 2009) log-t test. The results indicate six per capita income convergence clubs. Furthermore, ordered logit model results show that initial conditions explain club formation as well as structural characteristics.

Baumol and Wolff (1988) use different methods to test for convergence, coefficients of variation and moving averages (forms of sigma-convergence) as well as regressions of the convergence hypothesis, on different income groups of countries. They find 15 countries to be unambiguously converging; however, this convergence is slowing down. All countries exhibit some convergence at some point, except for the least developed countries. Their interests lie with the reasons why some countries achieve membership in the convergence club and why some get ejected from it.

Baumol, (1986) analyses Maddison's 1870-1979 data that include a historic record growth in productivity, gross domestic per capita income and exports, as well as the extraordinary convergence in productivities of industrialized market economies. Convergence is found to exist in "planned" economies, and not really in less developed countries. He also examines the relation of the lag of productivity "deindustrialization", balance of payments, and unemployment.

Bernard & Jones (1996) suggest that the empirical literature ignores the importance of technology and the potential for technology transfer. They suggest the use of simple models that account for technology transfer, as those can offer a better framework for examining convergence. From the empirical analysis, differences in labor productivity seem to go together with differences in technologies across economies.

Bernard and Durlauf (1991) formalize a general definition for stochastic convergence, using unit root and cointegration methods they test their concept of convergence across industrialized countries. They cannot reject the null of no convergence, while their time-series estimates of representation of cross-country output deviations show there are significantly persistent.

Bernard and Durlauf (1995) construct a stochastic definition of convergence based on the theory of integrated time series in order to test for convergence in per capita output across countries. Testing their new definition on 15 OECD countries reveals little evidence of convergence. However, they find evidence that there is substantial cointegration across OECD economies. In their view, the implication here is that there is a set of common long-run factors which jointly determines international output growth among these OECD economies.

Bernard and Durlauf (1996) point out that the existing frameworks of testing for convergence are based on diverse definitions and procedures and lead to conflicting conclusions. They appear unconvinced by either testing framework; cross-sectional evidence is not in complete accordance with the new growth theory and time series results may be influenced by transitional dynamics.

Bolea, Duarte, and Choliz (2018) study the recent evolution of the sigma convergence in Europe, paying attention to the multi-sectoral and increasingly multi-regional nature of income generation. They find a clear breakpoint in the process of E.U. convergence, around 2008, an increasing role of trade in explaining the domestic and total evolution of income in Europe, and a differential contribution of sectors according to their technological nature. They conclude with the need of including the productive structure and structural change in the analysis of global processes such as convergence.

Borsi and Metiu (2015) investigate per capita real income convergence in the European Union (E.U.) within a nonlinear latent factor framework between 1970 and 2010 in light of the institutional changes and processes of macroeconomic adjustment that take place over the last 40 years. Their findings suggest no overall income convergence in the E.U.; however, they identify convergence clubs using Phillips and Sul (2007, 2009) log-t test. The clubs are formed mainly based on geographic region, and clustering is not necessarily related to EMU membership. The results point to a strong long-run separation between the new and old E.U. members, as well as a division between the South-East vs. North-West since the 1990s.

Carrion-i-Silvestre and German-Soto (2008) analyzed the stochastic convergence amongst Mexican Federal entities in panel data framework. They find evidence in favor of it after accounting for cross-section dependence, as well as multiple structural breaks. However, as stochastic convergence is not a sufficient condition for most economic models of convergence, they also test for β-convergence. The results show that this has not been the case throughout the analyzed period.

Carlino and Mills (1993) employ time series techniques to examine whether the pattern of relative regional per-capita incomes in the U.S. is consistent with the convergence hypothesis. They are generally unable to reject the unit root null for any of the regions and find that region-specific shocks have highly persistent effects. Despite the lack of findings for stochastic convergence for U.S. regions they find that allowing for a break in the convergence rate allows the shocks to U.S. relative regional per-capita income to be characterized as temporary, a finding consistent with stochastic convergence. Last but not least, the findings also support the cross-sectional notion of β-convergence after allowing for a compensating differential among regions.

Cellini and Scorcu (2000) analyze the stochastic convergence in per capita income levels among the current G7 over the period 1900-89. When structural breaks are taken into account, more pair-wise differences between per capita GDP support the strong condition of stationarity than expected. Nonetheless, the first part of the time samples contains more instances of convergence than the second one.

Chapsa, Katrakilidis and Tabakis (2015) test for stochastic convergence, using unit root tests and a test proposed by Tomljanovich and Vogelsang, (2002) and Nieswiadomy and Strazicich, (2004) that is based on Carlino and Mills' (1993) methodology, in the E.U. countries with the Netherlands as the benchmark. They reject the unit root hypothesis for 6 out of 14 countries; however, they find stronger evidence in favor of convergence when accounting for one or two endogenous structural breaks in the intercept and slope of the trend function. The analysis that is based on the methodology of Carlino and Mills (1993), suggests clear evidence of convergence until the mid-1980, with the Netherlands as a benchmark country, for all countries except for the U.K. However, the behavior of the countries' is different in more recent years.

Charles, Darne, and Hoarau (2012) examine the absolute and conditional convergence of real GDP per capita in the Common Market for Eastern and Southern Africa (COMESA) during the period 1950–2003. They use various data unit root tests to examine income differentials across countries, but find no evidence supporting convergence. Nevertheless, applying economic development criterion allows the identification of two absolute convergence clubs into the COMESA. One of the clubs includes four of the most developed countries (Egypt, Libya, Mauritius, Seychelles), and the other the fourteen less developed ones, which suggests a sustained poverty trap process for most COMESA countries.

Cole and Neumayer (2003) test for beta-convergence but weigh for differences in population size and find substantial evidence for absolute convergence in population-weighted income levels. Although the analysis is not complicated, it involves 110 countries, covering approximately 85% of the world population.

De la Fuente (1997) conducts a selective survey of the empirical research on growth and convergence, focusing on various extensions of the neoclassical model, reviews stylized facts, results, and implications. He also describes the difficulties of progress on the subject, some of which are still existing. He also pronounces the significance of the expected payoff of improving our understanding of the growth process.

De Long (1988) focuses on correctly testing for convergence and points out an error in calculating the dependent variable of income at the time, as well as the danger of data selection bias. He explains the error in calculation and suggests building a sample as large as possible is important if it only includes nations social capability and prospects for growth. He re-tests for convergence considering the above conclusions and finds little evidence for convergence. He does believe in the forces creating convergence but suggests that the forces against it are stronger, drawing attention to Romer's (1986) argument about the widening income gap between rich and poor.

Deckers and Hank (2012) employed the definition of Pesaran, (2007) to test for output convergence across 51 economies, which involves output gaps to be stationary around a constant mean. However, when all $n(n-1)/2$ pairs of log per capita output gaps are considered, this results in more than 1,000 unit root tests to be conducted. As a result, and since the ensuing multiplicity of the test, a not unimportant segment of output gaps will be falsely characterized as stationary at a conventional significance level like 5%. To solve the problem, they employ recent multiple testing techniques that allow them to bound the expected fraction of false rejections at a desired level and use Monte Carlo simulations to prove the usefulness of the techniques. The empirical results show that the data do not support the notion of output convergence after controlling for multiplicity.

Dowrick and Nguyen (1989) test the hypothesis that GDP per capita levels and/or levels of Total Factor Productivity (TFP) have converged significantly within the country-members of the OECD, using non-parametric and econometric tests, as well as regression models. They reassess the relative growth performance of the group and find that convergence has been weak since 1973 and has not been systematic since 1950 except for certain groups. However, they find that a dominant and stable trend of TFP catch-up, that is also robust to their testing, showing a systematic tendency for poorer countries within the OECD to grow faster in terms of TFP, even after 1973 when convergence weakens.

Drennan, Lobo, and Strumsky (2004) test for unconditional sigma income convergence for metropolitan economies within the United States, by applying two Unit Root Tests to the time series of the two standard deviation measures. They find that income divergence among metropolitan economies is not decreasing, as the results show that the time series can be described as random walks with drift.

Durlauf and Quah (1999) provided with stylized facts on economic growth and convergence, which differ from those of Kaldor (1963). In surveying the convergence literature, they present theoretical growth models and their implications. Although the Solow model has substantial statistical power in explaining cross-country growth variation, it has many problems, and they wish to go beyond it finding the new growth empirics exciting.

Durlauf, Johnson, and Temple (2005) examine and survey the econometric methodologies used to study economic growth. They provide with some stylized facts that have motivated the development of growth econometrics, the most significant statistical tools employed to explain them, as well as the main statistical problems related to the study of growth. The questions posed by growth economics and the relevant conclusions are restricted by model uncertainty and data limitations.

Easterly and Levine (2001) document and analyze five stylized facts of economic growth, as well as the implications arising from them. They also discuss the different theoretical conceptions of TFP growth and its role in understanding global economic growth.

Evans (1998) uses panel data to compare different growth theories. More specifically, endogenous growth models that predict cross-country differences in trend growth rates, with exogenous that expect parallel balanced growth paths. Using his own method, and samples of rich countries and countries with strong human capital (well-educated populations), he rejects theories that predict any differences in trend growth rates. At the same time, an analysis of a sample of countries with poorly educated populations cannot reject theories that predict broadly different trend growth rates.

Evans and Karras (1996) investigate the existence of convergence in the U.S. states using their 4-spet procedure based on a modified version of the Levin and Lin, (1993) unit root test. They find that convergence occurs only under the condition that technology is stationary around a common trend. They also find strong evidence that the U.S. states are converging quickly to levels that are far apart, suggesting that factors and technology move freely across the states.

Evans and Kim (2011) Re-investigate the hypothesis that the catch-up rates stochastically converge for 13 Asian countries from 1960 to 2007, and find evidence supporting it. However, when allowing for multiple structural breaks and cross-section dependence, stochastic convergence is no longer supported.

Fleissig and Strauss (2001) tested for stochastic convergence of real per capita GDP in 15 OECD economies and a European subsample. Using the panel unit-root tests, they reject the hypothesis of stochastic convergence for the period 1900–87. However, adjusting the sample for the postwar period 1948–87, they find support for stochastic convergence in the OECD economies as well as in the European subsample. This implies that real per capita GDP differentials are stationary, and idiosyncratic country-specific shocks have temporary effects on long-run GDP movements. Permanent shocks to per capita real GDP do not affect international income gaps and imply economies move together in the long run. For the postwar period, the differential in income gaps or speed of adjustment is eliminated at the annual rate of 4.0–8.1% for OECD economies, and 5.8–9.0% for European economies.

Ghosh, Ghoshray & Malki (2012) examine regional divergence in income across different states in India and estimates convergence clubs endogenously. The data is analyzed using the novel method of Phillips and Sul (2007), leading to different conclusions in comparison to past studies, and secondly sectoral level data. Applying the novel approach to panel data relating to fifteen major states of India for the period 1968/69–2008/09, the results display significant divergence in per capita income across states at the aggregate and sectoral levels. They also find existing convergence clubs across sectors that vary in terms of number and composition. At the aggregate level, three convergence clubs are identified, while some are also found at the sectoral level, in the industrial, the agriculture and the services sectors.

Goddard and Wilson (2001) consider the relative merits of cross-sectional and panel estimation of convergence regressions and use Monte Carlo methods to investigate the implications of parameter heterogeneity problem involved with pooled or cross-sectional OLS estimations of convergence. They compared the commonly used estimators with the panel estimator proposed by Breitung and Meyer, (1994) and found that the latter outperforms both the unconditional and conditional cross-sectional and pooled OLS estimators.

Islam (2003) surveys the convergence literature, lays out the different definitions of convergence, and shows the link between the convergence issue and the growth theory debate. He shows the association of different methodological approaches as well as of their results. In his view, despite the existing impressions to the contrary, the results have considerable agreement among them. Despite the problems involved, he is still supporting the cross-sectional notion of beta-convergence, if we allow for a compensating differential among regions. He describes the ways the convergence research has helped growth theories, not only the neoclassical, along with some stylized facts regarding cross-country growth regularities.

Kang and Lee (2005) introduced a new convergence concept Q-convergence, which is based on whether the interquartile range shrinks (convergence) or expands (divergence). It shows changes in both dispersion and clusters and is insensitive to outliers. It is equivariant to log-transformation, leading to robust statistical inference and easier interpretation of different results. However, there is room for improvement; using quantiles other than quartiles in and allowing for more than two clusters to find an optimal number of clusters. They applied it to a panel data set drawn from the Penn World Tables and found that the income gap between the poor and rich countries increased but, the widening gap was rather small and insignificant because the income of the developing countries also increased as the gap widened.

King and Ramlogan-Dobson (2015) use Fourier-type tests, to examine stochastic convergence in eighteen Latin American economies, and find that in most, their growth is consistently related to that of the U.S. Nonetheless, they converge to quite low levels of income.

Lee, Pesaran, and Smith (1997) set out an explicitly stochastic Solow growth model, which is shown to have quite different properties, and consider international per capita output of 102 countries and its growth. They examine the econometric properties of beta-convergence estimates and find they are subject to biases. Allowing for heterogeneity across countries yields significantly higher estimates of beta-convergence, which are, however, imprecisely calculated and hard to interpret. The implications of these results on sigma-convergence are also discussed.

Le Pen (2011) used Pesaran's pair-wise approach to test income convergence on 195 European regions and found little evidence in favor of it, and the results did not change even when using unit root tests that allow for structural breaks. However, they also used the autocorrelation function approach of Caggiano and Leonida (2009), which is based on the evaluation of the persistence of shocks of output gaps, and the results showed that shocks to output gaps seem to disappear as time passes.

Li and Papell (1999) analyze convergence of per capita income in 16 OECD economies, testing for both deterministic and stochastic convergence. They propose approaches that include endogenous breaks to test the unit root hypothesis, i.e., the stochastic convergence hypothesis, in per capita output. They find evidence of deterministic convergence for 10, and stochastic convergence for 14, of the 16 OECD countries. They, too, agree that World War II is a significant break in relative output.

Liaskos and Papadas (2010) Investigate regional human capital convergence in Greece during the period 1971-2001, for the census years for the Greek prefectures (NUTS III areas). Human capital quality is expressed in terms of educational achievement. They investigate the existence of human capital β-convergence using panel data econometric analysis along with an examination of changes in the distributions of educational achievement, using different criteria. Results show that both space and time effects are significant, and there is an established conditional β-convergence. Nevertheless, actual convergence is not achieved over the examined period, and the dispersion of the observed human capital distributions has been increasing.

Liu and Ruiz (2006) test the convergence hypothesis by using a revised 4-step procedure of panel unit root test suggested by Evans and Karras, (1996), using data on output for 24 OECD countries for the period 1953-2000. They test for conditional and absolute convergence, and following a proposition by Baltagi, Bresson, and Pirotte, (2007), they incorporate spatial autoregressive error into a fixed effect panel model to account for the heterogeneous panel structure and for spatial dependence, which might induce lower statistical power of conventional panel unit root test. The analysis finds evidence of conditional output convergence, but at relatively lower speed than the relevant literature.

Lucke (2008) suggests a concept of convergence stronger than σ-convergence. This concept, ρ-convergence, is corresponds to β-divergence in reverse time, and infers bounds for convergence speed of economies that exhibit σ-convergence. It can empirically detect divergence episodes sooner than the σ- or β-concepts. For a given persistence of the initial income ranking, ρ-convergence implies faster convergence than σ-convergence, and the latter is faster than β-convergence. The absence of ρ-convergence may indicate long-run-divergence even if σ-convergence seems to be present.

Matkowski, Prochniak, and Rapacki (2016) analyze real income convergence between the 11 countries of Central Eastern Europe which have joined the European

Union (EU11) and 15 countries of Western Europe (EU15) in the period 1993-2015. The evolution of the income gap between the two groups of countries in terms of GDP per capita at PPP reveals a clear-cut tendency towards income convergence over the analyzed period, also confirmed by the results of β- and σ-convergence tests. However, the convergence period included a number of breaks and some divergence. The strongest convergence occurred during from 2000 to 2007, just before and following the E.U.'s expansion. This suggests that increasing economic integration stimulated the convergence process. However, the global economic crisis, along with financial perturbations in the euro area, have slowed down the convergence in most CEE countries, as reflected by changes in the income gap observed in the years 2007-2015.

Monfort, Cuestas & Ordóñez (2013) analyze real convergence in GDP per worker in the E.U.-14 member states. They find heterogeneity within the growth rates of the European countries that are converging to different steady states, suggesting divergence. Club convergence evidence may also suggest considerable productivity divergence in the area. Within the EU-14 member states, two convergence clubs are observed, which are not related to the fact that some countries belong to the euro area. Furthermore, Eastern European countries are also divided into two clubs, with a more direct effect of belonging to the eurozone in the composition of the clubs.

Pesaran (2007) proposed a pair-wise approach to testing for output convergence that considers all N(N-1)/2 possible pairs of log per-capita output gaps across N economies. The methodology is based on a probabilistic definition of income convergence, that suggests all output gap pairs should be stationary with a constant mean. The approach is compatible with individual output series having unit-roots, or other non-stationary common components and does not involve the choice of a reference country in the computation of output gaps. It is also applicable when N is large relative to T (the time dimension of the panel). After providing some encouraging Monte Carlo evidence on the small sample properties of the pair-wise test, the test is applied to output series in the Penn World Tables over 1950–2000. The empirical analysis does not find support for income convergence overall and questions the existing literature findings of convergence clubs. Nonetheless, he finds considerable evidence of growth convergence, which is reasonably robust to sample period selection and country groupings.

Pfaffermayr (2009) tests for sigma convergence based on a spatial maximum likelihood approach, in 212 EU regions. He finds pronounced heterogeneity in the convergence speeds, with a relatively low average speed around 0.4-0.6%.

Furthermore, using Wald tests for conditional spatial σ-convergence, significant sigma convergence is found at about 1.6% per year under the spatial Solow model.

Phillips and Sul (2007) propose a new panel model to represent the behavior of economies in transition, allowing for a wide range of possible time paths and individual heterogeneity. The model is expressed as a nonlinear time-varying factor model and has both common and individual-specific factors. They provide a framework of asymptotic representations for the factor components that enables the development of econometric procedures of estimation and testing. It is regression-based convergence test, and its asymptotic properties are analyzed under null as well as local alternatives. It also provides with a new method of clustering panels into convergence clubs. These econometric methods are applied to analyze convergence in the cost of living indices among 19 U.S. metropolitan cities.

Phillips and Sul (2009) discuss some extensions of neoclassical growth models that allow for cross-section heterogeneity among economies and evolution in rates of technological progress over time. The models can provide with a range of transitional paths among countries, including convergence to a common steady state, as well as several types of transitional divergence and convergence. Alternative regression methods are proposed, leading to a new test for convergence examination that includes a new procedure for club convergence examination. They apply their test to regional U.S. data, OECD data, and Penn World Table data, estimating transition curves for individual economies and subgroups of economies.

Quah (1993) aims to examine the determinants of long-run growth and to check if, after conditioning on the hypothesized explanatory variables that arose, per capita income converges towards a steady-state growth path, possibly differing across economies. His study produced interesting, robust characterizations of the tendency towards a two-camp world, divided between haves and have-nots, where escaping from the poverty trap is a low probability proposition, either over short- or long-runs. There is greater persistence, at long horizons, than predicted by the best-fitting low-order time-homogeneous models. Quah suggests that taking into account the empirical descriptions presented in this article, economic growth can be successfully analyzed using models of income distributions - where those are across, and not within, entire countries.

Quah (1996a) provided theoretical and empirical frameworks for studying convergence. He described a theoretical model of ideas and economic growth, in which convergence clubs endogenously form, and the distribution of income across economies polarizes. In his view, such a model produces equilibrium dynamics where conventional empirical methods are problematic. Alternative empirics based on analysis of the dynamics of evolving distributions could be more appropriate. The paper then gives results from such empirical analysis, suggesting the strength of cross-country polarization present in the world and some evidence supporting Baumol's idea of "convergence clubs".

Quah (1996b) aims at offering alternative empirics that appropriately address the key issues relevant to convergence analysis. In his view, that refers to what happens to the entire cross-sectional distribution of economies, not whether a single economy is tending towards its own, individual steady state. He describes a body of research that overcomes this shortcoming in the traditional approach. He suggests that theoretical ideas that differ from the traditionally used production-function accounting become relevant due to new findings, on persistence and stratification, on convergence club formation, and on the polarizing distribution between rich and poor.

Rapacki and Prochniak (2009) test for both beta and sigma convergence between the Central and Eastern European Countries (CEE-10) and the EU-15. They find the E.U. enlargement has significantly contributed to the economic growth of the CEE-10 countries, as well as their catching-up process. Their beta-convergence analysis shows that convergence will be achieved in 8 to 33 years.

Rassekh, Panik, and Kolluri (2001) apply a procedure that they propose avoids the problems associated with beta and sigma convergence tests, autoregressive–moving-average (ARMA) models, to 24 OECD countries concluding it lends only modest support to the convergence hypothesis. They find that the OECD convergence in the postwar period can be explained largely by the patterns of investment, government consumption, and exports, leaving little room for convergence forces as a source of additional growth for most of the sample period. Nevertheless, a different sample may generate different results; therefore, they conclude that convergence forces are not ubiquitous.

Sala-i-Martin (1996a) applies the concepts of beta- sigma- and conditional beta-convergence to a variety of datasets. A cross-section of 110 countries, a subsample of the OECD countries, U.S. states, prefectures of Japan and regions of European countries. All datasets except for the 110 countries exhibit strong evidence of sigma and absolute beta-convergence. The cross-section shows sigma and conditional beta. Once again, similar convergence speed is found in all datasets, around 2% a year. Sala-i-

Martin discusses the methodology and the potential for other models to successfully describe economic growth.

Sala-i-Martin (1996b) extends the empirical evidence on regional growth and convergence, investigating the U.S., Japan, and 5 European nations. He finds similar a convergence speed across datasets, around 2% a year. The distribution of incomes between regions has diminished for all countries, with the one-sector neoclassical growth model (with some or no capital mobility) and the hypothesis of technological diffusion as the most promising two of the potential explanations.

Simionescu (2014) tests the EU28 for sigma convergence using statistical variation measures; standard deviation and coefficient of variation for GDP per capita in PPS in the standard version and the variant that takes into account population's weight. Between 2000-2012 the degree of variation decreased, but the economic convergence is not confirmed, the coefficient of variation was more than 40% for both methods, although the weighted method was an improvement for this convergence condition. All in all, no convergence is confirmed, but there is a decrease in divergence.

Simionescu (2015) examine club convergence within the European Union, using the Phillips and Sul (2007, 2009) log-t test, and hypothesizing that high output differences between countries and regions impedes an overall convergence analysis. The empirical analysis uses GDP per capita convergence for EU-28 members and for 272 regions corresponding to NUTS2 level. The results show that at a national level, during 1995 – 2012 there are significant differences between foundation members and CEEC economies, while at regional level five convergence clubs were identified. By identifying convergence clubs, the EU could reduce income differences across regions, as no overall convergence is found between the EU28.

Solow (1957) suggested a simple way of segregating shifts of the aggregate production function from movements along with it. The factors are assumed to be paid their marginal products, but it could easily be extended to monopolistic factor markets. The paper includes a crude application to American data, 1909-49, and finds that technical change was neutral on average. The production function was mostly growing at a rate of about one per cent per year for the first half of the period and 2 per cent per year for the last half, while gross output per man-hour doubled over the interval, with most of the increase attributable to technical change and the remaining to increased use of capital. Finally, the aggregate production function, corrected for technical change, gives a distinct impression of diminishing returns, but the curvature is not violent.

Soukiazis (2000) attempts to distinguish three main approaches which explain the convergence, or divergence phenomena, from a theoretical perspective as well as from the empirical evidence. At the empirical level, the evidence is mostly supporting conditional convergence, with absolute being accepted only in some cases of relatively homogeneous economies. However, the tools used to examine it suffer from some weaknesses, and to this end, he presents examples of cumulative structural models as alternative approaches aiming at explaining the complex issue of convergence.

Swan (1956) aims to illustrate a theme common to Adam Smith, Mill, and Lewis, the theory of which is perhaps best seen in Ricardo: namely, the connection between capital accumulation and the growth of the productive labor force. The illustration of productivity and thrift takes a neo-classical form and enjoys the neo-classical as well as the Ricardian vice.

Temple (1999) surveys the convergence literature and highlights the importance of cross-country research while summarizing and discussing six main questions-topics in the economic growth literature. An important aspect of this discussion is that developing countries are not catching up to the rich, and to some extent, the international income distribution is becoming polarized. There is also an analysis of the variables shown to affect growth and a notion that the Solow-Swan model may not be the whole picture.

Young, Higgins & Levy (2013) estimate convergence rates for 22 individual U.S. states using county-level data. Initially, OLS fixed effects is employed, with the inclusion of control variables which were evaluated, and 4 of them were selected as instruments in a GMM estimation. They find significant heterogeneity; the California estimate is 19.9%, and the New York estimate is 3.3%. They also find that convergence rates are essentially uncorrelated with income levels.

Chapter
3. Econometric Estimation Methodologies

This chapter contains an extensive review on all the methodologies applied in this thesis, along with several of the most significant related methodologies. The chapter begins with a review of cointegration and causality tests, and panel data estimators, followed by a section that describes the various concepts of economic convergence and the most significant related methodologies. Panel unit root and stationarity tests are important to most empirical analyses and they are, in many cases, the necessary first step of the analysis. However, as they are not the main investigation of the thesis, they are presented in the last section of the chapter.

3.1. Cointegration Tests

The cointegration tests require the prior employment of unit root and/or stationarity tests, which are presented in **section 3.4**. Having established from unit root tests that two (or more) variables are stationary in levels and non-stationary in first differences, allows the possibility that there exists a long run co-integrated relationship between the variables. As it is known, if there exists a stationary linear combination of non-stationary variables, the variables combined are said to be cointegrated. Similarly to unit root testing, time-series cointegration tests expanded to panel data in order for more powerful tests to be created. The most notable panel co-integration tests are Pedroni's (1999, 2004), Kao's (1999), Maddala and Wu's (1999) and Westerlund's (2007). Pedroni and Westerlund's provide with a direction of the co-integrated relationship and the other three tests can only verify the existence of such a relationship. The Maddala and Wu test is, in many cases, also a means to acquire the error correction model, which will provide with information about the short-run effects.

3.1.1. Pedroni's Co-integration Test (1999 and 2004)

Pedroni's Co-integration Test (1999 and 2004) uses seven panel co-integration test statistics. Pedroni's tests are applied to evaluate the residuals from the co-integration regression after normalizing the panel statistics with the error correction terms. Pedroni's procedures use the fitted values of the residuals from the long-run regression that follows

$$y_{i,t} = \alpha_i + \delta_{it} + \beta_{1i}x_{1i,t} + \beta_{2i}x_{2i,t} + \cdots + \beta_{Mi} + x_{mi,t} + \varepsilon_{i,t} \qquad 3.1$$

where, $t = 1, \dots, T; i = 1, \dots, N; m = 1, \dots, M$. Where T is the number of observations over time, N is the number of cross-sections of the panel, and M is the number of regressions.

Pedroni considers two classes of statistics. The first class of statistics is based on pooling the residuals of the regression along the within dimension of the panel, while the second class of statistics is based on pooling the residuals of the regression along the between dimension of the panel. The first three panel co-integration statistics are non-parametric, the first is a type of non-parametric variance ratio statistic, the second is analogous to the Phillips and Perron rho-statistic, and the third is analogous to the Phillips and Perron t-statistic. The fourth, and last of the within dimension statistics, is a parametric statistic which is analogous to the augmented Dickey-Fuller t-statistic. The between dimension panel statistics are based on a group mean approach. The first is analogous to the Phillips and Perron rho-statistic, the second to the Phillips and Perron t-statistic and the last one to the augmented Dickey-Fuller t-statistic. Each panel co-integration statistic can be presented as follows.

1. Panel v-Statistic:

$$T^2 N^{3/2} Z_{\hat{v}N,T} \equiv T^2 N^{3/2} \left(\sum_{i=1}^{N}\sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2}\right)^{-1} \qquad 3.2$$

2. Panel ρ-Statistic:

$$T\sqrt{N}Z_{\hat{\rho}N,T-1} \equiv T\sqrt{N}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{2}\right)^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i) \quad 3.3$$

3. Panel t-Statistic (non-parametric):

$$Z_{tN,T} \equiv \left(\bar{\sigma}_{N,T}^{2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{2}\right)^{-1/2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i) \quad 3.4$$

4. Panel t-Statistic (parametric):

$$Z_{tN,T}^{*} \equiv \left(\bar{s}_{N,T}^{*2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{*2}\right)^{-1/2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{i,t-1}^{*}\Delta\hat{e}_{i,t}^{*} \quad 3.5$$

5. Group rho-Statistic:

$$TN^{-1/2}\bar{Z}_{\widehat{rho}N,T-1} \equiv TN^{-1/2}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{e}_{i,t-1}^{2}\right)^{-1}\sum_{t=1}^{T}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i) \quad 3.6$$

6. Group t-Statistic (non-parametric):

$$N^{-1/2}\bar{Z}_{tN,T} \equiv N^{-1/2}\sum_{i=1}^{N}\left(\hat{\sigma}_i^{2}\sum_{t=1}^{T}\hat{e}_{i,t-1}^{2}\right)^{-1/2}\sum_{t=1}^{T}(\hat{e}_{i,t-1}\Delta\hat{e}_{i,t}-\hat{\lambda}_i) \quad 3.7$$

7. Group t-Statistic (parametric):

$$N^{-1/2}Z\bar{Z}_{tN,T}^{*} \equiv N^{-1/2}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{s}_i^{*2}\hat{e}_{i,t-1}^{*2}\right)^{-1/2}\sum_{t=1}^{T}\hat{e}_{i,t-1}^{*}\Delta\hat{e}_{i,t}^{*} \quad 3.8$$

where

$\hat{\lambda}_i = \frac{1}{T}\sum_{s=1}^{k_i}(1-\frac{s}{k_i+1})\sum_{t=s+1}^{T}\hat{\mu}_{i,t}\hat{\mu}_{i,t-s}$, $\hat{s}_i^2 \equiv \frac{1}{T}\sum_{t=1}^{T}\hat{\mu}_{i,t}^2$, $\hat{\sigma}_i^2 = \hat{s}_i^2 + 2\hat{\lambda}_i$, $\bar{\sigma}_{N,T}^2 \equiv \frac{1}{N}\sum_{i=1}^{N}\hat{L}_{11i}^{-2}\hat{\sigma}_i^2$,

$\hat{s}_i^{*2} \equiv \frac{1}{t}\sum_{t=1}^{T}\hat{\mu}_{i,t}^{*2}$, $\bar{s}_{N,T}^{*2} \equiv \frac{1}{N}\sum_{i=1}^{N}\hat{s}_i^{*2}$, $\hat{L}_{11i}^2 = \frac{1}{T}\sum_{t=1}^{T}\hat{\eta}_{i,t}^2 + \frac{2}{T}\sum_{s=1}^{k_i}(1-\frac{s}{k_i+1})\sum_{t=s+1}^{T}\hat{\eta}_{i,t}\hat{\eta}_{i,t-s}$

and where the residuals $\hat{\mu}_{i,t}$, $\hat{\mu}_{i,t}^{*}$ and $\hat{\eta}_{i,t}$ derive from the following regressions:

$\hat{e}_{i,t} = ga\widehat{m}ma_i\hat{e}_{i,t-1} + \hat{\mu}_{i,t}$, $\hat{e}_{i,t} = ga\widehat{m}ma_i\hat{e}_{i,t-1} + \sum_{k=1}^{K_i}\hat{\gamma}_{i,k}\Delta\hat{e}_{i,t-k} + \hat{u}_{i,t}^{*}$ and
$\Delta y_{i,t} = \sum_{m=1}^{M}\hat{b}_{mi}\Delta x_{mi,t} + \hat{\eta}_{i,t}$

Gutierrez (2003) performed Monte Carlo simulations on a number of cointegration tests; for a large T dimension, the Pedroni tests have higher power than the Kao tests, while both tests outperformed the Larsson et al. (2003) LR-bar test. The simulations also indicate that the group p-test of the Pedroni tests is the most promising.

3.1.2. Kao (Engle-Granger based) Cointegration Test (1999)

Kao's (Engle-Granger based) Cointegration Test (1999) approach is quite similar to Pedroni's test, however, it has the restrictive setting of cross-section specific intercepts and homogeneous coefficients on the first-stage regressors. In the bivariate case, we have:

$$y_{it} = \alpha_i + \beta x_{it} + \varepsilon_{it} \tag{3.9}$$

For

$$y_{it} = y_{it-1} + u_{it} \tag{3.10}$$

$$x_{it} = x_{it-1} + e_{it} \tag{3.11}$$

For $t = 1, \ldots, T; i = 1, \ldots, N$.

The next step can either be running the pooled auxiliary regression,

$$e_{it} = \rho e_{it-1} + v_{it} \tag{3.12}$$

or the augmented version of the pooled specification,

$$e_{it} = \bar{\rho}e_{it-1} + \sum_{j=1}^{\rho} \psi_j \Delta e_{it-j} + v_{it} \qquad 3.13$$

Under the null hypothesis of no co-integration, Kao's test follows the following statistics,

$DF_{\rho} = \frac{T\sqrt{N}(\hat{\rho}-1)+3\sqrt{N}}{\sqrt{10.2}}$, $DF_t = \sqrt{1.25}t_{\rho} + \sqrt{1.875N}$, $DF_{\rho}^{*} = \frac{\sqrt{NT}(\hat{\rho}-1)+3\sqrt{N}\hat{\sigma}_u^2/\hat{\sigma}_{0u}^2}{\sqrt{3+36\hat{\sigma}_u^4/5\hat{\sigma}_{0u}^4}}$, $DF_{\rho}^{*} = \frac{t_{\rho}+\sqrt{6N}\hat{\sigma}_u/(2\hat{\sigma}_{0u})}{\sqrt{\hat{\sigma}_{0u}^2/(2\hat{\sigma}_u^2)+3\hat{\sigma}_u^2/(10\hat{\sigma}_{0u}^2)}}$ and for the augmented version, where ρ > 0, $ADF = \frac{t_{\bar{\rho}}+\sqrt{6N}\hat{\sigma}_u/(2\hat{\sigma}_{0u})}{\sqrt{\hat{\sigma}_{0u}^2/(2si\hat{g}ma_u^2)+3\hat{\sigma}_u^2/(10\hat{\sigma}_{0u}^2)}}$

Gutierrez (2003) performed Monte Carlo simulations on cointegration tests and showed that for a large T dimension, the Kao test outperforms the Larsson et al. (2003) LR-bar test, but is not as powerful as the Pedroni tests.

3.1.3. Combined Individual Tests (Fisher/Johansen) Maddala Wu (1999)

Maddala and Wu (1999) use Fisher's (1932) combined test, that utilizes the results of the individual independent tests, to propose an alternative approach to testing for co-integration in panel data by combining tests from individual cross-sections to obtain a test statistic for the full panel creating the Combined Individual Tests (Fisher/Johansen).

If π_i is the ρ-value from an individual co-integration test for cross-section i, then under the null hypothesis for the panel,

$$-2\sum_{\iota=1}^{N} \log(\pi_i) \rightarrow x^2 2N \qquad 3.14$$

The advantage here is that the cointegrated vectors are not specified, and the test searches for the number of stationary combinations that exist among the variables.

On the other hand, this means that the results only provide with an answer to the number of cointegrating vectors and not which they are.

3.1.4. Error Correction Model (ECM) - Engle and Granger (1987)

As already mentioned, through the Maddala and Wu (1999) cointegration test, one can obtain an error correction model, and through that information on the short-run relationship(s) of the variables under analysis. The most notable and commonly used error correction model (ECM) is attributed to Engle and Granger (1987), who consider a bivariate $I(1)$ vector $Y_t = (y_{1t}, y_{2t})'$ and assume that Y_t is co-integrated with co-integrating vector $\eta = (1, -\eta_2)'$ so that $\eta'^{Y_t} = y_{1t} - \eta_2 y_{2t}$ is $I(0)$.

The ECM connects the long-run equilibrium relationship between y_{1t} and y_{2t} implied by co-integration with the short-run dynamic adjustment mechanism that defines how the two series react when they deviate from the long-run equilibrium.

$$\Delta y_{1t} = \alpha_1 + \lambda_1(y_{1t-1} - \eta y_{2t-1}) + \sum_j \beta_{1j}\Delta y_{1t-j} + \sum_j \gamma_{1j}\Delta y_{2t-j} + e_{1t} \qquad 3.15$$

$$\Delta y_{2t} = \alpha_2 + \lambda_2(y_{1t-1} - \eta y_{2t-1}) + \sum_j \beta_{2j}\Delta y_{1t-j} + \sum_j \gamma_{2j}\Delta y_{2t-j} + e_{2t} \qquad 3.16$$

The parameters λ_1 and λ_2 asses the speed of adjustment of y_{1t} and y_{2t} to the long-run equilibrium, respectively.

3.1.5. Westerlund (2007)

Most residual-based cointegration tests have the requirement that the long-run parameters of the variables in levels are equal to the short-run parameters of the variables in their differences. And that is the case for most panel and time series tests. This is referred to as a common-factor restriction, and as Banerjee et al. (1998) and Kremers et al. (1992) have shown, when it does not hold, there is significant power loss in the relevant cointegration tests. Attempting to amend this, Westerlund (2007) developed four new panel cointegration tests that instead of relying on residual dynamics, are based on structural dynamics, and as a result, no common-factor restriction is imposed. The tests are based on testing the null hypothesis of no cointegration by examining if the error-correction term in a conditional panel error-correction model is zero. The specifics of the test are as follows.

Consider the following data generating process

$$\begin{aligned} y_{it} &= \varphi_{1i} + \varphi_{2i}t + z_{it}, \\ x_{it} &= x_{it-1} + v_{it} \end{aligned} \qquad 3.17$$

where t=1, ..., T and i=1, ..., N indexes the time series and cross-sectional units, respectively. For simplicity, the K dimensional vector x_{it} is modeled as a pure random walk while the scalar y_{it} consists of both a deterministic term $\varphi_{1i} + \varphi_{2i}t$ and a stochastic term z_{it}, which is modeled as

$$\alpha_i(L)\Delta z_{it} = \alpha_i\left(z_{it-1} - \beta'_i x_{it-1}\right) + y_i(L)' v_{it} + e_{it} \qquad 3.18$$

Where $\alpha_i(L) = 1 - \sum_{j=1}^{\rho_i} \alpha_{ij} L^j$ and $y_i(L) = \sum_{j=1}^{\rho_i} \gamma_{ij} L^j$ are scalar and K dimensional polynomials in the lag operator L. Equation 3.19 is a conditional error correction model for y_{it} that is created by substituting the first equation (3.17) into 3.18.

$$\alpha_i(L)\Delta y_{it} = \delta_{1i} + \delta_{2i}t + \alpha_i\left(y_{it-1} - \beta'_i x_{it-1}\right) + \gamma_i(L)' + e_{it} \qquad 3.19$$

We rewrite the above equation as follows

$$\Delta y_{it} = \delta'_i d_t + \alpha_i\left(y_{it-1} - \beta'_i x_{it-1}\right) + \sum_{j=1}^{\rho_i} \alpha_{ij} \Delta y_{it-j} + \sum_{j=1}^{\rho_i} \gamma_{ij} \Delta x_{it-j} + e_{it} \qquad 3.20$$

Where $d_t = (1, t)'$ now holds the deterministic components with $\delta_i = (\delta_{1i}, \delta_{2i})'$ being the associated vector parameters. This can be further parameterized as follows

$$\Delta y_{it} = \delta'_i d_t + \alpha_i y_{it-1} \lambda'_i x_{it-1} + \sum_{j=1}^{\rho_i} \alpha_{ij} \Delta y_{it-j} + \sum_{j=0}^{\rho_i} \gamma_{ij} \Delta x_{it-j} + e_{it} \qquad 3.21$$

The parameter α_i is not affected by inserting an arbitrary β_i, which implies that we can validly test H_0 versus H_1 using the least-squares estimate of α_i. Westerlund (2007) proposed four new tests based on the least-squares estimates of α_i in equation 3.21 and its t-ratio. The Stata code of this procedure was created by Persyn and Westerlund, (2008).

3.1.6. Dynamic OLS (DOLS) - Stock and Watson (1993)

Stock and Watson (1993) implemented a method for acquiring an asymptotically efficient estimator for the co-integrated vector η, as well as an accurate formula for estimating its asymptotic variance.

$$y_1 = X\beta + Y^*\eta^* + \sum_{j=-\rho}^{\rho} \Delta Y^*_{-j} \gamma_j + u \qquad 3.22$$

The Dynamic OLS (DOLS) specification enhances the standard co-integration regression with ρ leads and ρ lags of the first difference of the dependent variable (Y^*). This amplification eliminates the harmful effects that short-run dynamics of the equilibrium process u_t have on the estimate of the co-integrated vector η^*, which is consistent, asymptotically normally distributed, and efficient.

Asymptotically valid standard errors for the individual elements of $\hat{\eta}^*$ are given by the OLS standard errors from equation 3.22 multiplied by the ratio

$$\left(\frac{\hat{\sigma}_u^2}{l\hat{r}v(u_t)}\right)^{1/2} \qquad 3.23$$

Where $\hat{\sigma}_u^2$ is the OLS estimate of $var(u_t)$ and $l\hat{r}v(u_t)$ is any consistent estimate of the long-run variance of u_t using the residuals $\hat{u}_t$ from equation 3.22.

3.1.7. Fully Modified OLS (FMOLS) - Pedroni (2000)

According to Pedroni (2000), Fully Modified OLS (FMOLS) is able to accommodate considerable heterogeneity across individual members of the panel, produces an asymptotically unbiased estimator, and produces nuisance parameter-free, standard normal distributions. Pedroni considers the following co-integration system for a panel of $i = 1, \dots, N$ members,

$$\begin{aligned} y_{it} &= a_i + \beta x_{it} + \mu_{it}, \\ x_{it} &= x_{it-1} + e_{it} \end{aligned} \qquad 3.24$$

where the vector error process $\xi_{it} = (\mu_{it}, e_{it})'$ is stationary and the constant term, a_i, allows the co-integrating relationship to include member-specific fixed effects, x_i is an m dimensional vector of regressors, which are not co-integrated with each other.

Pedroni (2000) also states that the group-mean estimator, of this method, has an advantage over the pooled panel FMOLS estimators described in the Pedroni (1996), and that is, that the t-statistic for the former estimator allows for a more flexible alternative hypothesis. That is due to the fact that the group mean estimator is based on the "between dimension" of the panel, while the pooled estimator is based on the "within dimension" of the panel.

3.2. Panel data estimators

The above analysis has thoroughly described the methodologies appropriate for dealing with panel data while the variables under analysis are stationary in levels and non-stationary in first differences. However, that is not always the case, as many times, research has to deal with non-stationary variables, while there is also heterogeneity among the members of the panel sample. The dimensions of the panel data available for analysis are changing, from small T with large N to large T with large N, the asymptotics of which are quite different. Small panel T analysis is usually based on fixed- or random- effects estimators, or fixed-effects with the inclusion of instrumental variables, such as the Arellano and Bond (1991) generalized method of moments estimator (Blackburne and Frank, 2007). However, these methods involve pooling individual groups and allowing only for the intercepts to vary across groups, which is a problem when both N and T are large. As many researchers have found, for example, Im et al. (2003), Pesaran et al. (1999), Phillips and Moon (1999), assuming homogeneity of the slope parameters is frequently inappropriate.

The following sections present estimators, including some that are not bound by that assumption, progressing to estimators that have even less restrictive requirements.

3.2.1. Fixed and Random Effects Estimation

Other than the pooled estimation that does not account for any of the distinguishing characteristics of panel data, analysis on this type of data is most commonly performed using fixed, and sometimes random effects estimations, at least initially. Through these estimations the researcher can account for individual and period effects in the data sample. For example, the following model includes a cross-section effect, that may or may not be present, that can also be specified as a fixed effect.

$$Y_{it} = a + X_{it}\beta_i + \delta_i + \gamma_t + u_{it} \tag{3.25}$$

Cross-section and period specific effects, denoted as the terms δ_i and γ_t, respectively, can either be handled using fixed or random effects methods. For details on the estimation of such models see, for example, Baltagi (2005). With the implosion of some restrictions, models can be specified to contain effects in one or both dimensions. For instance, a fixed effect in the cross-section dimension, a random effect in the period dimension, or a fixed effect in the cross-section and a random effect in the period dimension. However, not all combinations are possible in most econometric software.

In the case of random effects specifications, the terms δ_i and γ_t are assumed to be realizations of independent random variables with mean zero and finite variance. Most importantly, the random effects specification assumes that the effect is uncorrelated with the idiosyncratic residual. For details on random effects models see Baltagi (2005), Baltagi and Chang (1994), Wansbeek and Kapteyn (1989).

3.2.2. Dynamic Panel Data

Many economic issues are dynamic by nature, which empirically translates into the presence of a lagged dependent variable among the regressors. Consider the following one-way error component model:

$$Y_{it} = \delta y_{i,t-1} + x'_{it}\beta + u_{it} \qquad 3.26$$

where $i = 1,2,\ldots,N$, $t = 1,2,\ldots,T$, $u_{it} = \mu_i + v_{it}$, with $\mu_i \sim IID(0,\sigma_\mu^2)$ and $\sigma_i \sim IID(0,\sigma_\mu^2)$. Since y_{it} is a function of μ_i, so is $y_{i,t-1}$.

As a result, the lagged variable makes OLS estimates biased and inconsistent even if the y_{it} are not serially correlated. Fixed effects estimation results are also biased, but they are consistent for T → ∞. This is the case because the within transformation wipes out the μ_i, but there are still problems because by construction, the $y_{i,t-1}$ is correlated with the $\bar{v}_i$, which contains $v_{i,t-1}$. The random effects estimator is also biased.

The following subsections present some of the most important panel data estimators that can be applied to dynamic panel data models.

3.2.2.1. The Arellano and Bond (1991, 1995) Estimator

Arellano and Bond (1991, 1995) argue that the orthogonality conditions that exist between lagged values of y_{it} and v_{it}, can be utilized to obtain additional instruments. They utilize the idea of Anderson and Hsiao (1981) to first differentiate the model to get rid of the μ_i, and then they suggest using all past information of y_{it} as instruments. Consider the model:

$$y_{it} = \delta y_{i,t-1} + u_{it} \qquad 3.27$$

where $i = 1, 2, \ldots, N$, $t = 1, 2, \ldots, T$, $u_{it} = \mu_i + v_{it}$, with $\mu_i \sim IID(0, \sigma_\mu^2)$ and $\sigma_i \sim IID(0, \sigma_\mu^2)$. The equation is differentiated to eliminate the individual effects:

$$y_{it} - y_{i,t-1} = \delta(y_{i,t-1} - y_{i,t-2}) + (v_{it} - v_{i,t-1}) \qquad 3.28$$

Instrumental variables can be used from t=3, and from there, the matrix of instruments containing all instruments of individual i is created. The variance-covariance matrix of the error term needs to be constructed accounting for the differenced error term $(v_{it} - v_{i,t-1})$. Performing GLS on the resulting model yields the Arellano and Bond one-step consistent estimator. However, it is mostly appropriate for panels with small N relative to the T dimension.

3.2.2.2.The Mean Group and the Pooled Mean Group Estimators

These estimators start by assuming an autoregressive distributive lag (ARDL) (p, q1, ..., qk) dynamic panel specification of the following form

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \acute{\delta}_{ij} X_{i,t-j} + \mu_i + e_{it} \qquad 3.29$$

where i=1, 2, ..., N is the number of the groups and t=1, 2, ..., T is the number of periods, $X_{i,t}$ is the vector of explanatory variables, δ_{it} are the coefficient vectors, λ_{ij} are scalars, and μ_i is the group-specific effect. This model requires a large enough T dimension for every group, while trends and other regressors can also be added.

If the variables in the above equation are integrated of order one, I(1), then the error term is a stationary process for all i, suggesting the existence of an error correction model, where deviations from the equilibrium affect short-run dynamics (Blackburne and Frank, 2007). Thus, the equation is often presented as follows.

$$\Delta y_{it} = \varphi_i (y_{i,t-1} - \theta'_i X_{it} + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta y_{i,t-1} + \sum_{j=0}^{q-1} \delta'^*_{ij} \Delta X_{i,t-j} + \mu_i + e_{it} \qquad 3.30$$

where $\varphi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$, $\theta_i = \sum_{j=0}^{q} {\delta_{ij}}\big/{(1 - \sum_k \lambda_{ik})}$, $\lambda^*_{ij} = -\sum_{m=j+1}^{p} \lambda_{im}$ - j=1, 2, ..., p-1, and $\delta^*_{ij} = -\sum_{m=j+1}^{q} \delta_{im}$ - j=1, 2, ..., q-1. The parameter φ_i acts as the error-correction speed of adjustment term.

Pesaran and Smith (1995) proposed approaching equation 3.30 by fitting the model separately for each group and then calculating an average of the coefficients. In the standard implementation, this is a simple arithmetic mean, but weights can also be applied in augmented versions. This is the Mean Group estimator, which allows intercepts, slope coefficients, and error variances to differ across groups.

A few years later, Pesaran et al. (1999), improved upon the Mean group estimator by proposing the Pooled Mean Group estimator that combines pooling and averaging. This estimator allows for a heterogeneous intercept, short-run coefficients, and error variances – same as the Mean Group estimator – but requires the long-run coefficients to be equal across groups, as the fixed-effects estimator would. Pesaran et al. (1999) develop a maximum likelihood approach for estimating equation 3.30, as it is non-linear in the parameters.

3.2.2.3. The Common Correlated Effects Mean Group Estimator

The Pesaran (2006) Common Correlated Effects Mean Group (CCEMG) begins with the following model, for which i=1, 2, ..., N and t=1, 2, ..., T

$$y_{i,t} = \beta_i x_{i,t} + u_{i,t} \tag{3.31}$$

$$\text{where } u_{i,t} = \alpha_{1i} + \lambda_i f_t + \varepsilon_{i,t} \tag{3.32}$$

$$x_{it} = \alpha_{2i} + \lambda_i f_t + \gamma_i g_t + e_{i,t} \tag{3.33}$$

The CCEMG estimator solves the problem of cross-sectional dependence with a simple but powerful augmentation of the equation: cross-section averages of the dependent and independent variables as additional regressors, apart from $x_{i,t}$ and intercept. Adding cross-sectional averages can account for the unobserved common factor (f_t), and the heterogeneous impact (λ_i) is given by construction, as the relationship is estimated separately for each member of the panel. See Eberhardt et al. (2013) for a discussion. So, the cross-sectional averages from the entire panel are calculated and added as explanatory variables in the relevant N regression equations. The estimated β coefficients are then averaged across cross-sections, with the option of weights available.

The estimator is robust to the presence of any number of “weak” factors, and of a few “strong” factors; where the former represents possible spillover effects, while the latter refers to potential shocks such as the global financial crisis (Chudik et al., 2011). Last but not least, Kapetanios et al. (2011) have shown that the estimator is robust to common factors that are non-stationary.

3.2.2.4. The Dynamic Common Correlated Effects Estimator

The Dynamic Common Correlated Effects Estimator (DCCE) proposed by Chudik and Pesaran (2015) extends the Common Correlated Effects Estimator (CCE) approach developed by Pesaran (2006) to dynamic heterogeneous panel data models with weakly exogenous regressors. It is a dynamic panel model that takes into account the time-series nature of the data and parameter heterogeneity with heterogeneous slopes, as well as cross-sectional dependence through an unobserved common factor (f_t) and a heterogeneous factor loading (γ_i).

$$y_{i,t} = \alpha_i + \lambda_i y_{i,t-1} + \beta_i x_{i,t} + u_{i,t} \quad 3.34$$

$$u_{i,t} = \gamma_i' f_t + e_{i,t} \quad 3.35$$

$$\beta_{MG} = \frac{1}{N}\sum_{i=1}^{N}\beta_i, \quad \lambda_{MG} = \frac{1}{N}\sum_{i=1}^{N}\lambda_i \quad 3.36$$

$$i = 1, \dots, N \text{ and } t = 1, \dots, T$$

with $u_{i,t} = \gamma_i' f_t + e_{i,t}$, heterogeneous coefficients that are randomly distributed around a common mean, $\beta_i = \beta + v_i$, $v_i \sim IID(0, \Omega_v)$ and $\lambda_i = \lambda + \varsigma_i$, $\varsigma_i \sim IID(0, \Omega_\varsigma)$. f_t is an unobserved common factor and γ_i a heterogeneous factor loading. Cross-sectional averages are used to approximate the unobserved common factor, Chudik, and Pesaran (2015) show that adding $p = \sqrt[3]{T}$ lags of the cross-sectional averages makes the estimator consistent even in the presence of endogeneity, which is likely to be the case when the model is dynamic.

An important factor in identifying reliable coefficients when analyzing a dynamic panel model is accounting for cross-country heterogeneity and dependence. Not accounting for cross-sectional dependence, which can arise from common unobserved factors or shocks, can lead to biased results (Cavalcanti et al., 2011). The Stata procedure for this methodology, authored for Stata by Ditzen (2018), can also implement the cross-sectional dependence test, CD-test, of Pesaran (2004).

$$CD_{Stat} = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \sim N(0,1) \quad 3.37$$

The test is based on the pair-wise correlation coefficients, has good small sample properties for both dimensions, and the test statistic that is presented above, has a zero mean for fixed values of T and N, under many panel data models, including heterogeneous dynamic models, potentially with multiple breaks in their slope coefficients and error variances[1]. This test allows for the improvement of the analyzed model by providing information about potential cross-sectional dependence.

3.3. Convergence Methodologies

The concept of convergence has been at the center of an extensive debate in the growth literature for decades. Outstanding surveys are those of Temple (1999), Durlauf and Quah (1999), and Islam (2003). The term "convergence" implies a process in which lagging behind countries catch up to wealthy ones in terms of income levels. Undoubtedly, the convergence literature studies an issue of great importance in economics: the distribution of riches across the world and its evolution over time. This is evident by the large body of theoretical and empirical research on economic convergence.

In the economic growth literature, there are two concepts of convergence across countries or regions. One concept (Barro, 1984; Baumol, 1986; De Long, 1988; Barro & Sala-i-Martin, 1992a, 1992b) describes convergence as a process of a poor economy that tends to grow faster than a rich one, so that the poor country tends to catch up to the rich one in terms of levels of per capita income or product. This is known as β-(beta) convergence. The other view (Easterlin, 1960; Borts and Stein, 1965; Streissler, 1979; Barro, 1984; Baumol, 1986; Dowrick and Nguyen, 1989; Barro et al., 1991; Barro and Sala-i-Martin, 1992) describes cross-sectional dispersion. In this view, convergence occurs if the dispersion of income between countries or regions declines over time. This dispersion, usually measured by the standard deviation of per capita

[1] So long as the unconditional means of y_{it} and x_{it} are time-invariant and their innovations are symmetrically distributed. See Pesaran (2004) for more.

income or product in logarithms, is called σ- (sigma) convergence. The first type of convergence (where lagging behind countries tend to grow faster than wealthy ones) has the tendency to create the second type of convergence (reduction of per capita income dispersion); however, there are other forces involved that disrupt this process.

3.3.1. β-convergence

Empirical papers in the literature initially investigated the convergence process by using growth regressions, with the level of initial income as the fundamental explanatory variable. A negative correlation between growth and initial income implies a tendency for lagging behind countries to catch up (Baumol, 1986). The convergence concept associated with these regressions is known as β- (beta) convergence. The beta convergence model is used to test the phenomena of convergence between countries in accordance with the work of Barro & Sala-i-Martin (1992a, 1992b). It is noteworthy that this kind of convergence could exist in homogeneous groups of economies, for example, European countries, U.S. states and prefectures of Japan (Barro & Sala-i-Martin, 1992a, 1992b) or homogeneous group of economies, such as the OECD (Baumol, 1986; De Long, 1988).

There are two kinds of β convergence, with the one being described so far referring to absolute convergence, there is also the concept of conditional β convergence, in which additional variable(s) are taken into account. Conditional β convergence is present if the growth rate of per capita income or product is negatively related to the starting level of per capita income or product, after holding fixed other variable(s), for example, initial levels of human capital, or proxies for government policies. Very similar to those discussed in section 2.2.

Following Sala-i-Martin's (1996b) exposition, assume that β convergence holds for economies i = 1, ..., N. Log-income of the i-th economy can be approximated by:

$$log(y_{it}) = a + (1-\beta)\log(y_{i,t-1}) + u_{it} \qquad 3.38$$

where 0 < β < 1 and u_{it} has mean zero, finite variance, σ_u^2, and is independent over t and transforming it yields:

$$\log\left(\frac{y_{it}}{y_{i,t-1}}\right) = a - \beta\log\left(y_{i,t-1}\right) + u_{it} \qquad 3.39$$

Thus, β > 0 implies a negative correlation between growth and initial log income. The sample variance of log income in t is given by

$$\sigma_t^2 = \left(\frac{1}{N}\right)\sum_{i=1}^{N}[\log(y_{it}) - \mu_t]^2 \qquad 3.40$$

where μ_t is the sample mean of (log) income, and the sample variance is close to the population variance when N is large.

Beta-convergence can also be examined in a recursive fashion, starting from the smallest possible length of sample period (at least 10 observations to obtain valid results), and adding one observation at a time before each re-estimation until all sample observations are included. This can theoretically be applied from either end of the time sample and can help in the identification of the periods with stronger or any evidence of convergence.

Beta is the most popular convergence methodology in the literature, it allows for user-defined club convergence while assuming an underlying deterministic trend. However, Lee et al. (1997) showed that σ convergence has an advantage over β and Q convergence (which will be reviewed in section 3.3.4.3).

3.3.2. σ-convergence

Barro and Sala-i-Martin (1995) and Sala-i-Martin (1996b), as already stated, make an important distinction between β and σ convergence. When the dispersion of real per capita income across a group of economies falls over time, there is σ-convergence. *Β* convergence is a necessary but not a sufficient condition for *σ* convergence. Quah (1993) and Friedman (1992) both suggest that σ-convergence should be examined since it speaks directly as to whether the distribution of income across economies is becoming more equitable. Still, β-convergence has remained a primary focus of growth empirics, perhaps because, it is a necessary condition for σ-convergence.

Equation 3.40 can be used to derive the evolution of σ_t^2

$$\sigma t2 \cong 1 - \beta 2 \sigma t - 12 + \sigma u2 \qquad 3.41$$

Only if 0 < β < 1 is the difference equation stable, so β-convergence is necessary for σ- convergence. Given 0 < β < 1, the steady-state variance is,

$$(\sigma_t^2)^* = \frac{\sigma_u^2}{[1-(1-\beta)^2]} \qquad 3.42$$

Consequently, the cross-sectional dispersion falls with β but rises with σ_t^2. Combining 3.41 and 3.42 yields

$$\sigma_t^2 = (1-\beta)^2\sigma_{t-1}^2 + [1-(1-\beta)^2](\sigma^2)^* \qquad 3.43$$

which is a first-order linear difference equation with constant coefficients. Its solution is given by,

$$\sigma_t^2 = (\sigma^2)^* + (1-\beta)^{2t}[\sigma_0^2 - (\sigma^2)^*] + c(1-\beta)^{2t} \qquad 3.44$$

where c is an arbitrary constant. Thus, since 0 < β < 1, we have |1 – β| < 1, which implies that

$$\lim_{t\to\infty}(1-\beta)^{2t} = 0 \qquad 3.45$$

This ensures the stability of σ_t^2 because it implies that,

$$\lim_{t\to\infty}\sigma_t^2 = (\sigma^2)^* \qquad 3.46$$

Moreover, since (1 – β) > 0, the approach to $(\sigma^2)^*$ is monotonic. It follows, therefore, that the variance will increase or decrease towards its steady-state value depending on the initial σ_0^2.

Sigma convergence focuses on the evolution of cross-section variance of income. Denoting the variance across i (countries re regions) of the log of per capita income $\log y_{i,t}$ as $\sigma_{\log y_t}^2$, it can be said that σ-convergence holds between times t and t+T if

$$\sigma^2_{\log y_t} - \sigma^2_{\log y_{t+T}} > 0 \qquad 3.47$$

Friedman, (1992) and Cannon and Duck, (2000) test for the existence of sigma convergence from a regression of the following form

$$\gamma_i = T^{-1}(\log y_{i,t+T} - \log y_{i,t}) = a + \pi \log y_{i,t+T} + \varepsilon_i \qquad 3.48$$

$$\pi = T^{-1}\left(1 - \frac{\sigma_{\log y_{i,t}, \log y_{i,t+T}}}{\sigma^2_{\log y_{i,t+T}}}\right) \qquad 3.49$$

π<0 implies that $\sigma_{\log y_{i,t}, \log y_{i,t+T}} < \sigma^2_{\log y_{i,t+T}}$, which by implication accepts sigma convergence. See Cannon and Duck (2000) or Durlauf et al. (2005) for proof.

As Bliss (1999, 2000) points out, however, sigma convergence tests are not easy to interpret as they presume that the data generating process is not invariant, there is an evolving distribution for data, which creates problems for the test distributions under the null, even when unit-roots are not present. Egger and Pfaffermayr (2009) proposed a Wald test for conditional sigma convergence in an effort to overcome some of the limitations linked with sigma convergence. Kang and Lee (2005) point out two disadvantages shared by σ convergence and clustering approaches; the first one they mention is the lack invariance to increasing transformation, having log transformation in mind, which is prevalent in practice, and the second concerns the subjective nature of these processes, as there are many ways to measure and define dispersion and clusters.

3.3.3. Stochastic convergence

The use of cross-sectional data in testing for convergence has its drawbacks; Bernard and Durlauf (1996) have shown that short-run transitional dynamics and long-run steady-states can be affected by a diminishing marginal product of capital. At the same time, the null and alternative hypotheses of the conventional convergence procedure are constrictive to "extreme" scenarios of all-or-nothing. To overcome those, an alternative approach was proposed where convergence is tested in an explicitly stochastic framework. Since convergence is, by definition, a dynamic concept, advocates of this approach (e.g., Bernard and Jones, 1996a, 1996b, 1996c; Bernard and Durlauf, 1995) claim that it cannot be described by cross-sectional studies. However, as Alexiadis (2013) notes, stochastic convergence does not have a clear theoretical background.

Bernard and Durlauf (1995) and followed by many others (Oxley and Greasley, 1995, and Camarero et al., 2002, for example) proposed testing for stochastic convergence through cointegration and unit root tests. One approach assumes that the individual output series, y_{it}, $i = 1; 2; \ldots, N;$ are $I(1)$ and applies the system cointegrating techniques directly to these series and tests for the existence of $N - 1$ cointegrating vectors of the form (1, -1) amongst these N series. Under this approach, it is important that the underlying model allows for the possibility of deterministic trends, with the cointegrating relations (if any) tested for co-trending. A second procedure considers testing for unit roots in $N - 1$ output gaps measured with respect to a benchmark country. Once again, this is not sufficient, and one also needs to test that the output gaps do not contain deterministic trends. The cointegrating system approach considers all linear combinations of individual output series and hence all linear combinations of pair-wise output gaps. However, its scope is limited in practice as it can efficiently handle only a small number of countries simultaneously. As a result, many researchers have confined the application of the system approach to a handful of countries (Pesaran, 2007b). Economies *i* and *j* are said to converge if they are cointegrated with a cointegrating vector $[1\ -1]$. Rejecting convergence does not preclude the existence of a long-run relationship between states as a common trend may exist if the states are cointegrated with cointegrating vectors $[1\ -a]$. Using the Johansen cointegration approach, Bernard and Durlauf (1995) rejected stochastic convergence across OECD economies with the data from Maddison (1991) for the 1900–87 period but found evidence of common trends and cointegration. A possible explanation for the rejection may be the presence of structural breaks during World War I, the Great Depression or World War II. These large, infrequent shocks affected economies differently and thus may have caused a rejection of stochastic convergence.

Stochastic convergence "essentially asks whether permanent movements in one country's per capita output are associated with permanent movements in another countries' output." (Bernard and Durlauf, 1991, p. 2). In other words, it examines whether common stochastic elements matter and how persistent the differences among countries are, in a time-series setting. This approach implies that idiosyncratic country-specific factors cannot explain long-run economic growth, with shocks to real per capita output having temporary effects (Fleissig and Strauss, 2001). This infers that that real per capita GDP differentials between economies are stationary (Carlino and Mills, 1993). Through the same frame of thought, Bernard and Durlauf (1995) propose an alternative approach to stochastic convergence, stating that economies i and j converge if they are cointegrated with a cointegrating vector *[1 -1]*.

Convergence testing of this approach is based on the dispersion of output (per capita or per worker) between regions or countries, and whether it has diminished or narrowed over the period in question (Durlauf and Quah, 1999). Accordingly, this method of testing for convergence uses all observations of the examined period and is therefore defined by the relationship between long-run forecasts of the time-series in output per worker, as opposed to the relationship between initial output and growth (Alexiadis, 2013). According to the definition of Bernard and Durlauf (1995), stochastic convergence between two economies i and j occurs if the long-run forecasts of output per worker for both economies are equal. They formally define this convergence property as follows (Bernard and Durlauf, 1995, p. 99):

$$\lim_{k \to \infty} E(y_{i,t+k} - y_{j,t+k} | I_t) = 0 \ \forall i \neq 1 \qquad 3.50$$

where E is the mathematical expectation, y_i is the logarithm of real output per worker in economy i, and I_t describes the information set available at time t. The above equation describes the conditions for absolute convergence between all members of the sample.

This is where one critical issue of this type of convergence lays; determining the appropriate econometric test for stochastic convergence. One of the most commonly used tests is the Augmented Dickey-Fuller (ADF) unit root test and the Kwiatkowski et al. (KPSS) stationarity test. The difference between the two outputs per-worker or per capita series is tested for unit root and/or stationarity. If this difference is found to contain a unit root, according to the concept of stochastic convergence, the economies will not converge, while the absence of a unit root points to convergence. Accordingly, when the difference is found to be non-stationary, the convergence hypothesis is rejected, while a stationary difference indicates convergence between the two economies.

By default, the analysis and examination of stochastic convergence is conducted between two countries, and even when studying many economies, the analysis is performed in a pair-wise fashion (see section 3.3.3.1). This eliminates the possibility of groups of countries to be following a similar convergence path, i.e., club convergence, thus limiting the spectrum of possible explanations and implications of the results. Another important drawback involved with stochastic convergence is its inability to detect co-movement towards a steady-state or the possibility of parallel paths towards long-run equilibrium states. As Alexiadis (2013) describes, unit root tests can detect diminishment of the disparity in outputs between two economies, they cannot, however, detect the occurrence of movement towards long-run equilibriums.

Originally, tests for stochastic convergence involved mostly the ADF unit root test and/or the Johansen cointegration test. These methodologies have gained significant attention, and as a result, more evolved versions of them have emerged, such as the one presented next.

3.3.3.1. Pair-wise convergence

Pesaran (2007a), following Lee et al. (1997), suggested and implemented a way to examine convergence in a distribution over a period. Pesaran considered all observations and took all possible pairwise differences between them, and proposed the following two measures of average convergence or divergence

$$D_t^2 = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (y_{it} - y_{jt})^2 \qquad 3.51$$

$$\Delta_t = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} |y_{it} - y_{jt}| \qquad 3.52$$

Also, if s^2 is the variance of the observed distribution, then $D_t^2 = 2s^2$ and $\Delta_t =$ (Gini coefficient at time t)x$\bar{y}_t$ where $\bar{y}_t$ is the average of the distribution at time t. This type of convergence is related to σ-convergence.

This measure is highlighted because it connects convergence testing approaches that use regressions to approaches using analysis of distribution dynamics supported and explored by Quah (1996b) and many others (e.g., Brock and Durlauf, 2001). Under the null of output convergence, none of these measures should have unit roots or exhibit deterministic trends (Pesaran, 2007a).

Furthermore, regarding stochastic convergence testing, Pesaran (2007a) proposes testing every possible pair of log per-capita output. This approach differs from cross-section or panel data techniques. If we have N regions, we test for convergence for all the N(N−1)/2 log per-capita outputs gaps. The percentage of stationary gaps will provide with evidence on the validity of the convergence hypothesis. After calculation of all possible output gaps, the dummy variable Z takes the value of 1 for each pair that rejects the null of a unit root, and 0 for the ones that fail to do that. The percentage rate of log per-capita output gaps for which the null hypothesis of unit root is rejected would be

$$\bar{Z}_{NT} = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} Z_{ij,T} \qquad 3.53$$

To verify this result, Pesaran (2007a), suggests the use of a Unit root as well as a Stationarity test. This way, in the first test the data must reject the null hypothesis (of a unit root) to suggest convergence, while the null of the stationarity test would have to not be rejected to draw the same conclusion. Consequently, the results are more robust, and the possibility for type 1 and 2 errors is minimized.

The implication of these type of tests that use unit root and stationarity tests for the existence of convergence is not insignificant. For the convergence hypothesis to be true, according to the stochastic convergence methodology, the difference between two cross-section needs not to have a unit root (i.e., to be stationary). However, if the time-series differential of two cross-sections has a unit root, it does not necessarily imply lack of convergence as there is a possibility for a co-movement between them (Phillips and Sul, 2007, 2009; Alexiadis, 2013).

3.3.4. Other convergence concepts

This section presents some of the most significant of the concepts that do not directly fall under the categories presented so far. There are certain convergence concepts, such as ρ- and γ- convergence, that are mostly variations of convergence methodologies already described, and are not included in the present section.

3.3.4.1. Log t convergence

This methodology, proposed by Phillips and Sul (2007, 2009), is capable of detecting stochastic as well as determinist trends of convergence; thus, it can be described as a combination convergence methodology, with respect to the nature of the underlying trend.

The log(t) convergence test, which was developed by Phillips and Sul (2007, 2009), is based on the principles of the neoclassical growth model but it allows for endogenous heterogeneity across individual economies and over time. It assumes that there is a systematic idiosyncratic element that evolves over time following a deterministic or a stochastic trend, which is modeled in a semi-parametric form by means of a time-varying factor loading coefficient. The regression for the relevant test over the period (0,T) is the following:

$$\log\left(\frac{H_1}{H_t}\right) - 2\log(\log t) = a + \gamma \log t + u_t \qquad for\ t = T_0, \dots, T \qquad 3.54$$

where the initial observation of the above regression is $T_0 = [rT]$ for some r>0, so that the first r% (usually between 20% and 30%) of the data sample is discarded, the term $-2\log(\log t)$ acts as a penalty function improving the test's performance and the cross-sectional variance ratio H_1/H_t is constructed using the specification:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2 \text{ and } h_{it} = \frac{y_{it}}{N^{-1}\sum_{i=1}^{N} y_{it}}, \qquad 3.55$$

where $y_{i,t}$ is the per capita GDP for economy i at time t and thus h_{it} is the constructed relative measure of transition coefficients, named the relative transition path, which measures the loading coefficient in relation to the panel, tracing out an individual trajectory for each economy i relative to the panel average. Prior to any estimation, following Phillips and Sul (2007), the Hodrick-Prescott filter is applied to the data, to remove any cyclical components.

Under the null hypothesis of growth convergence, the point estimate of the parameter γ converges in probability to double the speed of convergence parameter 2α.[2] If the convergence hypothesis is accepted, the sign and magnitude of the coefficient $\gamma = 2\alpha$ defines the type of convergence; if $\gamma \geq 2$ (i.e., $a \geq 1$) and the common growth component follows a random walk with a drift or a trend stationary process, then it is implied that there is convergence in the level of per capita income; If $2 > \gamma \geq 0$, then the speed of convergence corresponds to 'conditional convergence'[3], i.e., the growth rates of the per capita income converge over time.

As Phillips and Sul (2007, 2009) show, the test is based on the neoclassical growth model augmented with cross-country technological heterogeneity, thus overcoming the extensively used, and limiting, assumption of homogeneity in the technological progress across countries and time. Furthermore, any existing stochastic trends are not required to be common between countries, as it allows for individual transition paths. Additionally, the model can detect overall convergence, and the convergence predicted by the Solow growth model, to a single steady state, as well as club convergence. As some researchers have shown, for example, Azariadis (1996) and Galor (1996), this type of convergence can also be described as convergence to multiple steady-state equilibria. This is performed by a stepwise clustering algorithm that can identify convergence clusters or clubs in panel data and has the ability to distinguish potential clusters regardless of whether convergence in the entire sample exists or not. The details of the clustering algorithm are presented in the next subsection.

[2] It should be noted that the speed of convergence from the log(t) estimation is not quantitatively comparable to the speed of beta convergence and it should be studied on its own.

[3] Similarly, the term 'conditional convergence' has a different meaning than that of 'conditional beta conference'.

3.3.4.2.1. Clustering Algorithm (Phillips and Sul, 2007)

Phillips and Sul (2007) propose a clustering algorithm to detect possible convergence clubs within a sample. The algorithm aims at identifying a core subgroup G_k, with the possibility of multiple club convergence as $T \rightarrow \infty$. The precise procedure is described step by step as follows.

Step 1: *Last Observation Ordering*. All individuals (countries) (N) are ordered according to their last observations.

Step 2: *Core Group Formation*. The first k highest individuals are selected to create the subgroup G_k, with $N > k \geq 2$. The log t regression is run for this subgroup, and the corresponding test statistic is calculated, $t_{\hat{\gamma}} = t(G_k)$. The size of the core subgroup (k*) is chosen by maximizing t_k over k subject to $min\{t_{\hat{\gamma}}\} > -1.65$, so that the probability of a type II error is reduced, and the false inclusion rate is very low. In the cases where the condition $min\{t_{\hat{\gamma}}\} > -1.65$ does bot hold for k=2, then the highest individual is dropped, and a new subgroup is formed, and the steps are repeated as before. If the condition does not hold for each of the remaining pairs, then the conclusion is a lack of convergence subgroups. On the opposite end, if all individuals are part of the core subgroup, then the size of the convergence club is N.

Step 3: *Sieve Individuals for Club Membership*. One by one, individuals are added to the core (G_{k*}) and for each one, the log t is run and the t-statistic, $\hat{t}$, is derived and compared to chosen critical value c. If $\hat{t} > c$, the individual is included in the core subgroup. This is repeated for the remaining sample resulting in the creation of the first subgroup. Subsequently, the log t test is run on this group to ensure that the convergence condition $t_{\hat{\gamma}} > -1.65$ is met for the entire group. If it is not, the critical value, c, is increased (which also raises the discriminatory power of the test) and this is repeated until the condition is met.

Step 4: *Stopping Rule*. Similarly to the creation of the core subgroup, when a subgroup is formed (through Step 3), the log t test must be run to ensure that $t_{\hat{\gamma}} > -1.65$ and that the group converges. If that is not the case, Steps 1-3 are repeated for this subgroup, to check for a smaller convergent subgroup. If in Step 2, there is no k that satisfies the condition $t_{\hat{k}} > -1.65$, the remaining individuals appear to be non-convergent.

As concerns the critical value of c, which determines the conservativeness of the club formation, the Monte Carlo simulations of Phillips and Sul (2009) suggest that when T is large, it can be set to the critical value -1.65 and for small T or extreme conservatism, can be set to 0. In that case, the results may include an increased number of clubs. To overcome this consequence, there is a final step of possible club merging, where the Log t is performed sequentially on the created clubs to check if they can be merged (if the t-statistic is greater than the critical value, $t_{\hat{\gamma}} > -1.65$. And finally, there is the option of running log t regressions for the non-convergent individuals, to check if they can be added to any of the formed clubs.

3.3.4.2.Modal convergence

The idea of convergence clubs, put forward by Baumol (1986), describes the possibility that the countries of the world belong in distinct groups with common trends, or that this is true for some countries while others diverge from that trend and from the other countries. These possibilities have had some support in the following years; Durlauf and Johnson (1992), Quah (1996b), and Ben-David (1998).

The concept of club or modal convergence is not in contrast to the neoclassical growth model, as Azariadis (1996) and Galor (1996) show, the neoclassical growth model can support the existence of multiple equilibria and different steady-states, resulting in the formation of convergence clubs. Initial conditions remain important in this process, while differences in structural characteristics affect the creation and form of these clubs (see, e.g., Durlauf and Johnson, 1992; Galor, 1996; Bartkowska and Riedl, (2012).

From the methodologies presented so far, beta can be used for club convergence testing using user-defined clubs, while the methodology of log(t) offers the examination of data-driven, endogenously defined convergence clubs. The Q-convergence approach that is presented next can also be used for a form of club convergence testing.

3.3.4.3. Q-convergence

Another alternative definition of convergence was proposed by Kang and Lee (2005), in an effort to overcome the problems associated with the existing definitions of convergence, they named it 'Q-convergence'. This approach examines the interquartile range (IQR) of a distribution and its changes over a period. IQR is often used as a measure of dispersion of a distribution, Deaton (1997), for instance, used it a measure of income dispersion. There are also earlier versions of this approach, however not formally analyzed before Kang and Lee (2005), Beaudry et al. (2002) and Bianchi (1997), who compares the number of modes of GDP distribution at two periods, if the number of nodes declines, convergence is present (modal convergence, 3.4.6). However, Bianchi's approach does not necessarily show a declining standard deviation (SD).

Let L_{Nt} and U_{Nt} denote the lower quantile (25% quantile) and the upper quantile of the sample (75% quantile), M_{Nt} is the sample median quantile with $i = 1, \ldots, N,$ and $t = 0{,}1$. The Q-convergence hypothesis is

$$U_1 - L_1 - (U_0 - L_0) < 0 \qquad 3.56$$

As Liaskos and Papadas (2010) explain, the observations are ranked from the highest to the lowest value, if the range between the 75% quantile and the 25% quantile of the observations is diminished, then convergence has occurred. If we use logarithms, we get

$$\ln(U_1) - \ln(L_1) - [\ln(U_0) - \ln(L_0)] < 0 \quad \Leftrightarrow \qquad 3.57$$

$$\Leftrightarrow \quad \frac{U_1/L_1}{U_0/L_0} < 1 \quad \Leftrightarrow \quad \frac{U_1 - L_1}{L_1} < \frac{U_0 - L_0}{L_0} \qquad 3.58$$

The population lower and upper quartiles are $\ln(L_N)$ and $\ln(U_N)$, for an increasing transformation $T(\cdot)$, the ath quantile of $T(y)$ is $T(a\text{th quantile } of\ y)$. Because of this property, the Q-convergence approach is characterized as equivalent to increasing transformations. This property does not hold in the concept of σ-convergence, and thus, the results of Q-convergence are more easily interpretable when using log transformations. Nonetheless, equations 3.56 and 3.58 can produce opposite results, as in the σ-convergence approach.

With log-transformation, Kang, and Lee (2005) define convergence as a declining IQR relative to the lower quartile. Thus, equation 3.56 is called '(absolute) Q-convergence' while equation 3.58 is called 'relative Q-convergence'. Essentially, they have shown that Q-convergence renders clear interpretations regardless of whether the data is in levels or logs, which is not the case when using mode.

The main advantage of this alternative approach possibly lays in its insensitivity to outliers, which leads to robust statistical inferences. IQR can also be used in a modal convergence approach, as the lower and upper quartile can reflect the centers of two clusters, like two modes, do in a bimodal distribution.

3.4. Panel Unit Root and Stationarity Tests

3.4.1. Introduction

One of the initial attempts on panel unit root testing was by Quah (1992, 1994) in an effort to not only allow the consistent use of panel data in research but to increase the power of the available unit root tests. Another early effort was by Breitung and Meyer (1994), who adapted existing time series unit root tests to panel data in order to provide an insight into panel data properties. Although Quah's estimator was consistent and asymptotically normal, it depended on nuisance parameters that create estimation issues.

Many recent studies have demonstrated, using simulations, that panel unit root tests have notably more power than unit root tests that are based on individual time series. For example, Monte Carlo simulations performed by Levin, Lin, and Chu (2002) demonstrate that panel-based unit root tests are significantly more powerful than the individual time series unit root tests. Also, as Maddala and Wu (1999) point out, the increased power of panel unit root tests over tests that are carried out over a single series is argued in Oh (1996), Wu (1996), MacDonald (1996) and Frankel and Rose (1996).

Panel unit root tests are similar but not indistinguishable to time series unit root tests. The critical difference between them is that in panel data, we must consider the asymptotic behavior of the cross-sectional dimension (N), along with that of the time series dimension (T). To do that we have to consider the way these two dimensions converge to infinity. Although there has been significant analysis on the subject, the first formal theory was described by Phillips and Moon (1999), who define a regression limit theory for nonstationary panel data with large time series and cross-section dimensions. One of the possibilities for their distribution is a sequential limit theory, according to which, one dimension is fixed while the other can go to infinity, providing an intermediate limit from which the fixed dimension is allowed to grow. Another possibility is diagonal path limits; in this case, both dimensions go to infinity along a diagonal path of the type T=T(N) where N goes to infinity. Phillips and Moon (1999) also proposed the joint limits approach where both dimensions are allowed to grow to infinity at the same time, which is generally more robust, though, at the same time, it is more difficult to compute as it requires stronger conditions.

Unfortunately, as Breitung and Pesaran (2008) analyze, this is not the only complication that arises from using panel data. With the inclusion of the cross-section dimension, a considerable amount of unobserved heterogeneity is introduced, causing the model's parameters to be cross-section specific. This is another aspect that is problematic with panel data, the assumption of cross-sectional independence, which, as will be further analyzed in the following section, is an essential and restrictive assumption of the first-generation panel unit root tests. Fortunately, more and more panel unit root tests are being developed, providing researchers with tests that allow for various forms of cross-sectional dependence or avoid the assumption altogether. Finally, an important obstacle in working with panel tests is the interpretation of their outcome. The cross-section dimension complicates the rejection of the null hypothesis, or as Breitung and Pesaran (2008) describe it, the best that can be concluded is that "a significant fraction of the cross-section units is stationary".

In the sections that follow, a wide range of the existing panel unit root tests is presented, organized between first- and second-generation tests. The specifics of this categorization are described in introductory subsections before each category.

3.4.2. First Generation Tests

With the term “First Generation Tests”, we describe the first panel unit root tests that were designed for panels with cross-sectional independence. This basic assumption, as Hlouskova and Wagner (2006) describe it, considerably “simplifies the derivation of the asymptotic distributions of panel unit root and stationarity tests”. Some of the most significant panel unit root tests in this category are those of Levin, Lin, and Chu (2002) (LLC), Harris and Tzavalis (1999), Breitung (2001), Im, Pesaran, and Shin (1997, 2003), Maddala and Wu (1999) (MW) and Choi (2001). Noteworthy panel stationarity tests in this category are the ones of Hadri (2000) and Hadri and Larsson (2005).

Levin and Lin (1992), whose results were later published in Levin, Lin, and Chu (2002), proposed a nuisance parameter-free test, which became very popular, that allows the intercept and trend coefficients to vary across the members of the panel. However, the pooled t-statistic that it produces has a limiting normal distribution that depends on the specifications of the regression. Im, Pesaran, and Shin (1997, 2003) (IPS) proposed a procedure that differentiates from the LLC test as it allows for a heterogeneous coefficient of the lagged dependent variable. Their test is based on averaging individual augmented Dickey-Fuller (ADF) test statistics. Simulation results, however, suggest that the power of both the IPS and the LLC tests is subjective to the specification of the deterministic terms. Another significant panel unit root test was proposed by Maddala and Wu (1999) (MW) and by Choi (2001). They used the Fisher (1992) (Fisher, 1932, as seen in Maddala and Wu, 1999) test which centers on combining the p-values of the test statistic for a unit root in each cross-section. This test can be carried out with any unit root on a single time series, and it is not necessary to use the same unit root test in each cross-section, it does, however, require powerful computer software. The Harris and Tzavalis (1999) test uses a bias-adjusted least squares dummy variable (LSDV) or within estimation, and as a result, it allows non-normality but not heteroskedasticity. The test offers substantial improvements, especially for panels with a small T dimension relative to N, however, it crucially depends on the homoscedasticity of the error terms over time. Breitung (2001) developed a pooled panel unit root test that does not require bias correction factors and is generally considered a powerful test, an aptitude that applies to large panels in particular. The panel stationarity tests of Hadri (2000) and Hadri and Larsson (2005) are based on the time series unit root test of Kwiatkowski, Phillips, Schmidt, and Shin

(1992) and are often observed to underperform. If any substantial serial correlation is present, the null hypothesis of stationarity is rejected.

First-generation panel unit root tests have, in their basic model, one of two alternative hypotheses. H_{1a} assumes an identical autoregressive parameter for all cross-section units; for instance, the LLC (2002) is one of the tests that use this hypothesis, which is called the homogeneous alternative. The second one, H_{1b}, the heterogeneous alternative assumes that N_0 of the N ($0<N_0\leq N$) panel cross-sections are stationary with individual-specific autoregressive coefficients. The IPS (2003) is one of the first-generation panel unit root tests that use this alternative. It is necessary to assume that $N_0/N \rightarrow k>0$ as $N\rightarrow\infty$ for the test to maintain its consistency.

3.4.2.1. Levin, Lin, and Chu (LLC) (2002)

The Levin, Lin, and Chu (2002) (LLC) pooled t-test is an improved version of the Levin and Lin (1992) test as it allows for some cross-sectional heterogeneity. The test also allows for fixed effects as well as unit-specific time trends in addition to common time effects. However, the coefficient of the lagged dependent variable is constrained to be homogeneous across all units of the panel. The construction of the test begins with a pooled fixed effects regression

$$\Delta y_{it} = a_i + \varphi y_{i,t-1} + \varepsilon_{it}, \sim i.d.d.(0, \sigma_i^2) \tag{3.59}$$

The test is based on the t-ration of φ, given by

$$T_\varphi = \frac{\sum_{i=1}^{N} \hat{\sigma}_i^{-2} \Delta y'_i M_e y_{i,-1}}{\sqrt{\sum_{i=1}^{N} \hat{\sigma}_i^{-2} (y'_{i,-1} M_e y_{i,-1})}} \tag{3.60}$$

Where $\Delta y_i = (\Delta y_{i1}, \Delta y_{i2}, \dots, \Delta y_{iT})'$, $y_{i,-1} = (y_{i0}, y_{i1}, \dots, y_{i,T-1})'$, $M_e = I_T - e_T(e'_T e_T)^{-1} e'_T$, e_T is a Tx1 vector of ones, $\hat{\sigma}_i^2 = \frac{\Delta y'_i M_i \Delta y_i}{T-2}$, $M_i = I_T - X_i(X'_i X)^{-1} X'_i$ and $X_i = (e_T, y_{i,-1})$.

According to the authors, the statistic performs well when N lies between 10 and 250, and when T lies between 25 and 250. The power of the test is low if T is very small. One disadvantage of the test statistic is that it relies acutely on the assumption of cross-sectional dependence. Also, the null hypothesis is restricting:

H_0= φ=1 (each time series contains a unit root)

H_1= φ<1 (each time series is stationary)

It is not an option for *some* of the cross-section units to have a unit root. This limitation stems from the fact that the statistic is computed from a pooled regression. The power of the test, however, is higher than the power from individual tests on each panel unit. Furthermore, the general impression from Hlouskova and Wagner (2006) simulation is that the LLC (2002) and the Breitung (2001) tests have the smallest size distortions, with the LLC (2002) test, however, experiencing fast size distortions.

3.4.2.2.Breitung (2001)

Breitung (2001) developed an alternative pooled panel unit root test to the LLC (2002) that uses unbiased estimators rather than bias-corrected ones; this is attained by transforming the variables appropriately. Because the test is computed in pooled fashion, it is also a test against the homogeneous alternative. Following the suitable transformations, the residuals $\tilde{e}_{it}$ and $\tilde{f}_{it}$ are computed:

$$\tilde{e}_{it} = \Delta y_{it} - \sum_{j=1}^{\rho_i} \hat{\gamma}_{ij} \Delta y_{it-j} \qquad 3.61$$

$$\tilde{f}_{it} = y_{it-1} - \sum_{j=1}^{\rho_i} \hat{\gamma}_{ij} \Delta y_{it-j-1} \qquad 3.62$$

The residuals are then standardized to obtain $\hat{e}_{it}$ and $\hat{f}_{it-1}$. Next, they are orthogonalized through the following regressions:

$$e_{it}^{*} = \sqrt{\frac{T-t}{T-t+1}} \left(\Delta \hat{e}_{it} - \frac{1}{T-t} (\Delta \hat{e}_{it+1} + \cdots + \Delta \hat{e}_{iT}) \right) \qquad 3.63$$

$$f_{it}^{*} = \hat{f}_{it-1} - \hat{f}_{i1} + \frac{t-1}{T}(\hat{f}_{iT} - \hat{f}_{i1}) \quad 3.64$$

Finally, the pooled unit root test is performed in the regression that follows,

$$e_{it}^{*} = \varphi^{*} f_{it}^{*} + u_{it}^{*} \quad 3.65$$

Testing the hypotheses H_0: $\varphi^{*} = 0$

H_1: $\varphi^{*} < 0$

The resulting estimator is asymptotically distributed as a standard normal, under the null.

The general impression from Hlouskova and Wagner (2006) simulations is that the LLC (2002) and the Breitung (2001) tests have the smallest size distortions with the Breitung (2001) test exhibiting the most power on large panels.

3.4.2.3.Im, Pesaran, and Shin (IPS) (2003)

The panel unit root test proposed by Im et al. (2003) (IPS) allows for a heterogeneous coefficient of the lagged dependent variable and suggests averaging individual augmented Dickey-Fuller (ADF) unit root test statistics. The ADF regressions with which the method begins are specified as follows:

$$\Delta y_{it} = \alpha y_{it} - 1 + \sum_{j=1}^{\rho_i} \beta_{ij} \Delta y_{it-j} + X'_{it}\delta + e_{it} \quad 3.66$$

The null hypothesis is H_0: $\rho_i = 1$, for all i

and the alternative hypothesis is H_1: $\rho_i < 1$, for at least one i.

Averaging of all individual ADF regressions yields the IPS t-bar statistic as follows:

$$\bar{t}_{N,T} = \frac{1}{N}\sum_{i=1}^{N} t_{i,T} \quad 3.67$$

Under the alternative hypothesis, a properly standardized $\bar{t}_{N,T}$ has an asymptotic standard distribution. Let $E(t_{i,T}) = \mu$ and $V(t_{i,T}) = \sigma^2$, then the distribution is

$$\sqrt{N}\frac{\bar{t}_{N,T} - \mu}{\sigma} \overset{N}{\Rightarrow} N(0,1) \qquad 3.68$$

The IPS test assumes that $E(t_{i,T})$ and $V(t_{i,T})$ is the same for all cross-section units, implying that T is the same for all i. Consequently, the IPS test is applied, but only to balanced panel data. It does, however, remain valid for the case of serially correlated errors as N and T→∞, with the condition of N/T→k, where k is a finite non-zero constant.

The IPS test is less restrictive than the LLC test as it allows for heterogeneous coefficients. Furthermore, it has a more general alternative hypothesis than the LLC, that the ρ_i can vary, and *some* of the individual cross-sections can follow a unit root process. Nonetheless, its power diminishes acutely if a significant fraction of the cross-sections has a unit root. The power of this test can also vary along with the size of the time dimension. For large T, the test has high power, and for small T, the power of the test diminishes. According to Baltagi (2008), when N is small, the empirical size of the test is close to its nominal size of 5%. Westerlund and Breitung (2013) find the local power of the IPS test always to be smaller than that of the LLC test, a find that also corroborates with the results of Bowman (1999).

A block bootstrap version of this test was proposed, that is robust to cross-sectional dependence and some temporal dependencies, see Palm et al. (2011) for more information.

3.4.2.4. Fisher-ADF (1932) by Maddala and Wu (1999) and Choi (2001)

Maddala and Wu (1999) and Choi (2001) independently suggested a test against the heterogeneous alternative that combines the p-values from individual unit root tests using Fisher's (1932) results. Let π_i denote the p-value from any individual unit root test from cross-section i. The combined test statistic proposed by Maddala and Wu (1999) is computed as follows:

$$\bar{\pi} = -2\sum_{i=1}^{N} \log(\pi_i) \qquad 3.69$$

Another possibility, proposed by Choi (2001), is the inverse normal test defined by

$$Z_{INV} = \frac{1}{\sqrt{N}}\sum_{i=1}^{N} \Phi^{-1}(\pi_i) \qquad 3.70$$

Where Φ(·) is the standard normal cumulative distribution function. The null and alternative hypotheses are the same as in the IPS test. Under the null hypothesis $\bar{\pi}$ is x^2 distributed with 2N degrees of freedom, while Z_{INV} follows the standard normal distribution and thus holds as n→∞ and N→∞. Which means it can be used even for very large values of N.

Similarly to the IPS, this test relaxes the restrictive assumption of the LLC test that ρ_i must be the same for all cross-sections under the alternative hypothesis. The major benefit of this test, however, is that it does not require a balanced panel as the IPS does. Therefore, T can differ across cross-sections. It also does not require identical lag lengths in the individual equations, it does, however, assume cross-sectional independence. A less significant, in recent years, shortcoming of this test lies in its computational requirements.

3.4.2.5. Panel Stationarity Tests

This section includes tests for the null hypothesis of stationarity that are designed for independent panels, namely Hadri's (2000), Yin and Wu's (2001) and Choi (2001) combination tests. The difference between these and the panel unit root tests that have been analyzed so far is that these tests examine whether a panel variable is stationary, not whether it has a unit root. This means that stationarity tests and unit root tests examine opposite hypotheses and can thus serve as error tests for each other. The tests can be based on the following models,

$$y_{it} = \mu_{it} + \varepsilon_{it}, \qquad \varepsilon_{it} = \rho_i \varepsilon_{i,t-1} + u_{it}, \qquad (i = 1, \dots, N; t = 2, \dots, n) \qquad 3.71$$

and

$$y_{it} = \mu_{it} + \beta_i t + \varepsilon_{it}, \quad \varepsilon_{it} = \rho_i \varepsilon_{i,t-1} + u_{it}, \quad (i = 1, \dots, N; t = 2, \dots, n) \qquad 3.72$$

If we assume that u_{it} is $I(0)$ for all i and that u_{it} is cross-sectionally independent, the null hypothesis can be described as follows,

$$H_0: |\rho_i| < 1 \; for \; all \; i \qquad 3.73$$

Hadri's (2000) Lagrange Multiplier test for the null of stationarity is an extension on the Kwiatkowski et al., (KPSS) (1992) time-series test. The null hypothesis of the test is stationarity (3.73), against the alternative of a unit root on all units of the panel, which is a result of the pooled design of the test. The test can be defined by using the regression residuals from models 3.71 and 3.72. Letting $r_{it} = \sum_{k=1}^{t}(y_{ik} - \bar{y}_i)$ with $\bar{y}_i = \frac{1}{n}\sum_{t=1}^{n} y_{it}$, Hadri's test for model 3.71 can be defined by

$$LM_{Nn} \Rightarrow \frac{1}{N}\sum_{i=1}^{N}\frac{1}{n^2\hat{\sigma}^2}\sum_{t=1}^{n} r_{it}^2 \qquad 3.74$$

where $\hat{\sigma}_i^2$ is an estimation of the long-run variance of y_{it}. Hadri proposed a modification of the test for large N that can be defined as follows,

$$W_{LMbar} = \frac{\sqrt{N}(LM_{Nn} - \frac{1}{6})}{\sqrt{\frac{1}{45}}} \Rightarrow N(0,1) \qquad 3.75$$

If we reject the null hypothesis 3.73, as Choi (2006) describes, a realized value of the stationarity test G_{in} is greater than a constant. The asymptotic p-value for the G_{in} test is defined as

$$p_i = 1 - F(G_{in_i}) \qquad 3.76$$

where F(·) denotes the distribution function of the G_{in} test when n is sent to infinity. Yin and Wu's (2001) combination test employs KPSS (1992) and Leybourne and McCabe (1994) tests for G_{in} and combines the resulting p-values using Fisher's test. The limiting distribution of Yin and Wu's (2001) combination test for fixed N is described as follows

$$P \Rightarrow \chi^2_{2N} \quad 3.77$$

Another option suggested by Choi is the Z test defined in 3.69 in the Fisher-ADF subsection. Its distribution is a standard normal for both finite and infinite N.

Panel tests for the null of stationarity tend to have significant size distortions when the null is close to the alternative, therefore, interpreting their results should be done with caution (for example, in combination with unit root tests).

3.4.2.6. Finite T Unit Root Tests

There are a number of panel unit root tests that are designed for a fixed time dimension (T). They are, however, practically restrictive as homogeneity of the slope coefficient has to be imposed. These include Breitung and Meyer (1994), Harris and Tzavalis (1999) and Binder et al. (2005).

Breitung and Meyer (1994) propose an alternative route to avoid the bias, and therefore the correction terms, by using the initial value of the dependent variable of each of the cross-sections as an estimator of the constant term. Harris and Tzavalis (1999) enhance the Levin and Lin (1993) test and derive unit root tests with asymptotic properties only in the cross-section dimension, for serially uncorrelated panel data models. Despite its white noise error restriction, the Harris and Tzavalis' (1999) test offers improved results over the Levin and Lin (1993) test in short panels with small T and large N dimension. Binder et al. (2005) consider estimation and inference in panel vector auto-regressions (PVARs) with homogeneous slopes. For fixed time dimension Binder, Hsiao, and Pesaran derive asymptotic (N→∞) normality of the QMLEs (Quasi-Maximum Likelihood Estimators) using specifications of both random and fixed effects. These distributions are robust to the presence of unit roots; however, since T is fixed, homogeneity of the VAR coefficient should be imposed, which may be deemed too restrictive in applications using VAR. The Hadri and Larsson (2005) test is an extension on the Hadri (2000) test to the statistics with a fixed T dimension. They extract the exact sample mean and variance based on the KPSS (1992) test, as follows, and has an asymptotically normal distribution.

$$\eta_{iTm} = \frac{1}{T^2}\sum_{t=1}^{T}\frac{S_{iT}^2}{\hat{\sigma}_{ei}^2} \tag{3.78}$$

The potential benefit from finite T tests is the avoidance of problems associated with treating two dimensions as asymptotic (N as well as T). However, as Hlouskova and Wagner (2006) point out since T is fixed, only estimates for the long-run variances are available and thus asymptotic normal distribution may not hold exactly.

3.4.3. Second Generation Panel Tests

As already stated, first-generation unit root tests rely on cross-sectional independence, which is a restrictive assumption, especially in macroeconomic studies, such as the study of output convergence by Phillips and Sul (2003b) or the one by O'Connell (1998) concerning purchasing power parity.

Applying first-generation tests on panels that are characterized by cross-sectional dependencies leads to loss of power and size distortions (Banerjee et al., 2005; Strauss and Yigit, 2003), which makes this a prominent issue. That is the reason why more and more tests in the literature try to avoid the assumption of cross-sectional independence: Bai and Ng (2004, 2010), Chang (2002, 2004), Choi (2002), Moon and Perron (2004a), Pesaran (2003), Phillips and Sul (2003a), Pesaran (2005), the cross-section augmented Im–Pesaran–Shin (CIPS) and Sargan–Bhargava (CSB) tests of Pesaran (2007b) and Pesaran et al. (2013). These tests allow for the presence of cross-sectional dependence among the units, typically through the presence of dynamic factors. This section includes a brief analysis of the most significant contributions in this category, Hurlin and Mignon (2007) and Breitung and Pesaran (2008) provide a descriptive analysis of the second-generation panel unit root test.

3.4.3.1. Pesaran (2007), Pesaran, Smith and Yamagata (2013)

The cross-section augmented Im–Pesaran–Shin (CIPS) and Sargan–Bhargava (CSB) tests of Pesaran (2007b) and Pesaran et al. (2013) are two of the most popular second-generation tests yet, with numerous applications and extensions (see, for example, Westerlund et al. (2016)). The first test is based on a cross-section average (CA) augmentation approach (Pesaran, 2006), which uses the cross-section average $\overline{Y}$ of $Y_{i,t}$ as a proxy for the common component of the data. This proxy is then included, as an additional regressor, in the regression.

The asymptotic distributions of the resulting CIPS and CSB statistics, however, as Reese and Westerlund (2016) explain, will depend on the Brownian motion generated by $\overline{Y}_t$, making them highly non-standard. Nonetheless, as Pesaran et al. (2013) show, when properly implemented, the CIPS and CSB tests have relatively good small-sample performance. Another feature of these statistics is that they assume that the common and idiosyncratic components of the data have the same order of integration, which is not always the case in practice.

3.4.3.2. Bai and Ng (2004, 2010)

Bai and Ng (2004, 2010) proposed the first test of the unit root null hypothesis that takes into account the possibility of cross-sectional correlation. Their approach consists of a factor analytic model of the following form:

$$y_{i,t} = D_{i,t} + \lambda'_i F_t + e_{i,t} \qquad 3.79$$

where $D_{i,t}$ is a polynomial time function of order t, F_t is an (r,1) vector of common factors, and λ_i is a vector of factor loadings. This approach essentially decomposes the individual series into a heterogeneous deterministic component $D_{i,t}$, a common component $\lambda'_i F_t$ and a largely idiosyncratic error term $e_{i,t}$. As Hurlin and Mignon (2007) explain, it is the presence of the common factors F_t, according to which each there is an individually specific elasticity λ_i, which is at the origin of the cross-sectional dependencies.

The series in question is said to be nonstationary if at least one common factor of the vector F_t and/or the error term $e_{i,t}$ is nonstationary. However, these two terms can each have different dynamic properties. This creates problems in determining the dynamic properties of the entire series since one of its components could be large and stationary. To overcome this issue, Bai and Ng (2004) employ a procedure which they named PANIC (Panel Analysis of Non-stationarity in the Idiosyncratic and Common components). This procedure differentiates in this aspect from two of the cross-section-augmented Im–Pesaran–Shin (CIPS) and Sargan–Bhargava (CSB) tests of Pesaran (2007b) and Pesaran et al. (2013), as the PANIC approach allows for different order of integration for the common and idiosyncratic components of the data.

Bai and Ng (2004) accomplish this by first transforming the variable in question by taking first differences, estimating common and idiosyncratic components and then cumulating them up to levels. Because the first regression is applied on the first differences of the variable, one of the digest problems in dealing with panel data, common factors, such as international trends of business cycles, are eliminated from the data. Bai and Ng test the null hypothesis on the estimated variables of the idiosyncratic component and the common factors $\hat{e}_{i,t}$ and $\hat{F}_t$. The test does exhibit size distortions in small samples, see for example the Monte Carlo experiments in (Gengenbach et al., 2006; Gengenbach et al., 2016; Pesaran et al., 2013; Westerlund and Larsson, 2009). However, the simulations made by Bai and Ng (2004) show that their test gives satisfactory results in terms of size and power for large, and even for moderate panel sample sizes (N = 20).

3.4.3.3. Chang (2002)

Chang (2002) proposed a nonlinear instrumental variable (IV) approach, where the transformed variable

$$w_{1,t-1} = y_{1,t-1}e^{-c_i|y_{i,t-1}|} \qquad 3.80$$

with $c_i > 0$ is used as an instrument for estimating φ_i in the regression $\Delta y_{it} = \varphi_i y_{i,t-1} + \varepsilon_{it}$ (which may also include deterministic terms and lagged differences). Since $w_{1,t-1}$ tends to zero as $y_{i,t-1}$ tends to $\pm\infty$ the trending behavior of the nonstationary variable $y_{i,t-1}$ is eliminated. Using the results of Chang et al. (2003), Chang (2002) showed that the Wald test of $\varphi = 0$ based on the nonlinear IV estimator possesses a standard normal limiting distribution. Another significant aspect of this test is that the nonlinear transformation also takes account of possible contemporaneous dependence among the cross-section units. Consequently, Chang's panel unit root test claims to also be robust against cross-sectional dependence. Im et al. (2003), however, show that the test is not robust to the presence of cross-sectional correlations. Chang (2002) establishes that individual Dickey-Fuller (DF) or the augmented DF (ADF) statistics are asymptotically independent when an integrable function of the lagged dependent variables is used as an instrument. As a result, the test claims to be valid even when both T and N dimensions are large. However, as shown by Im et al. (2003), the test is valid only if $N \ln T/\sqrt{T} \to \infty$, which is a condition that is not likely to hold in practice, unless N is very small.

3.4.3.4. Choi (2002)

Choi (2002) considered a two-way error-component model to account for cross-dependence with one common factor, in contrast with Bai and Ng (2004) and Moon and Perron (2004), represented by θ_t.

$$y_{i,t} = a_i + \theta_t + u_{i,t} \quad 3.81$$

$$u_{i,t} = \sum_{j=1}^{p_i} d_{i,j} u_{i,t-j} + \varepsilon_{i,t} \quad 3.82$$

The assumption here is that the individual variables $y_{i,t}$ are equally affected by the common factor (r=1), which represents the time effect. It is possible, also, to test the weak stationarity hypothesis of this common factor. In this model (Choi also considers one with individual time trends), the null hypothesis is that there is a unit root in the idiosyncratic component $u_{i,t}$ for all individuals

$$H_0 : \sum_{j=1}^{p_i} d_{i,j} = 1 \ \forall \, i = 1, \dots, N \quad 3.83$$

against the alternative, that there exist some individuals i such that

$$\sum_{j=1}^{p_i} d_{i,j} < 1 \quad 3.84$$

3.4.3.5. Moon and Perron (2004a)

Moon and Perron (2004) tested for the presence of a unit root directly. In contrast to Bai and Ng (2004), they do not test the individual and common components separately, they do, however, use a factor model. Moon and Perron (2004) consider a standard autoregressive process with fixed effects, where residuals follow a factor model

$$y_{i,t} = a_i + y_{i,t}^0 \quad 3.85$$

$$y_{i,t}^0 = \varphi_i y_{i,t-1}^0 + \mu_{i,t} \quad 3.86$$

$$\mu_{i,t} = \lambda'_i F_t + e_{i,t} \quad 3.87$$

Where the dimension r of the vector F_t is known and the idiosyncratic shocks $e_{i,t}$ are uncorrelated in the individual dimension. λ_i determines the cross-sectional correlation of $y_{i,t}$ variables. The null hypothesis of the test is that all individuals have a unit root

$$H_0: \varphi_i = 1, \forall\ i = 1, \dots, N \quad 3.88$$

Against the alternative

$$H_1: \varphi_i < 1\ for\ at\ least\ one\ i \quad 3.89$$

Moon and Perron's (2004) model eliminates the common components of the series in question, thus removing the cross-sectional dependencies, and tests the de-factored series for the presence of a unit root, deriving normal asymptotic distributions. However, this test of Moon and Perron (2004), as well as the test of Pesaran (2005), may lead to misleading conclusions if y_t contains common stochastic components.

3.4.3.6. Pesaran (2003, 2005)

Pesaran (2003) modeled cross-sectional correlation using common factors using the following homogeneous autoregressive process

$$\Delta y_{it} = p_i y_{i,t-1} + \sum_{j=1}^{k_i} \varphi_{ij} \Delta y_{i,t-j} + \mu_i + \beta_{it} + u_{it} \quad 3.90$$

$$where\ \ i = 1, \dots, N\ \ and\ \ t = k_i + 2, \dots, n$$

He assumes that $u_{it} = \gamma_i f_t + \varepsilon_{it}$, where f is an unobserved common factor, γ_i a factor loading coefficient and ε_{it} are the idiosyncratic errors. The central idea of Pesaran's and Phillips' and Sul's tests is to remove the common factor f_t, essentially eliminating any cross-sectional dependence and consequently applying panel unit root tests that are designed for independent panels.

Pesaran's (2005) panel unit root test, similarly to Moon and Perron (2004) and, both in contrast to Bai and Ng (2004), assume that only the idiosyncratic components have unit roots and not the common stochastic components, which is an assumption that requires large datasets. As Choi (2006) describes, Pasaran's test is a shortened version of the IPS test that evades the problem of moment calculation by eliminating the presence of cross-sectional correlation. This is achieved by augmenting the regression with the cross-sectional averages of lagged levels and first differences.

As mentioned before, the tests of Moon and Perron (2004) and the test of Pesaran (2005) may lead to misleading conclusions if y_t contains common stochastic components. Simulations performed by Baltagi et al. (2007) in order to examine size distortions in panel unit root tests showed that they are evident even in tests that allow for weak dependence (such as the non-linear instrumental variable approach suggested by Chang (2002)). A fascinating outcome of their simulations is that Pesaran's test, although not created to account for weak cross-section dependence, as far as spacial type dependence, it tends to be the most robust.

3.4.3.7. Phillips and Sul (2003)

Phillips and Sul (2003a) considered a similar model with Moon and Perron (2004) with two main differences. Firstly, it is a more restrictive model since only one factor is independently distributed across time, making the common factors vector, a single N.i.d. (0, 1) variable. Secondly, Phillips and Sul (2003a) employ a moment method approach in order to remove the common factor, aiming at performing the unit root test on orthogonalized data. Their test uses the following model

$$\Delta y_{it} = p_i y_{i,t-1} + \sum_{j=1}^{k_i} \varphi_{ij} \Delta y_{i,t-j} + \mu_i + u_{it} \qquad 3.91$$

$$where \;\; i = 1, \dots, N \;\; and \;\; t = k_i + 2, \dots, n$$

Similarly to Pesaran (2005) they assume $u_{it} = \gamma_i f_t + \varepsilon_{it}$ where $\gamma_i f_t$ embodies the cross-sectional correlation. Phillips and Sul (2003a) eliminate the common factor from the series by estimating $[\gamma_1, \dots, \gamma_N]$ and $[\sigma_1^2, \dots, \sigma_N^2]$, using the principal-component method. Phillips and Sul (2003a) demonstrate that their panel unit root test performs fairly well in finite samples.

3.4.3.8. Breitung and Das (2005)

Breitung and Das (2005) proposed a panel unit root test that avoids the use of a nonparametric (kernel-based) estimator for the long-run variance with an alternative approach. Under the null hypothesis

$$\gamma_i(L)\Delta y_{it} = \delta_i' d_{it} + \varepsilon_{it} \qquad 3.92$$

Where, $\gamma_i(L) = 1 - \gamma_{i1}L - \cdots - \gamma_i, p_i L^P$ and L is the lag operator. y_{it} is then replaced by the pre-whitened $\hat{y}_{it} = \hat{\gamma}_i(L)y_{it}$, where the $\hat{\gamma}_i$ estimator of the lag polynomial is obtained from the least-squares regression

$$\Delta y_{it} = \delta_i' d_{it} + \gamma_{i1}\Delta y_{i,t-1} + \cdots + \gamma_i, p_i \Delta y_{i,t-p_i} + \varepsilon_{it} \qquad 3.93$$

The resulting t-statistic has a standard normal limiting distribution as T→∞ is followed by N→∞.

Chapter
4. Evaluation of Methodologies for the interactions of Economic Growth: An application on military spending[4]

The empirical analysis of this chapter examines the interaction relationships of economic growth utilizing popular methodologies that have been established as those that inform on the existence or not of a relationship between two factors, and in some cases on the direction of that relationship (cointegration tests of Pedroni, Kao, Maddala-Wu and Westerlund, Granger causality tests), along with methodologies that allow for the quantification of such a relationship (panel data estimators Pooled Mean Group, Dynamic OLS, Fully Modified OLS). The application of these methodologies utilizes the factor of military expenditure, for which the current bibliography provides an ambiguous picture about the potential causality, with often conflicting evidence. The research covers 138 countries, for the period 1988-2013, without making assumptions about the theoretical channels of influence or its direction, as they often require constricting assumptions. Additionally, the analysis is carried out in three groups of countries based on their income and developmental stage. The analysis shows a diversity in the results obtained from the different methodologies, which cannot be linked to any common country characteristics. In particular, military spending's causality to economic growth appears only in developing countries (positive long-term), while from economic growth towards military spending, there seems to be a positive effect for all groups of countries, except for the least developed countries. Also, the interaction seems more pronounced before the onset of the economic crisis.

4.1. Introduction

From the examination of the literature on economic growth arises the necessity to examine the methodologies involved with the analysis of the relationships of economic growth and its drivers, on a common sample. To appropriately examine those, the analysis must be applied on a selected determinant which is characterized by a lack of consensus on its effect on economic growth, without making pre-

[4] The present chapter is part of the published paper Desli, E., Gkoulgkoutsika, A. and Katrakilidis, C. (2017), Investigating the Dynamic Interaction between Military Spending and Economic Growth. *Review of Development Economics*, 21: 511-526. doi:10.1111/rode.12268

assumptions about the direction of that relationship. The selected determinant is the military expenditures.

The relationship of military spending and economic growth has been theoretically and empirically investigated since the 1970s, but there is no conclusive evidence towards the direction and the quantification of the impact between the two magnitudes. The use of different data sets, in terms of time periods, number and geographic location of countries, different theoretical backgrounds leading to different econometric specifications, and the type of econometric methodology, make any comparison impossible. Military spending has been steadily reducing from a worldwide country average closer to 4% of gross domestic product (GDP) in the 1980s to 2.3% of GDP in 2013 but it still consumes a significant share of global resources with the overall level of military spending being close to US$1.7 trillion (in constant 2005 prices). 2013 was the first year to experience a military spending reduction (of 2.4%) since 1998. Overall, during the years after the Cold War ended military spending was decreasing, but it doubled since 1998. The increase was particularly pronounced among larger economies, both developing and developed, with the lion's share belonging to the developed countries (69% of the total military spending in 1990, 87% in 2000 and 91% or more since 2006) and the USA leading the way (around 35% of the total military expenditure). The developing countries spend well over 3.5% of their GDP in military-related expenses, and at the same time, the least developed countries on average are reducing this type of spending to below 2% of their GDP especially after the start of the financial crisis.

The literature on the interaction of military spending and economic growth dates back in the 1970s with the Benoit Hypothesis (Benoit, 1973, 1978), that military spending stimulates the economic growth rate, being tested numerous times. However, the empirical results since then have been inconclusive and rather confusing with the interaction between military spending and economic growth and the direction of the influence between these magnitudes being one way or mutual, positive or negative or absent depending on the set of countries under study, the sample period, the theoretical channels linking these two magnitudes and/or the applied econometric methodology. A great number of studies use cross-sectional country-based data and hence ignore the impact of time, which might result in biased outcomes as well as their contribution is limited to the historic length of the sample period. The remaining majority of studies focus on a specific country or a pair of countries or a narrow geographic area with preference to developing countries and thus they cannot be compared as they refer not only to different countries but also frequently to different time periods. Therefore, most of the existing studies have a limited universal application with even more time-limited relevance. A few recent papers have used more broad data sets and applied panel data estimation techniques (Kollias et al., 2007; Chang et al., 2011; Chen et a., 2014) contributing significantly to the debate but also adding some contradictory results (e.g. Chang et al., (2011) found that there is a negative influence from military spending to economic growth while Chen et al. (2014) found no causality for the European region) and in general not producing comparable results owing to either the investigation of different set of countries in their data samples and/or the use a different econometric specifications and estimation techniques. Furthermore, the time periods in these papers do not capture the most recent years of the economic downturn. The inclusion of the most recent time period in the analysis becomes more significant as the contemporary belief since the start of the economic recession is that there is a high opportunity cost in the military spending especially for the hardest-hit countries by the financial crisis. Additionally, the vast majority of the studies that look at more than a pair or a small group of countries look only on the causality of military spending on the economic growth and ignore that a reverse relationship might also hold. Finally, the comparison of the findings might not be feasible because of the use of different data sources and different definitions of military spending. A review of the relevant research is analytically presented in **section 2.2.2**.

The question of interest in this paper is to examine whether and how the methodologies might lead to different conclusions whilst keeping the same sample. A secondary goal is to see whether and to what extent the military spending dynamically interacts with the economic growth on a global scale without any prior assumption about the channels of such interaction that might affect the findings. The worldwide sample employed consists of 138 countries covering the period 1988–2013[5], including the recent years of the global economic turmoil that might have changed the priorities in government spending. In order to obtain a clear and complete picture of the dynamics of such a relationship over time, both the long-run and short-run is examined for bi-directional causality. The investigation involves a variety of the methodologies and whether there are characteristics affecting their appropriateness that can be revealed through a common sample. Therefore, a long-run relationship is examined using a wide range of panel co-integration methodologies including quantifying the impact where possible using the standard dynamic ordinary least

[5] The analysis aimed for the widest possible sample from a cross-sectional perspective (i.e. as many economies as the data permits), which slightly limits the time dimension of the sample.

squares (DOLS) estimation technique, the fully modified ordinary least squares (FMOLS) and the Pesaran et al. (1999) pooled mean group estimation (PMG). Unlike the vast majority of the literature that investigates only the direction of influence from military spending to economic growth, the present analysis also examines the reverse interaction as economic growth might influence the decision to finance military spending, which will serve a country's foreign policy targets and defense needs. Furthermore, there is strong potential that there will be effects from economic growth to military spending, a result that will have significant implications, that will be discussed later. To fully explore the relationship, and more of the available methodologies, the analysis also looks into the short-run causality in both directions using Granger causality tests along with the PMG methodology. Additionally, the relationship between economic growth and military spending might not be linear (Barro, 1990) owing to income developmental stage potentially influencing the outcome of the analysis, and thus, the above investigation is repeated for developed, developing and a least-developed group of countries following the World Development Indicators classification (World Bank, 2015). Finally, the analysis also focuses on the 1988–2006 period, which is the time span is closer to the period that is researched in the recent literature, to examine the methodologies in a smaller time sample, and to detect any changes that might have been introduced by the recent financial crisis.

The following section provides a description of the model, data, and the estimation methodologies employed. Next, in section 4.3, the empirical evidence of the analysis is presented, and finally, the implications and main conclusions are presented in section 4.4.

4.2. Data, Model and Estimation Methodology

The aim of this study is to provide a clear picture of the various methodologies that can explore interrelations of economic growth, such as the dynamic interaction between the military expenditure and economic growth, and the direction of this interaction. The analysis is performed on a worldwide basis while looking into both their long-run and short-run relationship without adopting any a priori hypothesis on the theoretical background of such a relationship.

One of the main reasons behind the adverse findings regarding the relationship between military spending and economic growth in the existing literature is the frequently limited selection of countries as well as the time span of the sample. In this study, data for 138 countries are used for the period 1988–2013, which were extracted from the World Development Indicators (World Bank, 2015). The data sample contains all countries with available data that they also represent 93% of the measured worldwide GDP, providing with almost worldwide coverage. The time period of the sample covers the post-Cold War era that contains over 26 years of information since the thawing of the Cold War, including the more recent years of economic crisis. As none of the existing studies research beyond 2006 and the economic crisis forced the hardest-hit countries by the crisis to cut their government spending including their military spending, it becomes important to look into the potential impact of the economic crisis. Also, the use of panel data allows the control for country-specific effects and to incorporate such information over time. Military spending was constructed as the logarithm of the per capita military expenditure (MSP), while economic growth is the logarithm of the per capita GDP both in 2005 constant US dollars.

The use of a large number of countries introduces heterogeneity in the model as according to Barro (1990) the relationship between defense expenditure and economic growth may be nonlinear (most probably U-shaped) with different levels of income influencing the causality between the two magnitudes. To alleviate this problem, the countries are divided into three smaller panels groups based on their income development level based on the World Bank classification: developed (51 countries), developing (59 countries), and least developed (28 countries). Table 4.1 displays the list of countries in each group. Additionally, as the existing literature indicates, the underlying assumptions about the channels of influence between military spending and economic growth determine the econometric specification and thus guide the expected outcome. Since there is no standard framework into which the empirical work can be based, making no such prior assumptions, and interpreting ex-post the association of the findings with these theories. Furthermore, all previous studies (reaching into the 2000s) with a large number of countries look into only one type of relationship, namely either the long run or the short run and hence the results are difficult to interpret.

Prior to any analysis, the necessary steps to identify the integration properties of the series are performed. For robustness, three panel data unit root tests are used, which cover both the individual and the common unit root identification: (i) the Breitung (2001) unit root test that applies a common unit root test to the entire panel data sample after removing the autoregressive part and transforming and de-trending the standardized proxies, (ii) the Im et al. (2003) unit root test that investigates the individual augmented Dickey-Fuller (ADF) unit root tests prior to combining them to acquire the overall test statistics, and (iii) a Fisher-type unit root test developed by Maddala and Wu (1999) and Choi (2001) that combines the p-values from individual ADF unit root tests using Fisher's (1992) results.

Table 4. 1 List of Countries—Grouping is Based on their Income Development Stage

Developed countries (51)		*Developing countries (59)*		*Least developed countries (28)*
Argentina	Malta	Albania	Lebanon	Angola
Australia	Mexico	Algeria	Libya	Bangladesh
Austria	Moldova	Armenia	Malaysia	Burkina Faso
Belarus	Netherlands, The	Azerbaijan	Mauritius	Burundi
Belgium	New Zealand	Bahrain	Mongolia	Cambodia
Bulgaria	North Macedonia	Belize	Morocco	Chad
Bosnia and Herz.	Norway	Bolivia	Namibia	Congo, Dem Rep.
Brazil	Poland	Botswana	Nicaragua	Djibouti
Canada	Portugal	Brunei Darussalam	Nigeria	Ethiopia
China	Romania	Cape Verde Is.	Oman	Gambia, The
Croatia	Russian Federation	Cameroon	Pakistan	Guinea
Czech Rep.	Saudi Arabia	Chile	Papua New Guinea	Guinea-Bissau
Denmark	Serbia	Colombia	Paraguay	Lao PDR
Estonia	Slovak Republic	Cyprus	Peru	Lesotho
Finland	Slovenia	Dominican Republic	Philippines, The	Madagascar
France	South Africa	Ecuador	Seychelles	Mauritania
Germany	Spain	Egypt, Arab Rep.	Singapore	Malawi
Greece	Sweden	El Salvador	Sri Lanka	Mali
Hungary	Switzerland	Fiji	Swaziland	Mozambique
India	Turkey	Gabon	Syrian Arab Rep.	Nepal
Indonesia	Ukraine	Georgia	Tajikistan	Niger
Ireland	UK	Ghana	Thailand	Rwanda
Italy	USA	Guatemala	Tunisia	Senegal
Japan		Guyana	United Arab Emirates	Sierra Leone
Korea Rep.		Honduras	Uruguay	Sudan
Latvia		Iran, Islamic Rep.	Venezuela, RB	Tanzania
Lithuania		Israel	Zimbabwe	Uganda
Luxembourg		Jordan		Yemen, Rep.
		Kazakhstan		
		Kenya		
		Kuwait		
		Kyrgyz Republic		

Note: Based on the World Development Indicators classification (World Bank, 2015)

Once it is ensured the I(1) order of the variables, and in order to examine the existence of a long-run relationship between military spending and economic growth as well as the direction of such a relationship co-integration analysis tests are utilized. As one of the limitations in the previous studies was the choice of the estimation method and not all alternative estimation techniques provide the same outcome, a range of panel data co-integration tests are applied, with different statistical attributes for robustness and more well-defined results. Hence, the co-integration analysis comprises of five methodologies: (i) Pedroni (1999, 2004), (ii) Kao (1999), (iii) Johansen–Fisher test (Maddala and Wu, 1999), (iv) Stock and Watson, (1993) also known as DOLS, and (v) FMOLS from Pedroni (2000). The last two methodologies can be performed only when there is a clear indication from the first three tests that co-integration is present, and they can provide with information on the numerical impact of one magnitude to the other. Additionally, the DOLS and FMOLS tests are estimated with a constant and trend to capture the common global movements. To conclude the long-run investigation, the PMG estimation (Pesaran et al., 1999) is applied, that like the other two approaches allows for the heterogeneity of the cross-sections but follows a pooled approach. For the investigation of the short-run relationship along with the direction of the relationship, Granger causality tests and the short-run estimators of the PMG are used that, as mentioned earlier, gives the pooled approach. Analytical presentation of the unit root tests can be found in **section 3.4**, while all cointegration tests are presented and discussed in **section 3.1**. Additionally, the aforementioned analysis is repeated for the period 1998–2006, which is the period that is covered by the existing studies in order to look into whether there is a change after the financial crisis started, which is consistent with the remaining analysis.

4.3. Empirical Evidence

The main requirement prior to running any of the long-run and short-run evaluation tests is to check the stationarity of the variables as the use of non-stationary processes can lead to a spurious regression. Three panel unit root tests are employed—Breitung (2001), Im et al. (2003) and a Fisher-type test developed by Maddala and Wu (1999) and Choi (2001)—and from all these tests it can be deduced that both variables are non-stationary in levels, while they become stationary when examined in first differences. Subsequently, both variables can be described as integrated of order 1; I(1). The results of the unit root tests can be found in Table 4.2. The examination for the long-run relationship consists of five co-integration methodologies—Pedroni (1999, 2004), Kao (1999), Johansen–Fisher, DOLS, FMOLS—and the estimation of PMG model by Pesaran et al. (1999) (PMG/ARDL) for robustness. Table 4.3 contains all analytical relevant results, while Tables 4.4–4.6 give a schematic summary of the findings for the period 1988–2013. The first three cointegration tests that are presented in Table 4.4 do not reveal the direction of causality, but they indicate that there is co-integration for all groups of countries.

Table 4. 2 Panel Unit Root Tests: 1988-2013

	Breitung	Im, Pesaran and Shin	ADF - Fisher
All countries			
GDP	7.616	0.108	1.428
MSP	1.610	-0.908	-0.037
ΔGDP	-13.627 ***	-24.382 ***	-21.194 ***
ΔMSP	-11.697 ***	-29.748 ***	-29.071 ***
Developed			
GDP	4.282	1.237	1.746
MSP	1.058	-1.109	0.224
ΔGDP	-9.514 ***	-12.340 ***	328.391 ***
ΔMSP	-12.221 ***	-20.365 ***	575.982 ***
Developing			
GDP	3.097	-1.657	2.192
MSP	1.254	-0.713	-0.339
ΔGDP	-6.448 ***	-15.364 ***	460.233 ***
ΔMSP	-7.288 ***	-14.446 ***	538.756 ***
Least Developed			
GDP	7.667	-0.343	66.090
MSP	0.260	0.544	56.043
ΔGDP	-11.848 ***	-14.739 ***	286.749 ***
ΔMSP	-4.635 ***	-10.191 ***	236.063 ***

Notes: *, **, and *** denotes significance at 10%, 5%, and 1% level respectively

Table 4. 3 Panel Cointegration Tests (Long Run Estimation): 1988-2013

	All countries	*Developed*	*Developing*	*Least Developed*
Pedroni's Panel Cointegration test				
Panel v-Statistic	7.004 ***	0.588	3.663 ***	2.328 **
Panel rho-Statistic	-4.173 ***	-3.444 ***	-1.808 **	0.610
Panel PP-Statistic	-5.761 ***	8.554 ***	-8.679 ***	-1.649 **
Panel ADF-Statistic	-6.358 ***	-9.420 ***	-7.242 ***	-1.731 **
Group rho-Statistic	-0.094	0.899	2.874	2.488
Group PP-Statistic	-9.689 ***	-4.877 ***	-2.320 **	-0.063
Group ADF-Statistic	-10.305 ***	-5.825 ***	-2.878 ***	0.486
Kao's Panel Co-integration Test				
ADF	3.190 ***	-7.437 ***	1.755 **	3.016 ***
Johansen Fisher Panel Cointegration Test				
Hypothesized Number of CE(s): None				
Fisher Stat. (from trace test)	727.6 ***	250.9 ***	328.3 ***	148.4 ***
Fisher Stat. (from max-eigen test)	680.7 ***	235.0 ***	307.1 ***	138.6 ***
Hypothesized Number of CE(s): At most 1				
Fisher Stat. (from trace test)	279.3	99.17	123	57.06
Fisher Stat. (from max-eigen test)	279.3	99.17	123	57.06
Dynamic OLS Estimation Results				
GDP → MSP	0.740 *** (0.047)	0.906 *** (00073)	1.022 *** (0.075)	-
MSP → GDP	0.064 *** (0.004)	-	0.101 *** (0.011)	-
Fully Modified OLS Estimation Results				
GDP → MSP	0.743 *** (0.011)	0.718 *** (0.017)	0.592 *** (0.0174)	-
MSP → GDP	0.067 ** (0.014)	-	0.054 ** (0.023)	-
Pooled Mean Group / AR Distributed Lag Models				
GDP → MSP	0.918 *** (0.057)	0.481 *** (0.064)	0.479 *** (0.042)	0.672 *** (0.099)
MSP → GDP	0.505 *** (0.025)	0.144 *** (0.017)	0.597 *** (0.046)	-

Notes: *, **, *** Denote significance at 10%, 5%, and 1% levels, respectively; the standard errors are given in parenthesis where applicable; "→" implies impact of independent variable to dependent variable

The number of tests that indicate the presence of co-integration out of the seven Pedroni (1999, 2004) tests are given in parenthesis, but one should look carefully at which of the tests signal co-integration, as the econometric literature considers the more powerful the ADF and the Peron (PP) tests (Hlouskova and Wagner, 2007).

Based on the applied tests (Tables 4.3 and 4.4) there is clear evidence of bi-directional causality not only for the groups of developing countries but for the entire sample (although the evidence for the entire sample for the direction from the military spending to economic growth is weaker), while there is no influence to either direction for the least developed countries. For the group of developed countries, there is only the influence of economic growth on military spending. For the cases where co-integration is present, the estimation of DOLS and FMOLS with constant and trend are performed, where the impact is found positive and, especially in the case of developing countries, the impact from the economic growth to military spending is much stronger than vice versa.

Table 4. 4 Summary of Co-integration Tests (Long Run Estimation): 1988-2013

Test type	*All countries*	*Developed countries*	*Developing countries*	*Least developed countries*
Pedroni (1999, 2004)	MSP & GDP: yes (6/7)	MSP & GDP: yes (5/7)	MSP & GDP: yes (6/7)	MSP & GDP: no (3/7)
Kao (1999)	MSP & GDP: yes	MSP & GDP: yes	MSP & GDP: yes	MSP & GDP: yes
Johansen–Fisher	MSP & GDP: yes	MSP & GDP: yes	MSP & GDP: yes	MSP & GDP: yes

Note: the parentheses in the Pedroni (1999, 2004) tests give the number of tests in which a co-integrated relationship exists out of the seven tests

Table 4. 5 Summary of DOLS, FMOLS, PMG Tests (Long Run Estimation): 1988-2013

Test Type	All countries	Developed countries	Developing countries	Least Developed countries
DOLS	MSP $\xrightarrow{+}$ GDP (0.06 ***)	n/a	MSP $\xrightarrow{+}$ GDP (0.10 ***)	n/a
	GDP $\xrightarrow{+}$ MSP (0.74 ***)	GDP $\xrightarrow{+}$ MSP (0.91 ***)	GDP $\xrightarrow{+}$ MSP (0.74 ***)	n/a
FMOLS	MSP $\xrightarrow{+}$ GDP (0.06 ***)	n/a	MSP $\xrightarrow{+}$ GDP (1.02 ***)	n/a
	GDP $\xrightarrow{+}$ MSP (0.74 ***)	GDP $\xrightarrow{+}$ MSP (0.72 ***)	GDP $\xrightarrow{+}$ MSP (0.59 ***)	n/a
PMG	MSP→GDP (0.51 ***)	MSP→GDP (0.14 ***)	MSP→GDP (0.60 ***)	MSP→GDP: no
	GDP → MSP (0.86 ***)	GDP →MSP (0.48 ***)	GDP →MSP (0.47 ***)	GDP → MSP (0.67 ***)

*,**,*** denote significance at 10%, 5% and 1% levels, respectively; no comparison should be attempted across tests, they do not refer to the same measurements; numerical values in parenthesis should only be compared across groups; n/a: non-applicable; the impact is estimated only when the 3 tests indicate co-integration. "→" implies impact of independent variable to dependent variable

The numerical evaluation of the impact is reported in the parentheses of the relevant rows in Table 4.5, but the reported numbers should be treated with caution: coefficients for the same group should not be compared across methods as each method has a different measurement estimation approach; however, coefficients from the same test can be compared across groups. Thus, it seems that in the direction of economic growth towards military spending, the stronger impact is on the developing rather than the developed countries. Furthermore, when bidirectional causality is present, the impact of the economic growth to military spending is noticeably stronger than the reverse direction. The estimates of the PGM model indicate bi-directional influence for all groups of countries except the developing countries where only economic growth impacts military spending. In the short-run analysis, the Granger causality tests indicate that economic growth influences military spending for all groups except for the group of least developed countries where no causality is found. The PGM short-run estimation signals no causality for all directions and groups except a rather weak one—though positive—from military spending to economic growth for the entire sample with the quantified impact reported in the parentheses of the relevant row in Table 4.6.

Table 4. 6 Summary of Causality Tests (Short Run Estimation): 1988-2013

Test Type	All countries	Developed countries	Developing countries	Least Developed countries
Granger causality	MSP→GDP: no GDP→MSP: yes	MSP→GDP: no GDP→MSP: yes	MSP→GDP: no GDP→MSP: yes	MSP→GDP: no GDP→MSP: no
PMG	MSP$\overset{+}{\rightarrow}$GDP (0.03 ***) GDP → MSP: no	MSP→GDP: no GDP→MSP: no	MSP→GDP: no GDP→MSP: no	MSP→GDP: no GDP→MSP: no

*, **, *** Denote significance at 10%, 5% and 1% levels, respectively. "→" implies impact of independent variable to dependent variable

Next, the previous analysis is repeated for the period of 1988–2006, which on the one hand is comparable with the existing literature and on the other hand allows the evaluation of the impact of the recent economic crisis on the interaction between military spending and economic growth. The findings are summarized in Table 4.7 and, in general, following Pedroni's (1999, 2004) and Kao's (1999) results, there is evidence of bi-directional causality for all groups and not only for the developing countries as was found earlier. Also, the quantification of this interaction (see Table 4.8) resulted in the impact being positive and, as before, the impact from the economic growth to military spending is much stronger than vice versa. When looking at the influence of military spending on economic growth, the stronger impact is on the developing countries and the weakest is on the least developed countries. For the least developed group of countries, the military spending as a percentage of GDP steadily reduced since 2006 and that might explain the earlier finding of no causality between the two magnitudes. However, the PMG methodology finds evidence of a causal effect in fewer cases than in the more extended time period and identifies the presence of interaction from military spending to economic growth only for the developing countries and the reverse relationship for all the other groups.

Table 4. 7 Summary of Co-integration Tests (Long Run Estimation): 1988-2006

Test type	*All countries*	*Developed countries*	*Developing countries*	*Least developed countries*
Pedroni (1999, 2004)	MSP & GDP: yes (5/7)	MSP & GDP: yes (4/7)	MSP & GDP: yes (5/7)	MSP & GDP: yes (5/7)
Kao (1999)	MSP & GDP: yes	MSP & GDP: yes	MSP & GDP: yes	MSP & GDP: yes
Johansen–Fisher	MSP & GDP: no	MSP & GDP: no	MSP & GDP: no	MSP & GDP: yes

the parentheses in the Pedroni (1999, 2004) tests give the number of tests in which a co-integrated relationship exists out of the seven tests

Table 4. 8 Summary of DOLS, FMOLS, PMG Tests (Long Run Estimation): 1988-2006

Test Type	All countries	Developed countries	Developing countries	Least Developed countries
DOLS	MSP $\overset{+}{\rightarrow}$ GDP (0.07 ***) GDP $\overset{+}{\rightarrow}$ MSP (1.06 ***)	MSP $\overset{+}{\rightarrow}$ GDP (0.12 ***) GDP $\overset{+}{\rightarrow}$ MSP (0.84 ***)	MSP $\overset{+}{\rightarrow}$ GDP (0.10 ***) GDP $\overset{+}{\rightarrow}$ MSP (1.11 ***)	MSP $\overset{+}{\rightarrow}$ GDP (0.04 ***) GDP $\overset{+}{\rightarrow}$ MSP (1.09 ***)
FMOLS	MSP $\overset{+}{\rightarrow}$ GDP (0.05 ***) GDP $\overset{+}{\rightarrow}$ MSP (0.94 ***)	MSP $\overset{+}{\rightarrow}$ GDP (0.06 ***) GDP $\overset{+}{\rightarrow}$ MSP (0.85 ***)	MSP $\overset{+}{\rightarrow}$ GDP (0.10 ***) GDP $\overset{+}{\rightarrow}$ MSP (0.75 ***)	MSP $\overset{+}{\rightarrow}$ GDP (0.02 ***) GDP $\overset{+}{\rightarrow}$ MSP (1.45 ***)
PMG	MSP→GDP: no GDP →MSP (0.76 ***)	MSP→GDP: no GDP → MSP (0.82 ***)	MSP→GDP (0.60 ***) GDP →MSP: no	MSP→GDP: no GDP → MSP (1.13 ***)

*,**,*** denote significance at 10%, 5% and 1% levels, respectively; no comparison of the results should be attempted across tests as they do not refer to the same estimated measurements; the numerical values in parenthesis should only be compared across groups of data for the same test; n/a: non-applicable; the impact is estimated only when the first three tests indicate co-integration. "→" implies impact of independent variable to dependent variable

Table 4. 9 Summary of Causality Tests (Short Run Estimation): 1988-2006

Test Type	All countries	Developed countries	Developing countries	Least Developed countries
Granger causality	MSP→GDP: no GDP→MSP: yes	MSP→GDP: no GDP→MSP: yes	MSP→GDP: no GDP→MSP: yes	MSP→GDP: no GDP→MSP: no
PMG	MSP→GDP: no GDP→MSP: no	MSP→GDP: no GDP→MSP: no	MSP→GDP: no GDP→MSP: (0.03 ***)	MSP→GDP: no GDP→MSP: no

*, **, *** Denote significance at 10%, 5% and 1% levels, respectively. "→" implies impact of independent variable to dependent variable

In the context of the short-run analysis (see Table 4.9) the Granger causality tests suggest that there is a causal effect only of economic growth on military spending for all groups except the group of the least developed countries where no causality is found, and the PGM methodology indicates no causality for all cases except for the developing countries, from economic growth to military spending.

4.4. Overview

Regarding the specific relationship between economic growth and military spending, when looking into the shorter period of 1988–2006, which is the period that is comparable with the most recent studies, no causality in the short-run from the military spending to economic growth is found, but there is some evidence of causality from economic growth to military spending for the groups of developed and developing countries as well as the entire group. As the period is expanded to include the economic crisis years and thus covering the period 1988–2013, the short-run analysis results remain about the same, but in the long run, only the group of developing countries experience a bi-directional causality with the side of economic growth to military spending being affected by far the most. There is no interaction for the least developed countries, and regarding the remaining groups, the interaction is positive but only running from economic growth towards military spending. It is notable that since 2009 on average the military spending as a percentage of GDP is close to or below the 2%

level for the developed and least developed countries, while the developing countries have average military spending close or well above 4% of GDP. Perhaps, for military spending to have any significant impact on the economic growth of a country, it needs to be over a certain percentage of GDP. Furthermore, the economic crisis environment might have created additional needs for the society that increased the opportunity cost of military spending, and hence, its influence on economic growth appears diminished.

Over the years, the vast majority of the research has been focused on the impact of military spending on economic growth and its theoretical channels. However, it seems that the causality is stronger the other way around. As a country's economic growth is established, more government funds become available and after the financing of other pressing needs, such as education and health, is ensured, the government finds the monetary resources to finance and promote foreign policy targets, build defenses against real or perceived threats, expand its influence via peace-keeping operations and actively participate in multinational defense groups. The increase in military spending could also trigger the "military Keynesianism" mechanism, which is the most probable explanation for the positive impact of military spending on economic growth in developing countries even after the start of the economic crisis but not for the developed countries that are perceived to be more efficient. It is also possible that over time, while the economy enjoys positive economic growth, in the long run, the society is adjusted to the military spending by infusing some services of the military into the civilian life, e.g., through R&D, which in return fuels further economic growth. Finally, the lack of any dynamic interaction for the least developed countries once the economic crisis years are taken into account might be due to the fact that, on the one hand, the military spending is both low numerically, and a small percentage of their GDP and, on the other hand, any military spending fails to trigger the "military Keynesianism" mechanism as the countries usually suffer from a higher degree of inefficiency in their government spending process. This process is usually influenced by a higher level of corruption, which in turn allows the presence of interest groups composed of individuals, firms, and organizations to benefit from defense spending regardless of the country's actual needs and, hence overall, military spending is neither efficient nor beneficial in its contribution to economic growth.

The analysis from a wide variety of methodologies evidently shows that although military spending may have effects in some countries, the significant effects originate from economic growth. This is not a surprising find, it is however, a robust validation of the findings of a section of the empirical literature, that economic growth itself influences most of the economic areas that are expected to affect it, inflicting any relevant research with endogeneity issues. This has been expressed in numerous empirical articles, as the problem of regressor endogeneity in growth model regressions and was one of the reasons why the present analysis was performed with a wide range of methodologies, purposefully examining both directions for possible effects.

4.5. Conclusion

The present analysis examined and evaluated various econometric methodologies available for the examination of interrelationships of economic growth. The examination was performed on the dynamic interaction between military spending and economic growth, that is an economic area of great current interest, a long-time controversial issue as a policy measure with an ambiguous relationship to economic growth. The analysis is performed during the period 1988–2013 that includes the recent years of economic crisis and covers 138 countries. As indicated by the existing literature, the adoption of a theoretical channel of how military spending influences economic growth will guide the econometric specification of the model and might influence the outcome, and thus such prior assumptions are avoided. The analysis utilized popular methodologies that have been established as those that inform on the existence or not of a relationship between two factors, and in some cases on the direction of that relationship (cointegration tests of Pedroni, Kao, Maddala-Wu and Westerlund, Granger causality tests), along with methodologies that allow for the quantification of such a relationship (panel data estimators Pooled Mean Group, Dynamic OLS, Fully Modified OLS). Based on the empirical evidence in the previous section, there is a variety of outcomes that spur from different methodologies, which if viewed in isolation might lead to different conclusions.

The results show significant variability between econometric methodologies. The cointegration test of Pedroni (1999, 2004), consisting of seven test statistics allows for a “degree” in the acceptance of the cointegration hypothesis, which agrees with the developmental stage of the countries in each sample. For the cointegration test of Kao (1999), it seems difficult to reject the hypothesis of cointegration, and should thus never be applied solely. The Maddala-Wu (1999) cointegration test seems more sensitive, nonetheless both tests are limiting as they do not offer any information on the direction of any relationship proposed. The methodologies that also provide with coefficients of the interactions generally agree that the effect is more pronounced from economic growth to military spending than in the opposite direction. However, the DOLS (1993) and FMOLS (2000) methodologies both suggest that the difference is much greater than the PMG (1999) and the ARDL do. The Granger causality tests indicate a clear causality from growth to military spending, with the opposite occurring in a fraction of the cases. Although the analysis employed four different methodologies for the estimation of the relationship coefficients, another methodology was necessary in order to ensure an outcome. Therefore, the variability of the results enforces the view that it is essential to investigate using a range of tests and draw conclusions from all of them rather than adopt one type of test or methodology and deduce implications from them as each test is looking into different aspects of estimation issues.

Chapter
5. Evaluation of Methodologies for the examination of Economic Convergence: An application on top-income economies[6]

A wide range of literature suggests that the most significant determinant of economic growth is its own transition path, which leads to a discussion about the presence or not of economic convergence. The empirical analysis of this chapter studies three economic convergence econometric methodologies (beta convergence, log(t) convergence, and pairwise convergence), which assume deterministic, stochastic or combinatorial trends in data, and allow convergence testing by groups, which are either user-defined or data-driven, on a common sample. The sample consists of the scarcely analyzed economies, with no clear picture about their economic convergence, that are identified as the world's top-income economies. The sample includes OECD member countries ("developed"), but also non-OECD members, most of which are richer countries than some of the "developed" ones. All methods agree that the group of the world's top-income economies is participating in an ongoing convergence process, though the financial crisis might have disturbed it. The convergence evidence tends to grow weaker when the assumption of the deterministic underlying trend is enriched with a stochastic trend and finally abandoned. Something that should be expected – although the research literature often ignores it – as most national-economies have some long-term planning.

5.1. Introduction & Literature Review

There are different and often conflicting concepts of convergence in the literature of economic growth. At the same time, the investigation of economic convergence is one of the most important issues in economics that reveals whether differences in per capita income across economies will diminish and eventually, unless unexpected changes occur, disappear over time. Therefore, the investigation of the relevant methodologies on a common sample would contribute to the empirical

[6] The present chapter is part of the published paper Desli, E., & Gkoulgkoutsika, A. (2019). Economic convergence among the world's top-income economies. *The Quarterly Review of Economics and Finance*. doi.org/10.1016/j.qref.2019.03.001

literature of economic growth, by revealing the characteristics of the methodologies that determine their appropriateness. To that end, the present analysis employs three of the most prevailing approaches of convergence that each originates from a different school of thought, capturing deterministic, stochastic and combination trends. Firstly, the most widely used approach will be applied, namely the beta (β-) convergence following the Barro and Sala-i-Martin exposition Barro and Sala-i-Martin (1992, 2003), that is also directly linked, theoretically and algebraically, with the Solow model and which over time has been enhanced with the introduction of the distinction between unconditional and conditional convergence, with the latter allowing factors that influence the level of per capita income and its convergence process. It also allows the examination of researcher-defined potential clubs and provides reliable information about the speed of convergence. Secondly, the log(t) method (Phillips and Sul, 2007, 2009) is a popular method in identifying clusters of common economic growth patterns; it involves time-series estimations that utilize the ratio of variations of the per capita income and captures both underlying deterministic and stochastic trends. It puts emphasis on the identification of clusters of economies driven by the data rather than clubs defined by the researcher, it is based on a similar theoretical background to the beta convergence although there is no direct algebraic link to the theory, and it is augmented to allow endogenous technological progress. The third method is based on an explicitly stochastic framework, and it follows the Pesaran (2007) pairwise approach that is examining the existence or not of a unit root in the difference between the per capita income of two economies considering all the possible country combinations in the sample. The existence of convergence is measured by the percentage of these pairs that demonstrate stationarity in their respective output gaps. However, the last approach, as a measure of stochastic convergence, lacks a clear theoretical background, Alexiadis (2013). The second and third methods overcome the criticism that a method like beta-convergence is subjected to, i.e., that a dynamic concept like the convergence cannot be described by cross-sectional studies (Binder and Pesaran, 1999; Bernard and Durlauf, 1995), but undermining or omitting the presence of a deterministic trend when it is clearly present will weaken the outcome of the analysis. The first and the third methods can investigate potential researcher defined groups of countries but might miss indications hidden in the data that the automated second process will recognize. An analytical literature review of economic convergence can be found in **section 2.3**.

Therefore, the selection allows the examination and evaluation of the three most popular and diverse methodologies against each other. They will all be applied in the same sample of the top-income economies.

Using the World Bank classification of High-Income countries, a sample with forty (40) worldwide top-income economies with available data over the period 1980-2016 is created, out of which only twenty-six (26) are OECD members. This is a period that can also provide information about the impact of the crisis. In terms of trade, currently, these countries are the top trading partners to each other as well as the rest of world (OECD, 2018) since over the last few years, the OECD has strengthened its cooperation with non-OECD members (Mendonca, 2016). Also, whilst in the 1990s almost 68% of the trade operations of the OECD countries was with other OECD economies, as of 2016 these have reduced to 58% with the difference due to increased trading with the non-OECD richer countries in the sample (based on WITS, (2018) data). These 40 top-income countries shape the world production frontier by holding more than 60% of the world Gross Domestic Product (GDP) as of 2016, serving as the top trading partners for the entire world, as well as being the main source of innovation and technological progress (Statista, 2018). Therefore, the group of the world-leading economies is changing, it is infiltrated by rich but less developed economies, and it is time to consider which countries are converging to the top.

The main goal of the analysis is the comparison of the results using the same sample of the recently formed group of world top-income economies, their reconciliation and the evaluation of the impact of the assumed type of trend on the convergence outcome. The limited existing literature utilized methodologies that are more suitable for underlying deterministic trends that are present when economies formulate economic growth plans, and they are able to follow them. However, as the recent crisis demonstrated, there is no certainty, and hence, one needs to look at stochastic trends as well. The present analysis of convergence between the new group of world leaders employs for robustness three of the most prevailing approaches that each originates from a different school of thought, capturing deterministic, stochastic, and combination trends. Namely, the beta (β-) convergence, the log(t) method (Phillips and Sul, 2007, 2009), and the pairwise convergence of Pesaran (2007). The above methods will also be applied, where it is possible, to shorter periods of time in order to study how the presence of convergence and any clubs is changing over time including the impact of the economic crisis. The three methods do not yield quantitively comparable results, but their conceptually different way of approaching the examination of economic convergence will allow the confirmation (or not) of the arising of a new group that converges as world economic leaders. In order to quantitatively reconcile the three methodologies, the beta-convergence and the corresponding speed of convergence are also estimated, as well as the stochastic convergence percentages, for the clubs suggested by the log(t) approach. The above approaches act in a complementary way, by assuming that the underlying trend in the per capita income initially is deterministic, which is not an unreasonable assumption for top-income economies that have stable government and institutions, low political risk and long term economic strategies and plans, then it is enriched with a stochastic trend, which might be more suitable to describe the years related to unforeseen events like an economic crisis, and finally becomes a pure stochastic trend.

The rest of the article is organized as follows. The next section briefly discusses the empirical framework for the testing of economic convergence and the relevant data. Then follows the empirical analysis of the results from the three methods, and finally, conclusions are drawn in the last section.

5.2. Convergence Estimation Framework

The main theoretical background of convergence is based on the neoclassical assumption of capital's diminishing returns in an economy's production function and it predicts that the economies with lower per capita GDP will grow faster over time than their counterparts with higher per capita GDP. There is a variety of methodologies available with similarities and differences, and they can be characterized by the assumptions about deterministic or stochastic trends, the time-length of the sample that they can be utilized for and their ability to identify potential clubs. Some are directly linked to the Solow model, and some have no theoretical background. For this reason, it is difficult to compare the results from different studies that focus on the same sample as these methods are not directly comparable. The limited literature that investigated the convergence for income-based groups has adopted methodologies with deterministic trends, but as the years following the beginning of the financial crisis have shown, the type of underlying trend is not certain. The current analysis utilizes three popular methodologies, one with the ability to detect a deterministic trend, user-defined clubs, and direct links to the theory, more specifically the beta convergence (Barro and Sala-i-Martin, 1992), another that can detect both deterministic and stochastic trends, with automatically generated clubs and indirect links to the theory, namely the log(t) approach (Phillips and Sul, 2007, 2009), and finally one that finds stochastic trends, user-defined potential clubs but no specific theoretical background, in particular the Pesaran, (2007a) pairwise convergence approach. When countries consistently set up and follow long-term plans regarding their economic growth and development, then a deterministic trend for convergence is dominant. Hence, the choice of a method like beta-convergence, that assumes only a deterministic trend, would be suitable. On the other hand, stochastic events occur all the time, and depending on their severity may have a potential impact on the planned economic growth, and therefore, they should not be ignored. Thus, a choice like the log(t) convergence methodology, that assumes the presence of a trend regardless of its deterministic or stochastic type would also be suitable. However, when a methodology, like the pairwise convergence, assumes only a stochastic trend it neglects the dominant deterministic trend, and hence its convergence estimates are expected to be weaker and potentially biased due to this omission. Nonetheless, it captures the degree of common strategies trying to overcome these random obstacles and remain on track for the planned economic growth. The investigation view from different angles will ensure the robustness of the findings. The following section presents briefly these estimation techniques, their empirical framework of how they are applied, and the description of the data and their source.

5.2.1. The Convergence Hypothesis Estimation

For the empirical estimation of convergence three different methodologies are applied; the beta (β)-convergence approach (Barro and Sala-i-Martin, 1992, 2003), the log(t) convergence approach Phillips and Sul (2007, 2009), and the Pairwise stochastic convergence approach Pesaran (2007a). There is an analytical presentation of the convergence methodologies in **section 3.3**.

Regarding the Pairwise stochastic convergence approach, unit root as well as a stationarity test are used, as suggested by Pesaran (2007a). If convergence is tested with the use of a unit root test, then the null hypothesis (of a unit root) must be rejected in order to suggest convergence, while if a stationarity test is employed, then the null hypothesis should not be rejected for the existence of convergence. Studying both sets of outcomes, the overall results are more robust, and the possibility for type 1 and 2 errors is minimized. However, it should be noted that rejection of the null hypothesis from unit root tests and/or non-rejection of the null hypothesis from stationarity tests does not definitively imply rejection of convergence, as there is a possibility for co-movement across individuals Phillips and Sul (2007, 2009) and hence this approach tends to underestimate the presence of convergence. Additionally, Pesaran's (2007a) pairwise convergence methodology provides with higher convergence percentage when the analysis is performed at a more disaggregated level data (Holmes et al., 2014) and in this case aggregate data at a country level are used. Moreover, with the use of the two complementary tests, the researchers have two different sets of results that might provide with different conclusions with the stationarity test expected to give higher percentages as it is generally more difficult to reject the null hypothesis. In order to obtain a consistent comparison across subgroups of economies, a Pairwise Convergence Index (PCI) is constructed by combining the convergence's percentage from the two sets of results as the geometric mean of the outcome from the two types of tests.

Similarly to Pesaran (2007a), for the unit root test the Augmented Dickey-Fuller (ADF) test is applied, which is one of the most utilized tests in the literature mainly because of its simple construction and feasibility, and also it exhibits less size distortion than alternatives like the popular Phillips and Perron (1988) (Schwert, 1989). The order of this test is selected based on the Akaike information criterion (AIC), and the critical values are derived from MacKinnon (1996). For the stationarity test, the Kwiatkowski et al. (1992) (KPSS) test is performed, which achieves reliable results. Both tests are estimated with intercept only, because the differentials for convergence should be time-invariant (e.g., Carlino and Mills, 1996, and the inclusion of either a deterministic or a stochastic trend would violate that (Enders, 2014), as well as the power of the unit root tests, diminishes (sometimes significantly) with the inclusion of a trend term, and results could be biased and inconsistent (Silva Lopes, 2016). Then the PCI is calculated as mentioned above. The measures of dispersion that are discussed by Pesaran (2007a) are also estimated, i.e., the population-weighted average of the absolute gaps across country pairs "mean difference" (Δ_t), known as the "MD" coefficient and the similarly weighted average of the squared values of output gaps (D_t^2); for convergence to hold neither of these measures should have unit roots or exhibit deterministic trends.

5.2.2. Empirical Analysis Steps

As a first step, the convergence is evaluated using the absolute beta convergence approach for the entire sample (1980-2016) as well as for the decades of the 1980s, 1990s, 2000s and 2010s in the sample, that are characterized by different political, economic and cultural views, while the length of 10-year periods are also used in the literature, and the corresponding results are considered reliable. This will allow the formation of a picture of how the convergence process evolves over different decades and if it exists, how the speed of convergence fluctuates. To depict the full view, beta-convergence is also performed in a recursive fashion, starting from the period 1980-1990 and adding one year at a time in order to identify periods with stronger convergence. Additionally, the effect on the financial crisis is studied by comparing the pre-crisis period (1980-2008) with the years that followed (2008-2016). The latter is of particular interest since the countries with the higher income seem to have been affected the most by the financial crisis and, in many cases, they have not fully recovered yet. Also, the usual distinction based on the development level is also studied; by investigating different convergence patterns between the OECD members and non-members. For all the cases that convergence is found the corresponding average annual speed of convergence is also estimated.

Next, the log(t) approach is employed, initially for the entire sample (1980-2016) that for the log(t) is effectively being reduced to the period 1992-2016. Similarly, to the beta-convergence approach, the same decades as above as well as the pre- and post-crisis period are estimated. It should be noted that, for the latter, due to limitations of the log(t) procedure, the period has been modified to 2006-2016. As mentioned earlier, the results of the two methods are not quantitatively comparable, and thus, once the clubs are identified by the log(t) clustering algorithm, the corresponding beta convergence speed will be estimated, so the two sets of results are matched.

Finally, the pairwise stochastic approach is applied for the periods 1980-2016 as well as 1992-2016 that corresponds to the effective log(t) period. For each sample, a total of 780 pairs were examined both with the unit root test (ADF) and the stationarity test (KPSS) and the Pairwise Convergence Index (PCI) was created for each sample. Similarly, to the previous method, in order to quantitatively reconcile the results from the pairwise approach with the previous two methods, this process was repeated for the OECD and non-OECD members as well as for the clubs formed by the log(t) for an overall reconciliation of results. Unfortunately, due to the minimum requirements of approximately 25 periods in the sample, it is not possible to repeat the analysis for shorter time-periods, but in order to evaluate the impact of the economic crisis the results from the period 1980-2008 are also estimated and compared with the overall period.

5.2.3. Data

The sample covers the period 1980-2016, and all data were collected by the World Bank with the selection of the top high-income countries based on the World Bank High-Income Classification for 2016 (World Bank, 2018). The per capita GDP is defined as the gross domestic product divided by midyear population and is expressed in constant 2010 US$. Due to missing data prior to mid '90s for some countries, the sample contains forty (40) economies for which data are available over the period under study, and which alphabetically are as follows: Antigua and Barbuda, Australia, Austria, Belgium, (The) Bahamas, Barbados, Brunei Darussalam, Canada, Chile, Cyprus, Denmark, Finland, France, Germany, Greece, Greenland, Hong Kong SAR China, Iceland, Ireland, Israel, Italy, Japan, Korea Rep., Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Saudi Arabia, Seychelles, Singapore, Spain, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, United Kingdom, United States, and Uruguay. There are 26 OECD member countries among them with the richest OECD country being Luxemburg, which also is the richest economy in the World, in terms of per capita GDP, whilst the richest non-OECD member is Singapore.

5.3. Results and Discussion

5.3.1. Beta convergence results

In order to check for absolute beta-converge, the equation was estimated accounting for heteroscedasticity with the use of cross-section weights. The results are presented in Table 5.1, and they include the main period of the sample 1980-2016 as well as each decade, and the 2008 benchmark of the financial crisis. Table 5.2 shows corresponding results for two group of countries based on their development level, namely OECD and non-OECD members. The figures in Table 5.2 were estimated with the use of a dummy variable, and the equation was modified to allow for the dummy to affect both the constant as well as the speed of convergence. Convergence is found to hold for all the examined periods both for the sample with all countries as well as the OECD and non-OECD members samples. The overall average speed of 1.70% over the period 1980-2016 is slightly lower than the approximately 2% speed that is described by Abreu, et al. (2005) as 'the legendary 2%'. Looking at the decades, the 1980s display the highest speed of convergence, whilst the lowest prior to the financial crisis was in the 1990s. This is also supported by the findings of the recursive beta-convergence that appear in Figure 5.1, that depict the speed of convergence for the corresponding period shown in the horizontal axis, starting from the smaller acceptable period of 1980-1990 and adding successively one year for the entire sample as well as the OECD and non-OECD members. Overall, the speed of convergence seems to have been stabilized in the area between 1.50% and 1.85% in the last 10 years, but over time there are small fluctuations with the peak being reached in the period 1980-1997 and reducing quite rapidly up to 2003. Thereafter, it appears to increase even faster up to the start of the crisis. The latter might be related to a general euphoria that was present in the markets and even a potential bubble. The crisis brought initially a minor slowdown that continued as the crisis was becoming a longer-lasting phenomenon. Since 2013-2014, there is the belief that the worst of the crisis might be over, and this might explain the slightly raised speed of convergence. Looking more closely into the financial crisis, the convergence speed has been reduced to less than half of its prior values from 1.67% for the period 1980-2008 to 0.65% afterwards[7]. This is anticipated as the richer economies are the ones mostly affected by the crisis with a significant number of them in need of assistance to overcome their problems. However, it is alarming that the implied steady-state level of per capita income that is hidden in the constant term seems to have been drastically lowered since the start of

[7] Any period with less than 10 years span should be treated with caution as short-term disturbances could affect the measured growth rate and the estimation of the corresponding convergence.

the financial crisis and the countries might be closer now to their new lower steady-state and whilst this holds, the world economy is also settling for a lower steady-state.

Table 5. 1 Beta convergence results (all countries)

Period	Constant	b	β- Av. Annual Speed	T	obs
1980-2016	0.1417*** (0.0058)	-0.0127*** (0.0005)	1.6989%	36	40
1980-1990	0.1510*** (0.0294)	-0.0132** (0.0029)	1.4261%	10	40
1990-2000	0.1273*** (0.0048)	-0.0104*** (0.0004)	1.1000%	10	40
2000-2010	0.1346** (0.0022)	-0.0119** (0.0002)	1.2744%	10	40
2010-2016	0.0619*** (0.0101)	-0.0049*** (0.0009)	0.5040%	6	40
1980-2008	0.1512*** (19.047)	-0.0133*** (-16.6029)	1.6655%	28	40
2000-2008	0.1408** (0.0035)	-0.0119** (0.0003)	1.2585%	8	40
2008-2016	0.0712*** (0.0064)	-0.0063*** (0.0005)	0.6527%	8	40

*, ** and *** denote statistical significance at 90%, 95%, and 99% confidence level; values in parenthesis are standard errors; T stands for the number of periods (years), and obs is the number of observations in each regression

A similarly fluctuating convergence speed pattern is apparent for the OECD members though the overall speed of convergence is lower at 1.24% with the 1980s displaying the lowest speed and the 1990s the highest. Clearly, the economic crisis reduced the speed from 1.36% prior to the crisis to 1.12% during the crisis years, which is also confirmed by the recursive beta speeds. The overall speed is lower than the literature findings for the developed countries covering earlier periods (2.2% for OECD by Liu and Ruiz (2006) but the member list of the OECD group has been expanding, and it is consistent with the 1.86% speed for the more homogeneous EU economies found by Matkowski et al. (2016). At the same time, the Top-Income but non-OECD members demonstrate a speed of convergence impressively higher than their OECD counterparts for all periods, an indication that not only they are converging between themselves but (in combination with the results in Table 5.1) they converge to the other Top-Income economies that are OECD members and following the crisis, the gap seems to be reducing. This group of countries seems to have benefited the most from the technological, economic and political advances of the 1980s, while they were slowing down in the 1990s and 2000s, which is a view that is also supported by the recursive beta speed. Although they have been affected negatively by the economic crisis as well, their speed reduced only a little from 3.72% prior to the crisis to 3.29% during the crisis years, which comparing it with the slowdown of the 2000s, indicates that this group of countries was only marginally affected by the crisis and instead is utilizing it to reduce the income gap faster.

Table 5. 2 Beta convergence results (OECD and non-OECD members)

Period	Countries	Constant	b	β- Av. Annual Speed	T	obs
1980-2016	**OECD**	0.0826 *** (0.0045)	-0.0100 *** (0.0000)	1.24%	36	40
	non-OECD	0.1252 *** (0.0086)	-0.0191 *** (0.0000)	3.23%	36	40
1980-1990	**OECD**	0.1019 *** (0.0098)	-0.0101 *** (0.0013)	1.06%	10	40
	non-OECD	0.2548 *** (0.0228)	-0.0337 *** (0.0031)	4.10%	10	40
1990-2000	**OECD**	0.1315 *** (0.0055)	-0.0139 *** (0.0007)	1.50%	10	40
	non-OECD	0.1965 *** (0.0098)	-0.0249 *** (0.0013)	2.86%	10	40
2000-2010	**OECD**	0.1059 *** (0.0060)	-0.0105 *** (0.0007)	1.11%	10	40
	non-OECD	0.1344 *** (0.0154)	-0.0159 *** (0.0020)	1.73%	10	40
1980-2008	**OECD**	0.0979 *** (0.0081)	-0.0115 *** (0.0000)	1.36%	28	40
	non-OECD	0.1586 *** (0.0008)	-0.0230 *** (0.0000)	3.72%	28	40
2008-2016	**OECD**	0.0985 ** (0.0088)	-0.0064 *** (0.0000)	1.12%	9	40
	non-OECD	0.2310 ** (0.0077)	-0.0229 *** (0.0000)	3.29%	9	40

*, ** and *** denote statistical significance at 90%, 95% and 99% confidence level; values in parenthesis are standard errors; the standard errors of b and Constant of the OECD are derived from Wald tests; T stands for the number of periods (years), and obs is the number of observations in each regression

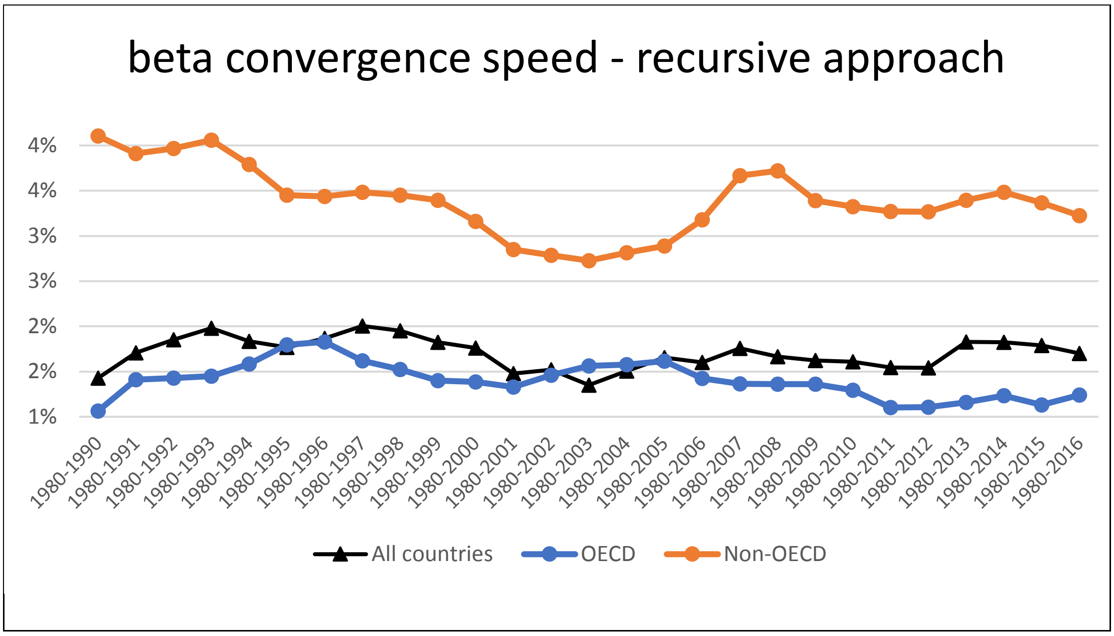

Figure 5. 1

Finally, following the argument that the richest countries define the frontier, the potential presence of further clubs is also investigated by creating two groups, one above the median and another below the median as well as clubs based on the statistical quartiles derived from the per capita GDP. However, no statistical evidence for significant diversification between such groups was found, implying that the group of the top-income countries is fairly homogeneous based on the magnitude of their per capita income.

5.3.2. Log(t) convergence results

The log(t) test is implemented using linear regressions with heteroskedasticity and autocorrelation consistent standard errors in the entire sample after the trend and cyclical components are extracted from each individual in the panel and used the Hodrick-Prescott (1997) filter to smooth all series. The procedure, as described in the previous section, automatically rejected the first 12 observations, and hence, the effective period becomes 1992-2016. Table 5.3 displays the results for all the countries in the sample, along with the estimated clubs. There is no convergence for the entire sample, which is in line with the literature findings that use the same method and they find only club convergence (Borsi and Metiu, 2015; Monfort et al., 2013). The procedure identified three clubs that display convergence at their growth rate levels and an additional club at the end that usually collects the non-convergent economies; in this case, it includes only Luxemburg[8]. In general, the last club in any log(t) convergence analysis contains economies that cannot be assigned to any of the above clubs, and they can be characterized as outliers. The initial 2nd and 3rd cluster of economies could be merged into one club, but the analysis is continued with the initial clustering as it is statistically significant for all clubs and it appears that when they are merged, their common speed of convergence is lower than their individual speeds. The countries whose name is in bold are the OECD member economies. It is apparent that most of the OECD member countries are in Club 1 (21 countries out of the 25 that can be classified within clusters). Club 2, that also has a lower average per capita income than Club 1, contains the remaining OECD members, namely Spain, Portugal, and Greece, that are the worst-hit countries by the financial crisis along with Italy for which there are growing concerns lately, along with a number of non-OECD members. Club 3 contains only three countries that are all non-OECD members from the same geographic location (Caribbean). Whilst Club 1 that displays the stronger evidence of convergence is dominated by the OECD countries, there is a significant number of non-OECD countries (6 out of 14) that are in Club 1 and thus there is evidence that the distinction based on the level of development is becoming less valid over time at least for the top-income countries. Also, the selection of Club 1 countries contains economies that are characterized as crucial for the world economy. Table 5.3 also contains the coefficient γ from which the speed of convergence has been obtained when convergence is present. Finally, the use of alternative filters, in order to eliminate business cycle components from the data, leads to similar results, Phillips and Sul (2009). Nonetheless, in order to ensure robustness, the log(t) results are replicated using the Butterworth (1936) filter with virtually the same results.

[8] As it can be seen in subsequent tables, Luxemburg usually cannot be assigned in any particular group, perhaps due to its extremely high per capita income compared to any other economy in the sample.

Table 5. 3 Log(t) convergence results (all countries)

Club	**Countries**				**Coefficient γ**	**Logt Speed**	**Proposed Club Merging**		
Full Sample [40]	40 countries				-0.2504 (-0.0222)	-		**Coefficient γ**	**Logt Speed**
Club 1 [27]	**Australia** **Austria** **Belgium** **Canada** **Chile** **Denmark** **Finland**	**France** **Germany** Greenland Hong Kong SAR **Ireland** **Iceland** **Israel**	**Japan** **Korea, Rep.** Malta **Netherlands** **Norway** **New Zealand** Singapore	**Sweden** **Switzerland** Trinidad and Tobago United Arab Emirates **United Kingdom** **United States**	**0.2341** * (0.0489)	0.1171	**Final Club 1 [27]**	**0.2341** * (0.0489)	0.1171
Club 2 [9]	Brunei Darussalam Cyprus **Spain** **Greece**	**Italy** **Portugal** Saudi Arabia	Seychelles Uruguay		**0.1711** * (0.0703)	0.0856	**Final Club 2 [12]**	**0.0188** * (0.0453)	0.0094
Club 3 [3]	Antigua and Barbuda	(The) Bahamas	Barbados		**0.2299** * (0.0225)	0.1149			
Club 4 [1] Non-convergent	**Luxembourg**				-	-	**Club 4 [1] Non-convergent**		

* no rejection of the null hypothesis of convergence at the 5% level or better; the numbers in [brackets] stand for the number of countries in a group; the numbers in (parenthesis) are S.E.; The following potential club merging have been tested: Club1+2 (γ=-0.0556 S.E.:0.0287), Club2+3 (γ=0.0188 * S.E.:0.0453) and Club3+4 (γ=-0.8861 S.E.:0.0088)

Tables A.1-A.6 in the Appendix display the corresponding results for the decades 1980-1990, 1990-2000, 2000-2010 and 1980-2008, 1980-2006, 2006-2016 to study the impact of the financial crisis. Although the length of the period is the minimum that one can safely use at the log(t) process (Phillips and Sul, 2007), due to the small number of points in the time series estimation, their figures should be treated with caution. For the same reason, it was not possible to repeat the estimates for the periods 2010-2016 or 2008-2016 and thus for basic comparison, the period 2006-2016 is estimated instead, and is presented in Table B.6. Similar to the entire period estimation, there is no evidence of overall convergence at any of the shorter length samples. However, when comparing the number of clubs of the entire period, there are more potential clubs when looking at the decades, which is expected as the time span of the periods reduces and the short-term volatility across time between the economies becomes more evident. During the period that covers the start of the financial crisis, it is becoming more difficult to identify clusters, which is in line with the increased uncertainty that the crisis introduced. Also, the speed of convergence exhibits notable variation across time and across clubs with the 1980s exhibiting higher speeds and most clubs with evidence of convergence. There are several clubs displaying convergence of GDP growth rates in each subperiod, but only three clubs exhibit stronger evidence of convergence at a GDP per capita level ($\gamma \geq 2$); Club 1 (Luxemburg, Norway, and United Arab Emirates) in the 1980s, and Club 7 (Greece and Israel) and Club 10 (Seychelles and Uruguay) in the 2000s. The decades 1990-2000 and 2006-2016 are the only time periods that the clubs cannot be further merged, and the overall result is slightly different from the one for the entire period. Even though the number of clubs is increasing during the periods with more economic instability, the relative ranking of the countries and their assignment in the top, middle or lower clubs is maintained in most cases as compared to the clubs from the entire period, with the OECD members appearing consistently in the first and stronger clubs or cannot be assigned in any cluster (like Luxemburg), whilst the more troubled OECD members (Greece, Spain, Portugal) are keeping their position in the middle clubs and the lower-ranked clubs mainly contain non-OECD members.

Table 5. 4 Log(t) convergence results (subperiods)

Period	Convergence (overall)	Number of Clubs	Number of Clubs with Convergence
1980-2016	no	3 + 1 NC	3 Clubs: GDP growth rate
1980-1990	no	7 + 1 NC	1 Club: GDP level 4 Clubs: GDP growth rate
1990-2000	no	9 + 1 NC	9 Clubs: GDP growth rate
2000-2010	no	10 + 1 NC	2 Club: GDP level 7 Clubs: GDP growth rate
1980-2008	no	2 + 1 NC	2 Clubs: GDP growth rate
1980-2006	no	2 + 1 NC	2 Clubs: GDP growth rate
2006-2016	no	6 + 1 NC	3 Clubs: GDP growth rate

the magnitude of the log t coefficient determines the existence and type of convergence (GDP growth rate or level); as per the rules of log t, a proportion of the first observations have been discarded before each regression; NC stands for the club of Non-Convergent countries

For robustness, all the above results were repeated whilst removing one of the countries that either could not usually be merged (e.g., Luxemburg) or had severe financial problems (e.g., Greece) but the findings remained the same. Also, when the OECD member countries are tested alone, the obtained results have almost the same club structure as is presented above, which is another indication that the non-

OECD countries are catching up -if not surpassing- the OECD members in terms of economic growth and convergence.

5.3.3. Pairwise stochastic convergence

The third approach assumes an underlying stochastic trend and is the pairwise stochastic approach by Pesaran (2007a). The results, displayed in Table 5.5, include the number of country pairs that the logarithm of their output gap was examined for convergence and the percentage of these pairs that suggest convergence for the entire sample for the period 1980-2016, the effective period from log(t), i.e. 1992-2016 and the period prior to the crisis (1980-2008). However, the removal of time series observations could affect the power of the unit root and stationarity tests. The process is repeated for the clubs that the log(t) convergence methodology suggested as well as for the groups with OECD and non-OECD only members. As mentioned in the previous section, unit root test (ADF) and a stationarity test (KPSS) are performed for all possible pair combinations at each sample and then calculated the PCI as the geometric mean of the two tests. Also, measures of dispersion are estimated, namely the population-weighted average of the squared values of output gaps across country pairs (D_t^2) and the "mean difference" that is used as the numerator of the Gini coefficient, again population-weighted (Δ_t). Neither of these exhibit unit roots or deterministic trends and thus convergence holds. The relevant statistics are presented in Table A.7, in the Appendix.

For the entire sample in terms of countries and period, the ADF and the KPSS tests offer similar percentages leading to a convergence percentage of close to 26%. There is quite a variation, though, in the estimated percentage for the log(t) determined clubs for the period 1980-2016, with low convergence percentage for all clubs but with the highest rate displayed by Club 2 in terms of PCI. Club 1 that displayed higher γ speed than Club 2 has now slightly lower PCI (the KPSS results maintain the same order with log(t), but the ADF results exhibit the reverse order from the log(t). There is more variation for the shortened period of 1992-2016 where the percentage of pairs exhibiting convergence drops in most cases as the number of observations reduces, which is consistent with the econometric properties of unit root and stationarity tests, as for most of them their power increases with T. In general, the pairwise approach provides evidence in favor of weak convergence but as mentioned earlier this method tends to underestimate the presence of convergence. Also, they indicate the degree of common effectiveness, of policies that target the stabilization of an economy following random events. Though the results are not directly comparable to the existing literature due to the different sample selection utilized here, they suggest similar if not stronger percentages of convergence than the literature, like Le Pen (2011), who used the same approach on the less aggregated data from European regions for the period 1980-2006 that one could argue that a European sample would be more disposed to exhibit convergence (the ADF tests reported around 20% and KPSS between 17-25% of the output gap pairs suggest convergence) and Deckers and Hanck (2012), who found no convergence for 51 economies during 1950-2003.

Table 5. 5 Pairwise Convergence results

Period	Sample	Number of Pairs	% of convergent Pairs		
			ADF	KPSS	PCI
1980-2016	All countries	780	24.49%	27.31%	25.86%
1980-2016	Club 1	351	20.23%	30.77%	24.95%
1980-2016	Club 2	36	41.67%	25.00%	32.27%
1980-2016	Final Club 2 (cl2+cl3)	66	36.36%	25.76%	30.60%
1980-2016	OECD	325	18.77%	35.38%	25.77%
1980-2016	non-OECD	91	30.77%	19.78%	24.67%
1992-2016	All countries	780	15.00%	25.00%	19.36%
1992-2016	Club 1	351	11.68%	16.81%	14.01%
1992-2016	Club 2	36	8.33%	50.00%	20.41%
1992-2016	Final Club 2 (cl2+cl3)	66	15.15%	45.45%	26.24%
1992-2016	OECD	325	13.85%	27.69%	19.58%
1992-2016	non-OECD	91	13.19%	23.08%	17.45%
1980-2008	All countries	780	23.59%	26.67%	25.08%
1980-2008	Club 1	351	17.66%	29.63%	22.88%
1980-2008	Club 2	36	55.56%	25.00%	37.27%
1980-2008	Final Club 2 (cl2+cl3)	66	40.91%	27.27%	33.40%
1980-2008	OECD	325	19.08%	32.92%	25.06%
1980-2008	non-OECD	91	32.97%	25.27%	28.86%

PCI stands for Pairwise Convergence Index, which is a measure constructed from the geometric mean of the two tests

The study of the impact of the financial crisis cannot be directly estimated with this approach by comparing the pre- and post-crisis years as the period following 2008 does not have enough observations. Instead, as a proxy, the entire period statistics are compared with the sub-period of the pre-crisis years (1980-2008). There is no noteworthy variation between the two sets of results as the PCI remains around 26%.

It is though interesting that there appears to be no large difference in the convergence percentages based on the OECD distinction with the non-OECD members exhibiting only slightly lower rate, close to 25% versus the 1% higher rate of their OECD peers, confirming that both groups move together with the non-OECD members moving a little faster, especially prior to the crisis. This, although of a small magnitude, is the opposite of what the other two methods suggest. Overall, this methodology suggests that the convergence process is in progress, with approximately 26% of the economies displaying stronger evidence of its occurrence between them.

5.4. Overview

The high-income countries in the sample exhibit characteristics of a robust political environment, employ long-term economic, strategic planning which they are continuously evaluating and adjusting, seeking economic alliances, applying economic policies with the ultimate target of continuous economic growth. They also tend to compare their economic progress to each other and have plans to correct for unexpected-stochastic events, and hence, a deterministic trend is present and dominant. With the use of beta convergence that assumes a deterministic trend, the group of the top income economies in the world displays clear evidence of convergence among them, whilst a closer investigation indicated the initial diversification between the OECD and non-OECD members tends to reduce over time. Also, the speed of convergence was higher in the 1980s with the financial crisis being responsible for a drastically lower speed of convergence, which is reduced by more than half. The finding of convergence within the OECD group is in accordance with the existing literature, but there is also clear evidence that the long-term strategic plans of the rich, but not yet OECD members, economies to promote economic growth is paying off, and they are emerging as world economic co-leaders.

On the other hand, when the condition for a deterministic behavior is relaxed, the log(t) approach finds no overall convergence but instead club convergence mainly at the growth rate level. The traditionally held distinction of OECD membership breaks down as frequently well-performing non-OECD countries belong to clubs with higher per capita GDPs, whilst poorly performing OECD countries belong in lower-ranked clubs. This might be due to strategic planning involving more recently established -and perhaps more aggressively monitored, adjusted, and hence flexible- institutions of the non-OECD economies. The formation of these groups provides evidence that the development level is not the only driving force for the convergence process. As the log(t)'s speed of convergence is based on an algebraically different process, it is not possible to directly compare the two sets of findings. Thus, the corresponding beta convergence speed is estimated for the period 1980-2016 for the clubs where this was possible, i.e., clubs with a sufficient number of countries. The results are presented in Table 5.6. The period 1992-2016 is also estimated as this is the period that effectively corresponds to the log(t) period of analysis (the log(t) approach removed the first 12 observations from the sample when it estimates the variation ratios). The 1992-2016 speed of beta convergence is lower when the decade with the strongest convergence is removed, which is also an indication of the robustness of the relevant analysis. Also, the clubs that are proposed by the log(t) approach have higher beta-speeds than the overall sample's speed confirming that the log(t) method efficiently selected clusters based on data information and it also provides information about interaction and competition within the group of top-income economies.

The pairwise stochastic approach confirms that convergence is present but offers evidence of weaker convergence than the other two methods. This is in line with literature findings of low levels of convergence -though for other groups- when a stochastic approach is applied. Also, this was anticipated as the pairwise stochastic approach ignores the deterministic trend that is clearly present in the economic environment of the sample's economies. Even more so this is the case in Club1-economies that are accepted as the more resilient economies over time, including during the more recent financial crisis. Overlooking the deterministic path, the PCI can also be viewed as the degree of commonality in reactions to stochastic elements that could affect the planned economic growth path. In relative terms, the pairwise stochastic methodology provides higher convergence rates for the log(t) clusters that are mixed with OECD and non-OECD countries versus the traditional distinction of OECD classification and thus endorsing that the development level is not an effective way of examining the existence of convergence anymore. Finally, since the start of the crisis, the convergence between the OECD members slows down, allowing the non-OECD members, that have also been negatively affected, to catch up.

Overall, with the use of the three approaches with different underlying assumptions, there is evidence that the convergence process between the world top-income economies is present as well as it still is an ongoing process that should be monitored. It is also clear that the converging economies as the world-leading economic group are those characterized as Top-Income, and this is irrespective of their development status, with the group of the world top-income countries is moving in unison in an ongoing convergence process. Finally, the hypothesis of a pure stochastic trend seems to weaken the evidence of convergence, which is due to the omission from the analysis of the dominant deterministic trend that is characteristic of all economies in the sample.

Table 5. 6 Summary of Results

Period	Sample	Beta speed	Log(t) speed	PCI
1980-2016	All countries	1.699%	-	25.859%
1992-2016		1.022%	no Conv	19.365%
1980-2016	Club 1	2.232%	-	24.948%
1992-2016		1.868%	0.1171	14.012%
1980-2016	Club 2	3.571%	-	32.275%
1992-2016		2.331%	0.0856	20.412%
1980-2016	Final Club 2 (cl2+cl3)	2.669%	-	30.605%
1992-2016		2.209%	0.0095	26.244%
1980-2008	All countries	1.699%	-	25.083%
1992-2008		1.216%	no Conv	-

PCI stands for Pairwise Convergence Index, which is a measure constructed from the geometric mean of the ADF unit root test and the KPSS stationarity test

5.5. Conclusion

The paper examined three distinctly different methodologies, namely the beta convergence, which is the most popular method and is considered to provide reliable estimates of the speed of convergence, whilst assuming an underlying deterministic trend, the log(t) convergence method that specializes in the estimation of potential clusters of economies and assumes an underlying trend that could be deterministic or stochastic, and the pairwise stochastic approach that compares all economies to each other whilst avoiding the comparison with a benchmark and investigates a pure stochastic trend. The analysis allows the evaluation and comparison of the most popular and diverse methodologies in the convergence literature, which are applied in group of the world's top-income economies as they are classified by the World Bank over the period 1980-2016 rather than the traditionally distinctive developed countries, as currently, this is the group of the world-leading economies, though its convergence is scarcely analyzed.

Overall, the results show unconditional beta convergence with a speed of 1.70% for the entire period of the sample as well as convergence - though at different speeds -for each decade. On the other hand, the log(t) favored the presence of clubs of economies being formed that included a mix of OECD and non-OECD members with the convergence being usually at the growth rate level rather than the level of GDP. The pairwise stochastic approach suggests that the convergence process is active with a percentage of around 26% of the economies clearly involved in it, and no important distinction is found based on the development level. This indicates a commonality in strategic reactions to stochastic elements that threaten economic growth. Also, following the financial crisis both the beta convergence speed and the corresponding steady state of the per capita income reduced dramatically whilst the log(t)'s increased number of clubs implies that the convergence process, though it holds, it has been disturbed.

The three methods cannot be directly quantitatively compared, but one may argue that they lead to similar results; for example, for the entire sample the beta-convergence examination clearly suggests that the top income economies exhibit convergence, whilst the log(t) provides instead with strong evidence of club convergences, and the pairwise stochastic approach finds levels of convergence both at the whole sample as well as for the log(t) defined clubs, indicating common economic strategies. However, there is an apparent drift in the strength of the evidence regarding the estimates of convergence as it tends to grow weaker when the assumption of a deterministic underlying trend is enriched with a stochastic trend and finally abandoned. As the economies in the sample exhibit a behavior with long-term planning for economic growth, as well as imitate each other and prepare – frequently in a similar way - for unexpected events that might impend their planned economic growth, there is an underlying deterministic trend in their economic performance, which a stochastic approach ignores and hence introduces bias in the analysis resulting in weaker evidence of convergence.

6. Summary

Economic growth plays an important role in the field of economics, whilst at the same time it is the main economic objective for most of the world's economies. The two most important directions in the empirical exploration of economic growth concern the investigation of relations between potential influential economic factors and economic growth, as well as examination of economic convergence. The thesis includes an overview of the relevant literature, and an overview of the corresponding econometric methodologies for panel data. The purpose of this thesis is to investigate the differences and similarities in the conclusions that can be drawn using different econometric methodologies, whilst keeping the sample constant.

Hence, the first part of the empirical analysis examines the interaction relationship utilizing popular methodologies that have been established as those that inform on the existence or not of a relationship between two factors, and in some cases on the direction of that relationship, along with methodologies that allow for the quantification of such a relationship. The application of these methodologies employs the factor of military expenditure, for which the current bibliography provides an ambiguous picture about the potential causality. The second part studies three economic convergence econometric methodologies, which assume deterministic, stochastic or combinatorial trends in data, and allow convergence testing by groups, which are either user-defined or data-driven, on a common sample. The sample consists of the scarcely analyzed economies, with no clear picture about their economic convergence, that are identified as the world's top-income economies.

Chapter 2 of the thesis entailed a literature review on the examined subjects, starting from economic growth and public expenditures, and focusing on military spending, before moving to economic growth. Chapter 3 presents all methodologies involved in the evaluation of the relationships between economic growth and its drivers, and those that examine economic convergence, along with the main underlying assumptions and requirements. Chapter 4 examines the possible relationships between economic growth and a selected determinant, namely military expenditure. Chapter 5 examines the impact of the assumed underlying deterministic, stochastic or combinatorial trends of three economic convergence econometric methodologies in the data, on a sample of the scarcely analyzed top-income economies. The current chapter summarizes and concludes the thesis. The main findings from Chapters 4 and 5 are summarized in the next two sub-sections.

6.1. Evaluation of Methodologies for the interactions of Economic Growth: An application on military spending

The empirical analysis examines interaction relationships utilizing popular methodologies that have been established as those that inform on the existence or not of a relationship between two factors, and in some cases on the direction of that relationship (cointegration tests of Pedroni, Kao, Maddala-Wu and Westerlund, Granger causality tests), along with methodologies that allow for the quantification of such a relationship (panel data estimators Pooled Mean Group, Dynamic OLS, Fully Modified OLS). The application of these methodologies utilizes the factor of military expenditure, for which the current bibliography provides an ambiguous picture about the potential causality, with often conflicting evidence. The research covers 138 countries, for the period 1988-2013, without making assumptions about the theoretical channels of influence or its direction, as they often require constricting assumptions. Additionally, the analysis is carried out in three groups of countries based on their income and developmental stage. The analysis shows a diversity in the results obtained from the different methodologies, which cannot be linked to any common country characteristics, and therefore, it is important to use a range of methodologies before drawing conclusions, that are carefully selected in respect to their suitability. In particular, military spending's causality to economic growth appears only in developing countries (positive long-term), while from economic growth towards military spending, there seems to be a positive effect for all groups of countries, except for the least developed countries. Also, the interaction seems more pronounced before the onset of the economic crisis.

6.2. Evaluation of Methodologies for the examination of Economic Convergence: An application on top-income economies

The empirical analysis studies three economic convergence econometric methodologies (beta convergence, log(t) convergence, and pairwise convergence), which assume deterministic, stochastic or combinatorial trends in data, and allow convergence testing by groups, which are either user-defined or data-driven. The sample consists of the scarcely analyzed economies, with no clear picture about their economic convergence, that are identified as the world's top-income economies. The sample includes OECD member countries ("developed"), but also non-OECD members, most of which are richer countries than some of the "developed" ones. All methods agree that the group of the world's top-income economies is participating in an ongoing convergence process, though the financial crisis might have disturbed it. The convergence evidence tends to grow weaker when the assumption of the deterministic underlying trend is enriched with a stochastic trend and finally abandoned. Something that should be expected – although the research literature often ignores it – as most national-economies have some long-term planning. Therefore, understanding the assumptions of each methodology is, once again, necessary before choosing the most appropriate method for the reliability of the results.

6.3. Overview

Many important issues in economics are investigated using different theoretical and methodological assumptions, as well as different samples, making the derivation of robust conclusions increasingly difficult. The present thesis has employed different econometric methodologies that can describe the relationships of economic growth with its potential determinants, without excluding any of the existing theoretical backgrounds, as well as various economic convergence methodologies each with their own methodological assumption, on a common sample, respectively, allowing for their assessment.

The theoretical analysis of the determinants of economic growth and of military spending, in particular, revealed that each potential influence has each own theoretical background, with numerous channels linking military spending to growth positively, negatively and negligibly. Thus, in order to truly explore any potential relationships, the analysis made no a-priori theoretical assumptions, and spanned in both directions of potential influence. Similarly, the examination of the theoretical backgrounds of convergence showed diverse strands of the literature, though not all with solid theoretical bases, but often contradicting. The corresponding methodologies of the leading ones where included in the comparative analysis.

The empirical analysis begins with the evaluation of various methodologies that can be used to examine the dynamic relationship of economic growth with the defense spending. The results show significant variability between econometric methodologies. The cointegration test of Pedroni (1999, 2004), consisting of seven test statistics allows for a "degree" in the acceptance of the cointegration hypothesis, which is in line with the developmental stage of the countries in each sample. For the cointegration test of Kao (1999), it seems difficult to reject the hypothesis of cointegration, and should thus never be applied solely. The Maddala-Wu (1999) cointegration test seems more sensitive, nonetheless both tests are limiting as they do not offer any information on the direction of any relationship proposed. The methodologies that also provide with coefficients of the interactions agree that the effect is more pronounced from economic growth to military spending than in the opposite direction. However, the DOLS (1993) and FMOLS (2000) methodologies both suggest that the difference is much greater than the PMG (1999) and the ARDL do. There is one more test in the analysis, which helps see which methodologies are most likely to be correct. The Granger causality test, which indicates a clear causality from growth to military spending, with the opposite occurring in a fraction of the cases comparatively. Thus, although the analysis employed four different methodologies for the estimation of the relationship coefficients, another methodology was necessary in order to ensure an outcome. No methodology clearly outperforms all the others, but not all methodologies provide with qualitatively similar evidence. Therefore, a variety of methodologies is needed in order to draw reliable conclusions.

Next, the empirical analysis examined three distinctly different convergence methodologies, namely the beta convergence, which assumes an underlying deterministic trend, the log(t) convergence method that assumes an underlying trend that could be deterministic or stochastic, and the pairwise stochastic approach that assumes a purely stochastic trend, on a common sample of the scarcely analyzed top-income world economies. A new index for the interpretation of the stochastic convergence results is proposed. The results from the three methods cannot be directly quantitatively compared but lead to similar conclusions; for example, for the entire sample the beta-convergence examination clearly suggests that the top income economies exhibit convergence, whilst the log(t) provides instead with strong evidence of club convergences, and the pairwise stochastic approach finds levels of convergence both at the whole sample as well as for the log(t) defined clubs, indicating common economic strategies. However, from a methodological perspective, the results show a drift in the strength of the evidence regarding the estimates of convergence as it tends to grow weaker when the assumption of a deterministic underlying trend is enriched with a stochastic trend and finally abandoned. In other words, the hypothesis of a pure stochastic trend seems to weaken the evidence of convergence, which is expected as the sample under analysis are expected to be characterized by a dominantly deterministic trend.

Overall, the investigation of the relevant econometric methodologies for the study of issues of economic growth, indicates the importance of methodological assumptions, which have a decisive impact on the research outcome. Finally, the selection of the econometric methodologies should not be overshadowed by popularity, but it requires a thorough selection as well as the non-limitation of empirical analysis in only one methodological approach. For example, it is reasonable that the literature obtains inconclusive evidence regarding the impact of defense spending, when the majority studies the wrong direction of impact, when the reverse direction should be studied. Similarly, examining for purely stochastic convergence will lead to weak evidence of economic convergence when most countries' economic environment nowadays includes long-term economic planning.

6.4. Future Research

The results and relevant implications offer the potential for further analysis in many aspects. Firstly, the analysis of military spending on economic growth could also be explored through more, and more recent, panel data estimators to also examine the regression-based analysis of the subject, to see if the implications apply there as well. Moreover, recent estimators can account for cross-sectional dependence and regressor endogeneity, obstacles that favored the use of cointegration and causality approaches. Additionally, the convergence hypothesis analysis could be extended to examine whether the implications, regarding the stochastic element of convergence that were derived for the world's wealthiest countries, also holds true for a world-wide coverage, and if the methodological characteristics will affect the results in a similar manner, i.e. whether less organized economies exhibit higher levels of stochastic convergence, and perhaps less evidence of deterministic convergence.

7. Appendix

Table A. 1 Log(t) results 1980-1990

Club	**Countries**				**Coefficient γ**	**Logt Speed**	**Proposed Club Merging**		
Full Sample [38]	38 countries				-0.9423 (0.0585)	-		**Coefficient γ**	**Logt Speed**
Club 1 [3]	**Luxembourg**	**Norway**	United Arab Emirates		**2.9320*** (1.0704)	1.4660	**Final Club 1 [3]**	**2.9320*** (1.0704)	1.4660
Club 2 [15]	**Australia** **Austria** **Belgium** Brunei Darussalam	**Canada** **Finland** **France** **Germany**	Greenland **Iceland** **Italy** **Japan**	**Netherlands** **Sweden** **United States**	**0.2153*** (0.1535)	0.1077	**Final Club 2 [15]**	**0.2153*** (0.1535)	0.1077
Club 3 [2]	**United Kingdom**	**New Zealand**			-2.3274 (2.0693)	-	**Final Club 3 [2]**	-2.3274 (2.0693)	-
Club 4 [6]	Cyprus **Greece**	**Ireland** **Israel**	Singapore **Spain**		**1.0456*** (0.3103)	0.5228	**Final Club 4 [8]**	**0.2838*** (0.1651)	0.1419
Club 5 [2]	Bahamas, The	Hong Kong SAR			-0.0229 (0.1714)	-			
Club 6 [4]	Antigua and Barbuda	Malta	**Portugal**	Saudi Arabia	**0.7969*** (0.2579)	0.3985	**Final Club 5 [4]**	**0.7969*** (0.2579)	0.3985
Club 7 [5]	**Chile** **Korea, Rep.**	Seychelles Trinidad and Tobago	Uruguay		**0.5478*** (0.2233)	0.2739	**Final Club 6 [5]**	**0.5478*** (0.2233)	0.2739
Club 8 [1] Non-convergent	**Denmark**				-1.2716 (0.0512)	-	**Final Club 7 - Non- convergent [1]**		

* no rejection of the null hypothesis of convergence at the 5% level or better; the numbers in [brackets] stand for the number of countries in a group; the numbers in (parenthesis) are S.E.; due to lack of data 2 countries were not included in this subsample (Barbados and Switzerland)

Table A. 2 Log(t) results 1990-2000

Club	**Countries**	**Coefficient γ**	**Logt Speed**
Full Sample [40]	40 countries	-0.9728 (0.0628)	-
Club 1 [3]	United Arab Emirates, **Denmark**, **Ireland**	**0.0946*** (0.1901)	0.0473
Club 2 [3]	**Japan**, **Netherlands**, **United States**	**0.6533*** (0.7076)	0.3267
Club 3 [2]	**Australia**, **Sweden**	**0.3190*** (0.9543)	0.1595
Club 4 [3]	**Austria**, **Canada**, Singapore	**0.0368*** (0.1565)	0.0184
Club 5 [7]	Brunei Darussalam, **France**, **Iceland**, **United Kingdom**, **Finland**, **Germany**, **Italy**	**0.1638*** (0.1620)	0.0819
Club 6 [5]	Cyprus, Greenland, **New Zealand**, **Spain**, **Israel**	**0.3816*** (0.1934)	0.1908
Club 7 [4]	Bahamas, The, **Greece**, Hong Kong SAR, **Portugal**	**0.3619*** (0.1817)	0.1810
Club 8 [3]	**Korea, Rep.**, Malta, Saudi Arabia	**0.5714*** (0.2482)	0.2857
Club 9 [3]	Antigua and Barbuda, **Chile**, Seychelles	**0.2808*** (0.1970)	0.1404
Club 10 [7] Non-convergent	Barbados, **Luxembourg**, **Switzerland**, Uruguay, **Belgium**, **Norway**, Trinidad and Tobago	-1.0678 (0.0602)	-

* no rejection of the null hypothesis of convergence at the 5% level or better; the numbers in [brackets] stand for the number of countries in a group; the numbers in (parenthesis) are S.E.; no further club merging was statistically significant

Table A. 3 Log(t) results 2000-2010

Club	Countries			Coefficient γ	Conv. Speed	Proposed Club Merging		
Full Sample [40]	40 countries			-0.9802 (0.0642)	-		**Coefficient**	**Speed**
Club 1 [3]	**Denmark**	**Ireland**	**Sweden**	-0.1608 (0.1319)	-	**Final Club 1 [3]**	-0.1608 (0.1319)	-
Club 2 [4]	**Australia** **Netherlands**	Singapore	United Arab Emirates	**0.4256*** (0.2412)	0.2128	**Final Club 2 [4]**	**0.4256*** (0.2412)	0.2128
Club 3 [4]	**Austria** **Canada**	**Finland**	**United States**	**0.2150*** (0.1685)	0.1075	**Final Club 3 [4]**	**0.2150*** (0.1685)	0.1075
Club 4 [4]	**Belgium** Greenland	**Iceland**	**Japan**	**0.0593*** (0.1771)	0.0297	**Final Club 4 [4]**	**0.0593*** (0.1771)	0.0297
Club 5 [3]	**France**	**Germany**	**United Kingdom**	**0.2110*** (0.1427)	0.1055	**Final Club 5 [3]**	**0.2110*** (0.1427)	0.1055
Club 6 [6]	Brunei Darussalam Cyprus	Hong Kong SAR **Italy**	**New Zealand** **Spain**	**0.4847*** (0.2300)	0.2424	**Final Club 6 [8]**	**0.0467*** (0.1641)	**0.0234**
Club 7 [2]	**Greece**	**Israel**		**2.2503*** (0.4108)	1.1252			
Club 8 [6]	Bahamas, The **Korea, Rep.**	Malta **Portugal**	Saudi Arabia Trinidad and Tobago	**0.5786*** (0.2282)	0.2893	**Final Club 7 [6]**	**0.5786*** (0.2282)	0.2893
Club 9 [2]	Antigua and Barbuda	**Chile**		**0.1706*** (0.2080)	0.0853	**Final Club 8 [2]**	**0.1706*** (0.2080)	0.0853
Club 10 [2]	Seychelles	Uruguay		**2.1861*** (0.9939)	1.0931	**Final Club 9 [2]**	**2.1861*** (0.9939)	1.0931
Club 11 [4] Non-convergent	Barbados	**Luxembourg** **Norway**	**Switzerland**	-1.1253 (0.0552)	-	**Final Club 10 [4] Non-convergent**		

* no rejection of the null hypothesis of convergence at the 5% level or better; the numbers in [brackets] stand for the number of countries in a group; the numbers in (parenthesis) are S.E.

Table A. 4 Log(t) results 2006-2016						
Club	**Countries**				**Coefficient γ**	**Conv. Speed**
Full Sample [40]	40 countries				-1.0080 (0.0566)	
Club 1 [7]	**Australia** **Denmark**	**Ireland** **Netherlands**	Singapore **Sweden**	**United States**	-0.0950 (0.1167)	-
Club 2 [7]	**Austria** **Belgium**	**Finland** **Germany**	**Iceland** **Japan**	Greenland	-0.0650 (0.1295)	-
Club 3 [8]	Brunei Darussalam **France**	Hong Kong SAR **Israel**	**Italy** **New Zealand**	United Arab Emirates **United Kingdom**	**0.0583*** (0.1036)	0.0292
Club 4 [6]	Cyprus **Greece**	**Korea, Rep.** Malta	Saudi Arabia **Spain**		-0.1157 (0.1163)	-
Club 5 [3]	Bahamas, The	**Portugal**	Uruguay		**0.0957*** (0.1769)	0.0479
Club 6 [4]	Barbados	**Chile**	Seychelles	Trinidad and Tobago	**0.3427*** (0.2195)	0.1714
Club 7 [5] Non-convergent	Antigua and Barbuda **Canada**	**Luxembourg** **Norway**	**Switzerland**		-1.1935 (0.0490)	-

* no rejection of the null hypothesis of convergence at the 5% level or better; the numbers in [brackets] stand for the number of countries in a group; the numbers in (parenthesis) are S.E.; no further club merging was statistically significant

Table A. 5 Log(t) results 1980-2008						
Club	**Countries**				**Coefficient γ**	**Logt Speed**
Full Sample [40]	40 countries				-0.3823 (0.0171)	-
Club 1 [32]	**Australia**	**Finland**	**Israel**	Singapore	**0.0742*** (0.0401)	0.0371
	Austria	**France**	**Italy**	**Spain**		
	Belgium	**Germany**	**Japan**	**Sweden**		
	Brunei Darussalam	**Greece**	**Korea, Rep.**	**Switzerland**		
	Canada	Greenland	Malta	Trinidad and Tobago		
	Chile	Hong Kong SAR	**Netherlands**	United Arab Emirates		
	Cyprus	**Ireland**	**New Zealand**	**United Kingdom**		
	Denmark	**Iceland**	**Portugal**	**United States**		
Club 2 [5]	Antigua and Barbuda		Saudi Arabia	Uruguay	**0.0787** * (0.0089)	0.03935
	Barbados		Seychelles			
Club 3 [3] Non-convergent	Bahamas (The)	**Luxembourg**	**Norway**		1.2797 (0.0130)	-

* no rejection of the null hypothesis of convergence at the 5% level or better; the numbers in [brackets] stand for the number of countries in a group; the numbers in (parenthesis) are S.E.

Table A. 6 Log(t) results 1980-2006						
Club	**Countries**				**Coefficient γ**	**Logt Speed**
Full Sample [40]	40 countries				-0.4458 (0.0161)	-
Club 1 [30]	**Australia**	**France**	**Italy**	**Spain**	**0.0834*** (0.0209)	0.0417
	Austria	**Germany**	**Japan**	**Sweden**		
	Belgium	**Greece**	**Korea, Rep.**	**Switzerland**		
	Brunei Darussalam	Greenland	Malta	United Arab Emirates		
	Canada	Hong Kong SAR	**Netherlands**	**United Kingdom**		
	Cyprus	**Ireland**	**New Zealand**	**United States**		
	Denmark	**Iceland**	**Portugal**			
	Finland	**Israel**	Singapore			
Club 2 [6]	Antigua and Barbuda	**Chile**	Seychelles		**0.7683** * (0.0942)	0.38415
	Barbados	Saudi Arabia	Trinidad and Tobago			
Club 3 [4] Non-convergent	Bahamas (The)	**Luxembourg**	**Norway**	Uruguay	-0.9094 (0.0052)	-

* no rejection of the null hypothesis of convergence at the 5% level or better; the numbers in [brackets] stand for the number of countries in a group; the numbers in (parenthesis) are S.E.

Table A. 7 Testing Dispersion Measures

Unit Root Tests

Variable	*Test*	*Statistic*	*Prob*
Δ_t	ADF	-1.3930	0.5745
D^2_t	ADF	-1.4254	0.8355

Stationarity Tests

Variable	*Test*	*Statistic*	*Prob*
Δ_t	KPSS	0.6923	0.025
D^2_t	KPSS	0.6930	0.025

ADF: Prob higher than 0.10 suggests rejection of the null hypothesis of a unit root; KPSS: Prob below 0.1 suggests no rejection of the null of stationarity.

Trend Test

Dependent Variable	*Trend*	*Constant*	Δ_t *(-1)*	D^2_t *(-1)*
Δ_t	-0.0002 (-0.4157)	0.0522 (0.8689)	0.9200 *** (12.0450)	-
D^2_t	-0.0006 (-0.6674)	0.0674 (1.0515)	-	0.9057 *** (13.9484)

*** denotes statistical significance at level 1%

8. Bibliography

Abreu, M., deGroot, H. L. F., & Florax, R. (2005). A Meta-Analysis of Β-Convergence: The Legendary 2%. *Journal of Economic Surveys*, *19*(3), 389–420.

Abu-Bader, S., & Abu-Qarn, A. S. (2003). Government expenditures, military spending and economic growth: causality evidence from Egypt, Israel, and Syria. *Journal of Policy Modeling*, *25*(6–7), 567–583. https://doi.org/10.1016/S0161-8938(03)00057-7

Acikgoz, B., & Cinar, S. (2017). Public Spending and Economic Growth: An Empirical Analysis of Developed Countries. *Ekonomicky Casopis*, *65*(5), 448-458.

Alexander, W. (1990). The Impact of Defense Spending on Economic Growth. *Defence Economics*, *2*(1), 39–55. https://doi.org/10.1080/10430719008404677

Alexiadis, S. (2013). *Convergence Clubs and Spatial Externalities*. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-31626-5

Alfaro, L., Chanda, A., Kalemli-Ozcan, S., & Sayek, S. (2004). FDI and economic growth: the role of local financial markets. *Journal of International Economics*, *64*(1), 89–112. https://doi.org/10.1016/S0022-1996(03)00081-3

Alptekin, A., & Levine, P. (2012). Military expenditure and economic growth: A meta-analysis. *European Journal of Political Economy*, *28*(4), 636–650. https://doi.org/10.1016/J.EJPOLECO.2012.07.002

Andreano, M. S., Laureti, L., & Postiglione, P. (2013). Economic growth in MENA countries: Is there convergence of per-capita GDPs? *Journal of Policy Modeling*, *35*(4), 669–683. https://doi.org/10.1016/j.jpolmod.2013.02.005

Ang, J. B. (2009). Financial development and the FDI-growth nexus: the Malaysian experience. *Applied Economics*, *41*(13), 1595–1601. https://doi.org/10.1080/00036840701222553

Arellano, M., & Bond, S. (1991). Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *The Review of Economic Studies*, *58*(2), 277-297. https://doi.org/10.2307/2297968

Azariadis, C. (1996). The Economics of Poverty Traps: Part One: Complete Markets. *Journal of Economic Growth*, *1*(4), 449–496. Retrieved from https://econpapers.repec.org/RePEc:kap:jecgro:v:1:y:1996:i:4:p:449-96

Azomahou, T. T., El ouardighi, J., Nguyen-Van, P., & Pham, T. K. C. (2011). Testing convergence of European regions: A semiparametric approach. *Economic Modelling*, *28*(3), 1202–1210. https://doi.org/10.1016/j.econmod.2010.12.010

Bai, J., & Ng, S. (2004). A PANIC Attack on Unit Roots and Cointegration. *Econometrica*, *72*(4), 1127–1177. https://doi.org/10.1111/j.1468-0262.2004.00528.x

Bai, J., & Ng, S. (2010). Panel Unit Root Tests With Cross-Section Dependence: a Further Investigation. *Econometric Theory*, *26*(04), 1088–1114. https://doi.org/10.1017/S0266466609990478

Baltagi, B. H. (2008). *Econometric analysis of panel data*. John Wiley & Sons.

Baltagi, B. H., Bresson, G., & Pirotte, A. (2007). Panel unit root tests and spatial dependence. *Journal of Applied Econometrics*, *22*(2), 339–360. https://doi.org/10.1002/jae.950

Banerjee, A., Dolado, J., & Mestre, R. (1998). Error-correction Mechanism Tests for Cointegration in a Single-equation Framework. *Journal of Time Series Analysis*, *19*(3), 267–283. https://doi.org/10.1111/1467-9892.00091

Banerjee, A., Marcellino, M., & Osbat, C. (2005). Testing for PPP: Should we use panel methods? *Empirical Economics*, *30*(1), 77–91. https://doi.org/10.1007/s00181-004-0222-8

Barrios, C., Flores, E., & Martínez, M. Á. (2019). Club convergence in innovation activity across European regions. *Papers in Regional Science*, *98*(4), 1545–1565.

https://doi.org/10.1111/pirs.12429

Barro, R. (1990). Government Spending in a Simple Model of Endogeneous Growth. *Journal of Political Economy*, *98*(5, Part 2), S103–S125. https://doi.org/10.1086/261726

Barro, R. (2003). Determinants of Economic Growth in a Panel of Countries. *Annals of Economics and Finance*, *4*, 231–274. Retrieved from https://scholar.harvard.edu/barro/publications/determinants-economic-growth-panel-countries

Barro, R. J. (1984). *Macroeconomics*. MIT Press. Retrieved from https://mitpress.mit.edu/books/macroeconomics-0

Barro, R. J. (1991). Economic Growth in a Cross Section of Countries. *The Quarterly Journal of Economics*, *106*(2), 407. https://doi.org/10.2307/2937943

Barro, R. J., & Sala-i-Martin, X. (1992). Convergence. *Journal of Political Economy*. The University of Chicago Press. https://doi.org/10.2307/2138606

Barro, R. J., & Sala-i-Martin, X. (2003). *Economic growth*. MIT Press. Retrieved from https://mitpress.mit.edu/books/economic-growth

Barro, R. J., Sala-I-Martin, X., Blanchard, O. J., & Hall, R. E. (1991). Convergence Across States and Regions. *Brookings Papers on Economic Activity*, *1991*(1), 107. https://doi.org/10.2307/2534639

Barro, R. j, & Sala-i-Martin, X. (1992). Convergence. *The Journal of Political Economy*, *100*(2), 223–252.

Barro, R., & Sala-i-Martin, X. (1990). *Economic Growth and Convergence across The United States*. Cambridge, MA. https://doi.org/10.3386/w3419

Barro, R., & Sala-i-Martin, X. (1995). *Technological Diffusion, Convergence, and Growth*. Cambridge, MA. https://doi.org/10.3386/w5151

Barro, R. T., & Sala-I-Martin, X. (1992). Regional growth and migration: A Japan-United States comparison. *Journal of the Japanese and International Economies*, *6*(4), 312–346. https://doi.org/10.1016/0889-1583(92)90002-L

Bartkowska, M., & Riedl, A. (2012). Regional convergence clubs in Europe: Identification and conditioning factors. *Economic Modelling*, *29*(1), 22–31. https://doi.org/10.1016/j.econmod.2011.01.013

Batchelor, P., Dunne, J. P., & Saal, D. S. (2000). Military spending and economic growth in South Africa. *Defence and Peace Economics*, *11*(4), 553–571. https://doi.org/10.1080/10430710008404966

Baumol, W. J. (1986). Productivity Growth, Convergence, and Welfare: What the Long-run Data Show. *American Economic Review*, *76*(5), 1072–1085. https://doi.org/10.2307/1816469

Baumol, W. J., Blackman, S. A. B., & Wolff, E. N. (1991). *Productivity and American leadership : the long view*. MIT Press.

Baumol, W. J., & Wolff, E. N. (1988). Productivity Growth, Convergence, and Welfare: Reply. *The American Economic Review*, *78*, 1155–1159. https://doi.org/10.2307/1807175

Beaudry, P., Collard, F., & Green, D. (2002). *Decomposing the Twin-peaks in the World Distribution of Output-per-worker*. Cambridge, MA. https://doi.org/10.3386/w9240

Ben-David, D. (1998). Convergence clubs and subsistence economies. *Journal of Development Economics*, *55*(1), 155–171. https://doi.org/10.1016/S0304-3878(97)00060-6

Benoit, E. (1973). Growth and Defense in Developing Countries. *Economic Development and Cultural Change, 26, 271-280*. The University of Chicago Press. https://doi.org/10.2307/1153245

Benoit, E. (1978). Growth and Defense in Developing Countries. *Economic Development and Cultural Change*, *26*(2), 271–280. https://doi.org/10.1086/451015

Bernard, A. B., & Durlauf, S. (1991). *Convergence of International Output Movements*. Cambridge, MA. https://doi.org/10.3386/w3717

Bernard, A. B., & Durlauf, S. N. (1995). Convergence in international output. *Journal of Applied*

Econometrics, *10*(2), 97–108. https://doi.org/10.1002/jae.3950100202

Bernard, A. B., & Durlauf, S. N. (1996). Interpreting tests of the convergence hypothesis. *Journal of Econometrics*, *71*(1–2), 161–173. https://doi.org/10.1016/0304-4076(94)01699-2

Bernard, A. B., & Jones, C. I. (1996a). Productivity Across Industries and Countries: Time Series Theory and Evidence. *The Review of Economics and Statistics*, *78*(1), 135. https://doi.org/10.2307/2109853

Bernard, A. B., & Jones, C. I. (1996b). Productivity and convergence across U.S. States and industries. *Empirical Economics*, *21*(1), 113–135. https://doi.org/10.1007/BF01205496

Bernard, A. B., & Jones, C. I. (1996c). Technology and Convergence. *The Economic Journal*, *106*(437), 1037. https://doi.org/10.2307/2235376

Bianchi, M. (1997). Testing for convergence: Evidence from non-parametric multimodality tests. *Journal of Applied Econometrics*, *12*(4), 393–409. https://doi.org/10.1002/(SICI)1099-1255(199707)12:4<393::AID-JAE447>3.0.CO;2-J

Binder, M., Hsiao, C., & Pesaran, M. H. (2005). Estimation and inference in short panel vector autoregressions with unit roots and cointegration. *Econometric Theory*, *21*(4), 795–837.

Binder, Michael, & Pesaran, M. H. (1999). Stochastic Growth Models and Their Econometric Implications. *Journal of Economic Growth*, *4*(2), 139–183. https://doi.org/10.1023/A:1009802421114

Biswas, B., & Ram, R. (1986). Military Expenditures and Economic Growth in Less Developed Countries: An Augmented Model and Further Evidence. *Economic Development and Cultural Change*, *34*, 361–372. https://doi.org/10.2307/1153856

Blackburne, E., & Frank, M. (2007). Estimation of nonstationary heterogeneous panels. *Stata Journal*, *7*(2), 197–208. Retrieved from https://econpapers.repec.org/RePEc:tsj:stataj:v:7:y:2007:i:2:p:197-208

Bliss, C. (1999). Galton's fallacy and economic convergence. *Oxford Economic Papers*, *51*(1), 4–14. https://doi.org/10.1093/oep/51.1.4

Bliss, C. (2000). Galton's fallacy and economic convergence: a reply to Cannon and Duck. *Oxford Economic Papers*, *52*(2), 420–422. https://doi.org/10.1093/oep/52.2.420

Bolea, L., Duarte, R., & Chóliz, J. S. (2018). From convergence to divergence? Some new insights into the evolution of the European Union. *Structural Change and Economic Dynamics, 47, 82-95*. https://doi.org/10.1016/J.STRUECO.2018.07.006

Borsi, M. T., & Metiu, N. (2015). The evolution of economic convergence in the European Union. *Empirical Economics*, *48*(2), 657–681. https://doi.org/10.1007/s00181-014-0801-2

Borts, G. H., & Stein, J. L. (1965). Economic growth in a free market. *The Economic Journal*, *75*(300), 822–824.

Bowman, D. (1999). Efficient Tests for Autoregressive Unit Roots in Panel Data, *FRB International Finance Discussion Paper No. 646*. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=231803

Boyle, G. E., & McCarthy, T. G. (1999). Simple measures of convergence in per capita GDP: a note on some further international evidence. *Applied Economics Letters*, *6*(6), 343–347. https://doi.org/10.1080/135048599353041

Breitung, J. (2001). The local power of some unit root tests for panel data. In *Nonstationary Panels, Panel Cointegration, and Dynamic Panels (Advances in Econometrics, Volume 15)* (pp. 161–177). Emerald Group Publishing Limited. https://doi.org/10.1016/S0731-9053(00)15006-6

Breitung, J., & Meyer, W. (1994). Testing for unit roots in panel data: are wages on different bargaining levels cointegrated? *Applied Economics*, *26*(4), 353–361. https://doi.org/10.1080/00036849400000081

Breitung, J., & Pesaran, M. H. (2008). Unit Roots and Cointegration in Panels. In L. Mátyás & P.

Sevestre (Eds.), *The Econometrics of Panel Data: Fundamentals and Recent Developments in Theory and Practice* (pp. 279–322). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-75892-1_9

Breitung, Jörg, & Das, S. (2005). Panel unit root tests under cross-sectional dependence. *Statistica Neerlandica*, *59*(4), 414–433. https://doi.org/10.1111/j.1467-9574.2005.00299.x

Brock, W. A., & Durlauf, S. N. (2001). Discrete choice with social interactions. *Review of Economic Studies*, *68*(2), 235–260. https://doi.org/10.1111/1467-937X.00168

Butterworth, S. (1930). On the theory of filter amplifiers. *Wireless Engineer*, *7*((6)), 536–541.

Camarero, M., Ordónez, J., & Tamarit, C. R. (2002). Tests for interest rate convergence and structural breaks in the EMS: Further analysis. *Applied Financial Economics*, *12*(6), 447–456. https://doi.org/10.1080/09603100010005294

Cannon, E. S., & Duck, N. W. (2000). Galton's Fallacy and Economic Convergence. *Oxford Economic Papers*, *52*(2), 415–419.

Cappelen, Å., Gleditsch, N. P., & Bjerkholt, O. (1984). Military Spending and Economic Growth in the OECD Countries. *Journal of Peace Research*. Sage Publications, Ltd. https://doi.org/10.2307/423749

Carlino, G. A., & Mills, L. O. (1993). Are U.S. regional incomes converging?: A time series analysis. *Journal of Monetary Economics*, *32*(2), 335–346. https://doi.org/10.1016/0304-3932(93)90009-5

Carlino, G., & Mills, L. (1996). Convergence And The U.S. States: A Time-Series Analysis. *Journal of Regional Science*, *36*(4), 597–616. https://doi.org/10.1111/j.1467-9787.1996.tb01120.x

Carrion-i-Silvestre, J. L., & German-Soto, V. (2009). Panel data stochastic convergence analysis of the Mexican regions. *Empirical Economics*, *37*(2), 303–327. https://doi.org/10.1007/s00181-008-0234-x

Cellini, R., & Scorcu, A. E. (2000). Segmented stochastic convergence across the G-7 countries. *Empirical Economics*, *25*(3), 463–474. https://doi.org/10.1007/s001810000027

Chang, H.-C., Huang, B.-N., & Yang, C. W. (2011). Military expenditure and economic growth across different groups: A dynamic panel Granger-causality approach. *Economic Modelling*, *28*(6), 2416–2423. https://doi.org/10.1016/J.ECONMOD.2011.06.001

Chang, Y. (2002). Nonlinear IV unit root tests in panels with cross-sectional dependency. *Journal of Econometrics*, *110*(2), 261–292. https://doi.org/10.1016/S0304-4076(02)00095-7

Chang, Y. (2004). Bootstrap unit root tests in panels with cross-sectional dependency. *Journal of Econometrics*, *120*(2), 263–293. https://doi.org/10.1016/S0304-4076(03)00214-8

Chang, Y., Park, J. Y., & Phillips, P. C. B. (2003). Nonlinear econometric models with cointegrated and deterministically trending regressors. *The Econometrics Journal*, *4*(1), 1–36. https://doi.org/10.1111/1368-423x.00054

Chapsa, X., Katrakilidis, C., & Tabakis, N. (2015). Investigating the Convergence Hypothesis in the Eu: More Evidence Accounting for Structural Breaks. In P. P. Karasavvoglou A., Ongan S. (Ed.), *EU Crisis and the Role of the Periphery* (pp. 21–39). Springer, Cham. https://doi.org/10.1007/978-3-319-10133-0_2

Charles, A., Darne, O., & Hoarau, J.-F. (2012). Convergence of real per capita GDP within COMESA countries: A panel unit root evidence. *The Annals of Regional Science*, *49*(1), 53–71. https://doi.org/10.1007/s00168-010-0427-z

Chen, K., Gong, X., & Marcus, R. D. (2014). The new evidence to tendency of convergence in Solow model. *Economic Modelling*, *41*, 263–266. https://doi.org/10.1016/j.econmod.2014.02.029

Chen, P. F., Lee, C. C., & Chiu, Y. Bin. (2014). The nexus between defense expenditure and economic growth: New global evidence. *Economic Modelling, 36, 474-483*. https://doi.org/10.1016/j.econmod.2013.10.019

Choi, I. (2001). Unit root tests for panel data. *Journal of International Money and Finance*, *20*(2), 249–272. https://doi.org/10.1016/S0261-5606(00)00048-6

Choi, I. (2002). Combination unit root tests for cross-sectionally correlated pannels. In *Econometric theory and practice : frontiers of analysis and applied research (2006)*. Cambridge University Press. Retrieved from http://repository.ust.hk/ir/Record/1783.1-129

Choi, I. (2006). Nonstationary panels. In *Palgrave Handbook of Econometrics, 1*. (pp. 511–539).

Chortareas, G., Magkonis, G., Moschos, D., & Panagiotidis, T. (2015). Financial Development and Economic Activity in Advanced and Developing Open Economies: Evidence from Panel Cointegration. *Review of Development Economics*, *19*(1), 163–177. https://doi.org/10.1111/rode.12132

Chudik, A., & Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *Journal of Econometrics*, *188*(2), 393–420. https://doi.org/10.1016/J.JECONOM.2015.03.007

Chudik, A., Pesaran, M. H., & Tosetti, E. (2011). Weak and strong cross-section dependence and estimation of large panels. *Econometrics Journal*, *14*, C45-C90. https://doi.org/10.1111/j.1368-423X.2010.00330.x

Churchill, A. S., Ugur, M., & Yew, S. L. (2017). Government education expenditures and economic growth: a meta-analysis. *The B.E. Journal of Macroeconomics*, *17*(2). https://doi.org/10.1515/bejm-2016-0109

Churchill, A. S., & Yew, S. L. (2018). The effect of military expenditure on growth: an empirical synthesis. *Empirical Economics*, *55*(3), 1357–1387. https://doi.org/10.1007/s00181-017-1300-z

Cole, M. A., & Neumayer, E. (2003). The pitfalls of convergence analysis: is the income gap really widening? *Applied Economics Letters*, *10*(6), 355–357. https://doi.org/10.1080/1350485032000072361

Cuaresma, J. C., & Reitschuler, G. (2004). A non-linear defence-growth nexus? evidence from the US economy. *Defence and Peace Economics*, *15*(1), 71–82. https://doi.org/10.1080/1024269042000164504

d'Agostino, G., Dunne, J. P., & Pieroni, L. (2011). Optimal military spending in the US: A time series analysis. *Economic Modelling*, *28*(3), 1068–1077. https://doi.org/10.1016/J.ECONMOD.2010.11.021

Dakurah, A. H., Davies, S. P., & Sampath, R. K. (2001). Defense spending and economic growth in developing countries: A causality analysis. *Journal of Policy Modeling*, *23*(6), 651–658. https://doi.org/10.1016/S0161-8938(01)00079-5

de la Fuente, A. (1997). The empirics of growth and convergence: A selective review. *Journal of Economic Dynamics and Control*, *21*(1), 23–73. https://doi.org/10.1016/0165-1889(95)00925-6

De Long, J. B. (1988). Productivity Growth, Convergence, and Welfare: Comment. *American Economic Review*, *78*(5), 1138–1154.

Deaton, A. (1997). *The analysis of household surveys: a microeconometric approach to development policy*. The World Bank.

Deckers, T., & Hanck, C. (2012). Multiple Testing For Output Convergence. *Macroeconomic Dynamics*, *18*(01), 199–214. https://doi.org/10.1017/S1365100512000338

Deger, S. (1986). Economic Development and Defense Expenditure. *Economic Development and Cultural Change*, *35*, 179–196. https://doi.org/10.2307/1154149

Deger, S., & Sen, S. (1983). Military expenditure, spin-off and economic development. *Journal of Development Economics*, *13*(1–2), 67–83. https://doi.org/10.1016/0304-3878(83)90050-0

Deger, S., & Smith, R. (1983). Military Expenditure and Growth in Less Developed Countries. *Journal of Conflict Resolution*, *27*(2), 335–353. https://doi.org/10.1177/0022002783027002006

DeGrasse, R. W. (1983). *Military Expansion, Economic Decline: Impact of Military Spending on United*

States Economic Performance. Taylor & Francis. Retrieved from https://books.google.gr/books?id=7nSTDAAAQBAJ

Deidda, L., & Fattouh, B. (2002). Non-linearity between finance and growth. *Economics Letters*, *74*(3), 339–345. https://doi.org/10.1016/S0165-1765(01)00571-7

Delgado, F. J., Fernández-Rodríguez, E., Martínez-Arias, A., & Presno, M. J. (2019). Club convergence in the corporate income tax: The case of European effective rates. *Physica A: Statistical Mechanics and Its Applications*, *523*, 942–953. https://doi.org/10.1016/j.physa.2019.04.212

DeRouen, K. R. (1994). Defense spending and economic growth in Latin America: The externalities effects. *International Interactions*, *19*(3), 193–212. https://doi.org/10.1080/03050629408434827

Ditzen, J. (2018). Estimating Dynamic Common-Correlated Effects in Stata. *The Stata Journal: Promoting Communications on Statistics and Stata*, *18*(3), 585–617. https://doi.org/10.1177/1536867X1801800306

Dowrick, S., & Nguyen, D.-T. (1989). OECD Comparative Economic Growth 1950-85: Catch-Up and Convergence. *The American Economic Review*, *79*(5), 1010–1030. https://doi.org/10.2307/1831434

Drennan, M. P., Lobo, J., & Strumsky, D. (2004). Unit root tests of sigma income convergence across us metropolitan areas. *Journal of Economic Geography*, *4*(5), 583–595. https://doi.org/10.1093/jnlecg/lbh035

Dritsakis, N. (2004). Defense spending and economic growth: An empirical investigation for Greece and Turkey. *Journal of Policy Modeling, 26(2), 249-264..* https://doi.org/10.1016/j.jpolmod.2004.03.011

Dunne, J. P., & Mohammed, N. A. L. (1995). Military Spending in Sub-Saharan Africa: Some Evidence for 1967-85. *Journal of Peace Research*, *32*(3), 331–343. https://doi.org/10.1177/0022343395032003006

Dunne, P., Nikolaidou, E., & Vougas, D. (2001). Defence spending and economic growth: A causal analysis for Greece and Turkey. *Defence and Peace Economics*, *12*(1), 5–26. https://doi.org/10.1080/10430710108404974

Dunne, P., & Perlo-Freeman, S. (2003). The Demand for Military Spending in Developing Countries. *International Review of Applied Economics*, *17*(1), 23–48. https://doi.org/10.1080/713673166

Dunne, P., & Tian, N. (2013). Military expenditure and economic growth: A survey. *The Economics of Peace and Security Journal*, *8*(1). https://doi.org/10.15355/epsj.8.1.5

Dunne, P., & Uye, M. (2010). Defence spending and development. In A. T. H. Tan (Ed.), *The Global Arms Trade*. Routledge. https://doi.org/10.4324/9780203851456-21

Durlauf, S., & Johnson, P. (1992). *Local Versus Global Convergence Across National Economies*. Cambridge, MA. https://doi.org/10.3386/w3996

Durlauf, S. N., Johnson, P. A., & Temple, J. R. W. (2005). Chapter 8 Growth Econometrics. In S. N. D. Philippe Aghion (Ed.), *Handbook of Economic Growth* (Vol. 1, pp. 555–677). Elsevier. https://doi.org/10.1016/S1574-0684(05)01008-7

Durlauf, S. N., & Quah, D. T. (1999). Chapter 4 The new empirics of economic growth. In S. N. D. Philippe Aghion (Ed.), *Handbook of Macroeconomics* (Vol. 1). Elsevier. https://doi.org/10.1016/S1574-0048(99)01007-1

Easterlin, R. A. (1960). Regional Growth of Income: Long-Run Tendencies. In E. Simon Kuznets, Ann Ratner Miller, and Richard A. Easterlin (Ed.), *Population Redistribution and Economic Growth, United States, 1870–1950. II: Analyses of Economic Change. Philadelphia: American Philosophical Society.*

Easterly, W., & Levine, R. (2001). What have we learned from a decade of empirical research on growth? It's Not Factor Accumulation: Stylized Facts and Growth Models. *The World Bank Economic Review*, *15*(2), 177–219. https://doi.org/10.1093/wber/15.2.177

Eberhardt, M., Helmers, C., & Strauss, H. (2013). Do Spillovers Matter When Estimating Private Returns to R&D? *The Review of Economics and Statistics*, *95*(2), 436–448. Retrieved from https://econpapers.repec.org/RePEc:tpr:restat:v:95:y:2013:i:2:p:436-448

Edison, H. J., Levine, R., Ricci, L., & Sløk, T. (2002). International financial integration and economic growth. *Journal of International Money and Finance*, *21*(6), 749–776. https://doi.org/10.1016/S0261-5606(02)00021-9

Egger, P., & Pfaffermayr, M. (2009). On testing conditional sigma - Convergence. *Oxford Bulletin of Economics and Statistics*, *71*(4), 453–473. https://doi.org/10.1111/j.1468-0084.2007.00467.x

Eichengreen, B., & Leblang, D. (2003). Capital account liberalization and growth: was Mr. Mahathir right? *International Journal of Finance & Economics*, *8*(3), 205–224. https://doi.org/10.1002/ijfe.208

Enders, W. (2014). *Applied econometric time series* (4rth Edition). John Wiley & Sons. Retrieved from https://www.wiley.com/en-gr/Applied+Econometric+Time+Series,+4th+Edition-p-9781118808566

Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica*, *55*(2), 251–276.

Evans, P. (1998). Using Panel Data to Evaluate Growth Theories. *International Economic Review*, *39*(2), 295. https://doi.org/10.2307/2527294

Evans, P., & Karras, G. (1996). Convergence revisited. *Journal of Monetary Economics*, *37*(2), 249–265. https://doi.org/10.1016/S0304-3932(96)90036-7

Evans, P., & Kim, J. U. (2011). Stochastic convergence of the catch-up rate and multiple structural breaks in Asian countries. *Economics Letters*, *111*(3), 260–263. https://doi.org/10.1016/j.econlet.2011.02.012

Faini, R., Annez, P., & Taylor, L. (1984). Defense Spending, Economic Structure, and Growth: Evidence among Countries and over Time. *Economic Development and Cultural Change*, *32*, 487–498. https://doi.org/10.2307/1153333

Feder, G. (1983). On exports and economic growth. *Journal of Development Economics*, *12*(1–2), 59–73. https://doi.org/10.1016/0304-3878(83)90031-7

Fisher, R. A. (1992). Statistical Methods for Research Workers. In S. K. L. Johnson (Ed.), *Breakthroughs in Statistics*. Springer, New York, NY. https://doi.org/10.1007/978-1-4612-4380-9_6

Fleissig, A., & Strauss, J. (2001). Panel Unit-Root Tests of OECD Stochastic Convergence. *Review of International Economics*, *9*(1), 153–162. https://doi.org/10.1111/1467-9396.00270

Frankel, J. A., & Rose, A. K. (1996). A panel project on purchasing power parity: Mean reversion within and between countries. *Journal of International Economics*, *40*(1–2), 209–224. https://doi.org/10.1016/0022-1996(95)01396-2

Frederiksen, P. C., & Looney, R. E. (1983). Defense Expenditures and Economic Growth in Development Countries: Some Further Empirical Evidence. *Armed Forces & Society*, *9*(4), 633–645.

Friedman, M. (1992). Do Old Fallacies Ever Die? *Journal of Economic Literature*, *30*(4), 2129–2132. Retrieved from https://econpapers.repec.org/RePEc:aea:jeclit:v:30:y:1992:i:4:p:2129-32

Galor, O. (1996). Convergence? Inferences from Theoretical Models. *The Economic Journal*, *106*(437), 1056. https://doi.org/10.2307/2235378

Gamlath, S., & Lahiri, R. (2018). Public and private education expenditures, variable elasticity of substitution and economic growth. *Economic Modelling*, *70*, 1–14. https://doi.org/10.1016/j.econmod.2017.10.007

Gaulier, G., Hurlin, C., & Jean-Pierre, P. (1999). Testing Convergence: A Panel Data Approach. *Annales d'Économie et de Statistique*, (55/56), 411. https://doi.org/10.2307/20076205

Gengenbach, C., Palm, F. C., & Urbain, J. P. (2006). Cointegration testing in panels with common factors. In *Oxford Bulletin of Economics and Statistics* (Vol. 68, pp. 683–719).

https://doi.org/10.1111/j.1468-0084.2006.00452.x

Gengenbach, C., Urbain, J. P., & Westerlund, J. (2016). Error Correction Testing in Panels with Common Stochastic Trends. *Journal of Applied Econometrics*, *31*(6), 982–1004. https://doi.org/10.1002/jae.2475

George, J., & Sandler, T. (2018). Demand for military spending in NATO, 1968–2015: A spatial panel approach. *European Journal of Political Economy*, *53*, 222–236. https://doi.org/10.1016/j.ejpoleco.2017.09.002

Gerschenkron, A. (1962). *Economic backwardness in historical perspective: a book of essays*. Belknap Press of Harvard University Press. Retrieved from http://www.hup.harvard.edu/catalog.php?isbn=9780674226005

Ghosh, M., Ghoshray, A., & Malki, I. (2013). Regional divergence and club convergence in India. *Economic Modelling*, *30*, 733–742. https://doi.org/10.1016/j.econmod.2012.10.008

Goddard, J., & Wilson, J. (2001). Cross sectional and panel estimation of convergence. *Economics Letters*, *70*(3), 327–333. https://doi.org/10.1016/S0165-1765(00)00387-6

Gomulka, S. (1971). *Inventive activity, diffusion, and the stages of economic growth Vol. 24*. Aarhus University, Institute of Economics Aarhus.

Gutierrez, L. (2003). On the power of panel cointegration tests: a Monte Carlo comparison. *Economics Letters*, *80*(1), 105–111. https://doi.org/10.1016/S0165-1765(03)00066-1

Hadri, K. (2000). Testing for Stationarity in Heterogenous Panel Data. *The Econometrics Journal*, *3*(2), 148–161. https://doi.org/10.1111/1368-423X.00043

Hadri, K., & Larsson, R. (2005). Testing for stationarity in heterogeneous panel data where the time dimension is finite. *The Econometrics Journal*, *8*(1), 55–69. https://doi.org/10.1111/j.1368-423X.2005.00151.x

Harris, R. D. F., & Tzavalis, E. (1999). Inference for unit roots in dynamic panels where the time dimension is fixed. *Journal of Econometrics*, *91*(2), 201–226. https://doi.org/10.1016/S0304-4076(98)00076-1

Hatam, N., Tourani, S., Homaie Rad, E., & Bastani, P. (2016). Estimating the Relationship between Economic Growth and Health Expenditures in ECO Countries Using Panel Cointegration Approach. *Acta Medica Iranica*, *54*(2), 102–106. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/26997596

Hlouskova, J., & Wagner, M. (2007). The Performance of Panel Unit Root and Stationarity Tests: Results from a Large Scale Simulation Study. *Econometric Reviews*, *25*(1), 85–116. https://doi.org/10.1080/07474930500545504

Hodrick, R. J., & Prescott, E. C. (1997). Postwar U.S. Business Cycles: An Empirical Investigation. *Journal of Money, Credit and Banking*, *29*(1), 1. https://doi.org/10.2307/2953682

Holmes, M. J., Otero, J., & Panagiotidis, T. (2014). A Note On The Extent Of U.S. Regional Income Convergence. *Macroeconomic Dynamics*, *18*(07), 1635–1655. https://doi.org/10.1017/S1365100513000060

Holmes, M. J., Otero, J., & Panagiotidis, T. (2019). Property heterogeneity and convergence club formation among local house prices. *Journal of Housing Economics*, *43*, 1–13. https://doi.org/10.1016/j.jhe.2018.09.002

Huang, C., & Mintz, A. (1991). Defence expenditures and economic growth: The externality effect. *Defence Economics*, *3*(1), 35–40. https://doi.org/10.1080/10430719108404713

Hurlin, C., & Mignon, V. (2007). *Second Generation Panel Unit Root Tests*. Working paper *HAL University halshs00159842*, Retrieved from https://hal.archives-ouvertes.fr/halshs-00159842/

Iamsiraroj, S. (2016). The foreign direct investment–economic growth nexus. *International Review of Economics & Finance*, *42*, 116–133. https://doi.org/10.1016/j.iref.2015.10.044

Im, K. S., Pesaran, M. H., & Shin, Y. (1997). Testing for unit roots in panel data, *University of*

Cambridge Working Paper No, 9526.

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*(1), 53–74. https://doi.org/10.1016/S0304-4076(03)00092-7

Islam, N. (2003). What have We Learnt from the Convergence Debate? *Journal of Economic Surveys*, *17*(3), 309–362. https://doi.org/10.1111/1467-6419.00197

Joerding, W. (1986). Economic growth and defense spending: Granger Causality. *Journal of Development Economics*, *21*(1), 35–40. https://doi.org/10.1016/0304-3878(86)90037-4

Kaldor, N. (1961). Capital Accumulation and Economic Growth. In *The Theory of Capital* (pp. 177–222). London: Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-08452-4_10

Kang, S. J., & Lee, M. (2005). Q-convergence with interquartile ranges. *Journal of Economic Dynamics and Control*, *29*(10), 1785–1806. https://doi.org/10.1016/j.jedc.2004.10.004

Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, 90(1), 1-44. https://doi.org/10.1016/S0304-4076(98)00023-2

Kapetanios, G., Pesaran, M. H., & Yamagata, T. (2011). Panels with non-stationary multifactor error structures. *Journal of Econometrics*, *160*(2), 326–348. https://doi.org/10.1016/j.jeconom.2010.10.001

Kennedy, G. (1983). *Defense economics*. St. Martin's Press.

King, A., & Ramlogan-Dobson, C. (2015). International income convergence: Is Latin America actually different? *Economic Modelling*, *49*, 212–222. https://doi.org/10.1016/j.econmod.2015.04.008

Kinsella, D. (1990). Defence spending and economic performance in the United States: A causal analysis. *Defence Economics*, *1*(4), 295–309. https://doi.org/10.1080/10430719008404669

Klein, M. W., & Olivei, G. P. (2008). Capital account liberalization, financial depth, and economic growth. *Journal of International Money and Finance*, *27*(6), 861–875. https://doi.org/10.1016/j.jimonfin.2008.05.002

Kollias, C., Mylonidis, N., & Paleologou, S. (2007). A Panel Data Analysis of the Nexus Between Defence Spending and Growth in the European Union. *Defence and Peace Economics*, *18*(1), 75–85. https://doi.org/10.1080/10242690600722636

Kollias, C., & Paleologou, S.-M. (2013). Guns, highways and economic growth in the United States. *Economic Modelling*, *30*, 449–455. https://doi.org/10.1016/j.econmod.2012.09.048

Kremers, J. J. M., Ericsson, N. R., & Dolado, J. J. (1992). The Power Of Cointegration Tests. *Oxford Bulletin of Economics and Statistics*, *54*(3), 325–348. https://doi.org/10.1111/j.1468-0084.1992.tb00005.x

Kuznets, S. (1955). Economic Growth and Income Inequality. *The American Economic Review*, *45*(1), 1–28. Retrieved from http://www.jstor.org/stable/1811581

Kwiatkowski, D., Phillips, P. C. B., Schmidt, P., & Shin, Y. (1992). Testing the null hypothesis of stationarity against the alternative of a unit root. How sure are we that economic time series have a unit root? *Journal of Econometrics*, *54*(1–3), 159–178. https://doi.org/10.1016/0304-4076(92)90104-Y

Laboure, M., & Taugourdeau, E. (2018). Does Government Expenditure Matter for Economic Growth? *Global Policy*, *9*(2), 203–215. https://doi.org/10.1111/1758-5899.12540

Landau, D. (1996). Is one of the "peace dividends" negative? Military expenditure and economic growth in the wealthy OECD countries. *Quarterly Review of Economics and Finance*, 36(2), 183-195. https://doi.org/10.1016/S1062-9769(96)90038-1

Larsson, R., Lyhagen, J., & Löthgren, M. (2003). Likelihood-based cointegration tests in heterogeneous panels. *The Econometrics Journal*, *4*(1), 109–142. https://doi.org/10.1111/1368-423x.00059

Le Pen, Y. (2011). A pair-wise approach to output convergence between European regions. *Economic Modelling*, *28*(3), 955–964. https://doi.org/10.1016/j.econmod.2010.11.006

Lee, K., Pesaran, M. H., & Smith, R. (1997). Growth and convergence in a multi-country empirical stochastic Solow model. *Journal of Applied Econometrics*, *12*(4), 357–392. https://doi.org/10.1002/(SICI)1099-1255(199707)12:4<357::AID-JAE441>3.0.CO;2-T

Lenkoski, A., Eicher, T. S., & Raftery, A. E. (2014). Two-Stage Bayesian Model Averaging in Endogenous Variable Models. *Econometric Reviews*, *33*(1–4), 122–151. https://doi.org/10.1080/07474938.2013.807150

León-González, R., & Montolio, D. (2015). Endogeneity and panel data in growth regressions: A Bayesian model averaging approach. *Journal of Macroeconomics*, *46*, 23–39. https://doi.org/10.1016/j.jmacro.2015.07.003

Levin, A., & Lin, C. F. (1992). Unit root test in panel data: asymptotic and finite sample properties *(Discussion Paper No. 92-93)*. San Diego.

Levin, A., & Lin, C. F. (1993). Unit root tests in panel data: new results. (*Economics Working Paper Series*). San Diego.

Levin, A., Lin, C. F., & Chu, C.-S. J. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Econometrics*, *108*(1), 1–24. https://doi.org/https://doi.org/10.1016/S0304-4076(01)00098-7

Levine, R., Loayza, N., & Beck, T. (2000). Financial intermediation and growth: Causality and causes. *Journal of Monetary Economics*, *46*(1), 31–77. https://doi.org/10.1016/S0304-3932(00)00017-9

Leybourne, S. J., & McCabe, B. P. M. (1994). A Consistent Test for a Unit Root. *Journal of Business & Economic Statistics*, *12*(2), 157–166. https://doi.org/10.1080/07350015.1994.10510004

Li, K.-W., Zhou, X., & Pan, Z. (2016). Cross-Country Output Convergence and Growth: Evidence from Varying Coefficient Nonparametric Method. *Economic Modelling*, 55, 32-41. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2728101

Li, Q., & Papell, D. (1999). Convergence of international output Time series evidence for 16 OECD countries. *International Review of Economics & Finance*, *8*(3), 267–280. https://doi.org/10.1016/S1059-0560(99)00020-9

Liaskos, G., & Papadas, C. (2010). Human Capital Convergence in Greece: A Panel Data Analysis (*Working Papers 2009-10*). Retrieved from https://ideas.repec.org/p/aua/wpaper/2009-10.html

Lim, D. (1983). Another Look at Growth and Defense in Less Developed Countries. *Economic Development and Cultural Change*. The University of Chicago Press. https://doi.org/10.2307/1153485

Liu, L., & Ruiz, I. (2006). Convergence Hypothesis: Evidence from Panel Unit Root Test with Spatial Dependence, (23), 37–56. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1138013

Loizides, J., & Vamvoukas, G. (2005). Government Expenditure and Economic Growth: Evidence from Trivariate Causality Testing. *Journal of Applied Economics*. https://doi.org/10.1080/15140326.2005.12040621

Looney, R. E. (1988). Impact of Indigenous Arms Production on Third-World Military Expenditures. In R. E. (eds) Looney (Ed.), *Third-World Military Expenditure and Arms Production*. London: Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-09658-9_1

Lucke, B. (2008). γ-Convergence. *Economics Letters*, *99*(3), 439–442. https://doi.org/10.1016/j.econlet.2007.09.017

MacDonald, R. (1996). Panel unit root tests and real exchange rates. *Economics Letters*, *50*(1), 7–11. https://doi.org/10.1016/0165-1765(95)00730-X

MacKinnon, J. G. (1996). Numerical Distribution Functions for Unit Root and Cointegration Tests. *Journal of Applied Econometrics*, *11*(6), 601–618. Retrieved from http://www.jstor.org/stable/2285154

Maddala, G. S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 631–652. https://doi.org/10.1111/1468-

0084.0610s1631

Malešević Perović, L., Golem, S., & Mihaljević Kosor, M. (2018). The impact of education expenditures on growth in the EU28 – a spatial econometric perspective. *Acta Oeconomica*, *68*(2), 271–294. https://doi.org/10.1556/032.2018.68.2.5

Matkowski, Z., Prochniak, M., & Rapacki, R. (2016). Real Income Convergence between Central Eastern and Western Europe: Past, Present, and Prospects. C*openhagen: 33rd CIRET (Centre for International Research on Economic Tendency Surveys) Conference on Economic Tendency Surveys and Economic Policy*. Retrieved from https://www.econstor.eu/handle/10419/146992

McCaig, B., & Stengos, T. (2005). Financial intermediation and growth: Some robustness results. *Economics Letters*, *88*(3), 306–312. https://doi.org/10.1016/j.econlet.2004.12.031

McKenzie, D. J. (2001). The impact of capital controls on growth convergence. *Journal of Economic Development*, *26*(1), 1–24.

McKinnon, R. I. (1973). *Money and Capital in Economic Development*. (R. M. Witcomb, Ed.), *The Brookings Institution*. Washington D.C. https://doi.org/10.2307/2231282

Mendonca, S. (2016). *The Role of the OECD in Shaping EU Trade Policy*. Retrieved from http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/570455/EXPO_BRI(2016)570455_EN.pdf

Mintz, A., & Huang, C. (1990). Defense Expenditures, Economic Growth, and The "Peace Dividend." *The American Political Science Review*, *84*(4), 1283-1293. https://doi.org/10.2307/1963264

Mintz, A., & Stevenson, R. T. (1995). Defense Expenditures, Economic Growth, and The "Peace Dividend." *Journal of Conflict Resolution*, *39*(2), 283–305. https://doi.org/10.1177/0022002795039002004

Miyamoto, W., Nguyen, T. L., & Sheremirov, V. (2019). The effects of government spending on real exchange rates: Evidence from military spending panel data. *Journal of International Economics*, *116*, 144–157. https://doi.org/10.1016/j.jinteco.2018.11.009

Monfort, M., Cuestas, J. C., & Ordóñez, J. (2013). Real convergence in Europe: A cluster analysis. *Economic Modelling*, *33*, 689–694. https://doi.org/10.1016/j.econmod.2013.05.015

Moon, H. R., & Perron, B. (2004). Testing for a unit root in panels with dynamic factors. *Journal of Econometrics*, *122*(1), 81–126. https://doi.org/10.1016/j.jeconom.2003.10.020

Morales-Zumaquero, A., & Sosvilla-Rivero, S. (2016). A contribution to the empirics of convergence in real GDP growth: the role of financial crises and exchange-rate regimes. *Applied Economics*, *48*(23), 2156–2169. https://doi.org/10.1080/00036846.2015.1114581

Mueller, M., & Atesoglu, H. (1993). Defense Spending, Technological Change, and Economic Growth in the United States. *Defence and Peace Economics*, *4*, 259–269. https://doi.org/10.1080/10430719308404765

Nghiem, S. H., & Connelly, L. B. (2017). Convergence and determinants of health expenditures in OECD countries. *Health Economics Review*, *7*(1), 29. https://doi.org/10.1186/s13561-017-0164-4

O'Connell, P. G. J. (1998). The overvaluation of purchasing power parity. *Journal of International Economics*, *44*(1), 1–19. https://doi.org/10.1016/S0022-1996(97)00017-2

OECD. (2018). *The OECD-WTO Balanced Trade in Services Database*. Retrieved from http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=STD/CSSP/WPTGS(2018)2&docLanguage=En

Oh, K.-Y. (1996). Purchasing power parity and unit root tests using panel data. *Journal of International Money and Finance*, *15*(3), 405–418. https://doi.org/10.1016/0261-5606(96)00012-5

Ortiz, C., Alvarado, R., & Salinas, A. (2019). The effect of military spending on output: New evidence at the global and country group levels using panel data cointegration techniques. *Economic Analysis and Policy*, *62*, 402–414. https://doi.org/10.1016/j.eap.2018.10.004

Oxley, L., & Greasley, D. (1995). A Time-Series Perspective on Convergence: Australia, UK and USA since 1870. *Economic Record*, *71*(3), 259–270. https://doi.org/10.1111/j.1475-4932.1995.tb01893.x

Palm, F. C., Smeekes, S., & Urbain, J. P. (2011). Cross-sectional dependence robust block bootstrap panel unit root tests. In *Journal of Econometrics* (Vol. 163, pp. 85–104). https://doi.org/10.1016/j.jeconom.2010.11.010

Payne, J. E., & Ross, K. L. (1992). Defense spending and the macroeconomy. *Defence Economics*, *3*(2), 161–168. https://doi.org/10.1080/10430719208404724

Pedroni, P. (1996). Fully modified OLS for heterogeneous cointegrated panels and the case of purchasing power parity. *Manuscript, Department of Economics, Indiana University*, 1–45.

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 653–670. https://doi.org/10.1111/1468-0084.0610s1653

Pedroni, P. (2000). Fully Modified Ols for Heterogeneous Cointegrated Panels. *Department of Economics Working Papers 2000-2003, Department of Economics, Williams College*.

Pedroni, P. (2004). Panel Cointegration: Asymptotic And Finite Sample Properties Of Pooled Time Series Tests With An Application To. *The Econometric Press*, *20*(3), 597–625.

Persyn, D., & Westerlund, J. (2008). Error-correction-based cointegration tests for panel data. *Stata Journal*, *8*(2), 232–241. Retrieved from http://www.stata-journal.com/article.html?article=st0146

Pesaran, M. H. (2003). *A simple panel unit root test in the presence of cross-section d 2003 (revised January 2005)*. Cambridge University DAE Working Paper.

Pesaran, M. H. (2004). General Diagnostic Tests for Cross Section Dependence in Panels. *Cambridge Working Papers in Economics, University of Cambridge*, *No. 435* (Working Paper Series No. 1229). Retrieved from http://ftp.iza.org/dp1240.pdf

Pesaran, M. H. (2005). *A Simple Panel Unit Root Test in the Presence of Cross Section Dependence*. *Cambridge Working Papers in Economics 0346, revised Version, University of Cambridge*.

Pesaran, M. H. (2006). Estimation and Inference in Large Heterogeneous Panels with a Multifactor Error Structure. *Econometrica*, *74*(4), 967–1012. https://doi.org/10.1111/j.1468-0262.2006.00692.x

Pesaran, M. H. (2007a). A pair-wise approach to testing for output and growth convergence. *Journal of Econometrics*, *138*(1), 312–355. https://doi.org/10.1016/J.JECONOM.2006.05.024

Pesaran, M. H. (2007b). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled Mean Group Estimation of Dynamic Heterogeneous Panels. *Journal of the American Statistical Association*, *94*(446), 621–634. https://doi.org/10.1080/01621459.1999.10474156

Pesaran, M. H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics*, *68*(1), 79–113. https://doi.org/10.1016/0304-4076(94)01644-F

Pesaran, M. H., Vanessa Smith, L., & Yamagata, T. (2013). Panel unit root tests in the presence of a multifactor error structure. *Journal of Econometrics*, *175*(2), 94–115. https://doi.org/10.1016/j.jeconom.2013.02.001

Pfaffermayr, M. (2009). Conditional β- and σ-convergence in space: A maximum likelihood approach. *Regional Science and Urban Economics*, *39*(1), 63–78. https://doi.org/10.1016/j.regsciurbeco.2008.06.004

Phillips, P. C. B., & Moon, H. R. (1999). Linear regression limit theory for nonstationary panel data. *Econometrica*, *67*(5), 1057–1111. https://doi.org/10.1111/1468-0262.00070

Phillips, P. C. B., & Perron, P. (1988). Testing for a Unit Root in Time Series Regression. *Biometrika*, *75*(2), 335. https://doi.org/10.2307/2336182

Phillips, P. C. B., & Sul, D. (2003a). Dynamic panel estimation and homogeneity testing under cross section dependence. *The Econometrics Journal*, *6*(1), 217–259. https://doi.org/10.1111/1368-423X.00108

Phillips, P. C. B., & Sul, D. (2003b, February 1). The Elusive Empirical Shadow of Growth Convergence. Cowles Foundation Discussion Paper No. 1398. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=384923

Phillips, P. C. B., & Sul, D. (2007). Transition modeling and econometric convergence tests. *Econometrica*, *75*(6), 1771–1855. https://doi.org/10.1111/j.1468-0262.2007.00811.x

Phillips, P. C. B., & Sul, D. (2009). Economic transition and growth. *Journal of Applied Econometrics*, *24*(7), 1153–1185. https://doi.org/10.1002/jae.1080

Pieroni, L. (2009). Military Expenditure and Economic Growth. *Defence and Peace Economics*, *20*(4), 327–339. https://doi.org/10.1080/10242690701589876

Quah, D. (1992). The Relative Importance of Permanent and Transitory Components: Identification and Some Theoretical Bounds. *Econometrica*, *60*(1), 107. https://doi.org/10.2307/2951678

Quah, D. (1993). Galton's Fallacy and Tests of the Convergence Hypothesis. *The Scandinavian Journal of Economics*, *95*(4), 427. https://doi.org/10.2307/3440905

Quah, D. (1994). Exploiting cross-section variation for unit root inference in dynamic data. *Economics Letters*, *44*(1–2), 9–19. https://doi.org/10.1016/0165-1765(93)00302-5

Quah, D. T. (1996a). Empirics for economic growth and convergence. *European Economic Review*, *40*(6), 1353–1375. https://doi.org/10.1016/0014-2921(95)00051-8

Quah, D. T. (1996b). Twin Peaks: Growth and Convergence in Models of Distribution Dynamics. *The Economic Journal*, *106*(437), 1045. https://doi.org/10.2307/2235377

Quinn, D. (1997). The Correlates of Change in International Financial Regulation. *American Political Science Review*, *91*(3), 531–551. https://doi.org/10.2307/2952073

Quinn, D. P., & Toyoda, A. M. (2008). Does Capital Account Liberalization Lead to Growth? *Review of Financial Studies*, *21*(3), 1403–1449. https://doi.org/10.1093/rfs/hhn034

Ram, R. (2006). Defense Expenditure and Economic Growth: Evidence from Cross-Country Panel Data. In *The Elgar Companion to Public Economics*. Edward Elgar Publishing. Retrieved from https://ideas.repec.org/h/elg/eechap/3537_11.html

Rapacki, R., & Próchniak, M. (2009). *The EU Enlargement and Economic Growth In the CEE New Member Countries*. European Commission, Directorate-General for Economic and Financial Affairs.

Reese, S., & Westerlund, J. (2016). PANICCA: PANIC On Cross-Section Averages. *Journal Of Applied Econometrics*, *31*, 961–981.

Rioja, F., & Valev, N. (2004). Does one size fit all?: a reexamination of the finance and growth relationship. *Journal of Development Economics*, *74*(2), 429–447. https://doi.org/10.1016/j.jdeveco.2003.06.006

Rodrik, D. (1998). Who Needs Capital-Account Convertibility? *Essays in International Finance*, *207*, 55–65. Retrieved from https://drodrik.scholar.harvard.edu/publications/who-needs-capital-account-convertibility

Romer, P. M. (1986). Increasing Returns and Long-Run Growth. *Journal of Political Economy*, *94*(5), 1002–1037. https://doi.org/10.2307/1833190

Rostow, W. W. (Walt W. (1990). *The stages of economic growth : a non-communist manifesto*. Cambridge University Press.

Sala-i-Martin, X. (1994). Cross-sectional regressions and the empirics of economic growth. *European Economic Review*, *38*(3–4), 739–747. https://doi.org/10.1016/0014-2921(94)90109-0

Sala-i-Martin, X., Doppelhofer, G., & Miller, R. I. (2004). Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach. *The American Economic Review*, *94*(4), 813–835. Retrieved from http://www.jstor.org/stable/3592794

Sala-i-Martin, X. X. (1996a). Regional cohesion: evidence and theories of regional growth and convergence. *European Economic Review*, *40*(6), 1325–1352. https://doi.org/10.1016/0014-2921(95)00029-1

Sala-i-Martin, X. X. (1996b). The Classical Approach to Convergence Analysis. *The Economic Journal*, *106*(437), 1019. https://doi.org/10.2307/2235375

Schumpeter, J. A. (1934). *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*. Oxford University Press. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1496199

Schwert, G. W. (1989). Why Does Stock Market Volatility Change Over Time? *The Journal of Finance*, *44*(5), 1115–1153. https://doi.org/10.1111/j.1540-6261.1989.tb02647.x

Shaw, E. S. (1973). *Financial Deepening in Economic Development*. New York: Oxford University Press.

Silva Lopes, A. (2016). A simple proposal to improve the power of income convergence tests. *Economics Letters*, *138*, 92–95. https://doi.org/10.1016/J.ECONLET.2015.11.041

Simionescu, M. (2014). The economic convergence in European Union based on concentration and entropy approach. *Euro Economica*, *33*(1), 31–42.

Simionescu, M. (2015). About regional convergence clubs in the European Union. In *Proceeding of Rijeka Faculty of Economics* (pp. 67–80). University of Rijeka. Retrieved from https://ideas.repec.org/a/rfe/zbefri/v33y2015i1p67-80.html

Smith, R. P. (1980). Military expenditure and investment in OECD countries, 1954–1973. *Journal of Comparative Economics*, *4*(1), 19–32. https://doi.org/10.1016/0147-5967(80)90050-5

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics (The MIT Press)*, *70*(1), 65–94.

Solow, R. M. (1957). Technical Change and the Aggregate Production Function. *The Review of Economics and Statistics*, *39*(3), 312. https://doi.org/10.2307/1926047

Soukiazis, E. (2000). What have we Learnt About Convergence in Europe? Some theoretical and empirical considerations. *Working paper University of Coimbra*

Statista. (2018). *Ranking of the 10 countries who filed the most international patent applications in 2017*. Retrieved from https://www.statista.com/statistics/256845/ranking-of-the-10-countries-who-filed-the-most-international-patent-applications/

Stock, J. H., & Watson, M. W. (1993). A Simple Estimator of Cointegrating Vectors in Higher Order Integrated Systems. *The Econometric Society*, *61*(4), 783–820.

Strauss, J., & Yigit, T. (2003). Shortfalls of panel unit root testing. *Economics Letters*, *81*(3), 309–313. https://doi.org/10.1016/S0165-1765(03)00210-6

Streissler, E. (1979). Growth Models as Diffusion Processes: II. Empirical illustrations. *Kyklos*, *32*(3), 571–586.

Swan, T. W. (1956). Economic Growth and Capital Accumulation. *Economic Record*, *32*(2), 334–361. https://doi.org/10.1111/j.1475-4932.1956.tb00434.x

Temple, J. (1999). The New Growth Evidence. *Journal of Economic Literature*. American Economic Association. https://doi.org/10.2307/2564727

Vu Le, M., & Suruga, T. (2005). Foreign direct investment, public expenditure and economic growth: the empirical evidence for the period 1970–2001. *Applied Economics Letters*, *12*(1), 45–49. https://doi.org/10.1080/1350485042000293130

Wagner, A. (1958). Three Extracts on Public Finance. In International Economic Association Series (Ed.), *Classics in the Theory of Public Finance* (pp. 1–15). London: Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-23426-4_1

Wahab, M. (2004). Economic growth and government expenditure: evidence from a new test specification. *Applied Economics*, *36*(19), 2125–2135. https://doi.org/10.1080/0003684042000306923

Ward, M. D., & Davis, D. R. (1992). Sizing up the Peace Dividend: Economic Growth and Military Spending in the United States, 1948–1996. *American Political Science Review*, *86*(03), 748–755. https://doi.org/10.2307/1964136

Weede, E. (1983). Military participation ratios, human capital formation, and economic growth: a cross-national analysis. *JPMS: Journal of Political and Military Sociology*, *11*(1), 11.

Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*, *69*(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Westerlund, J., & Breitung, J. (2013). Lessons from a Decade of IPS and LLC. *Econometric Reviews*, *32*(5–6), 547–591. https://doi.org/10.1080/07474938.2013.741023

Westerlund, J., Hosseinkouchack, M., & Solberger, M. (2016). The Local Power of the CADF and CIPS Panel Unit Root Tests. *Econometric Reviews*, *35*(5), 845–870. https://doi.org/10.1080/07474938.2014.977077

Westerlund, J., & Larsson, R. (2009). A note on the pooling of individual panic unit root tests. *Econometric Theory*, *25*(6), 1851–1868. https://doi.org/10.1017/S0266466609990351

Wijeweera, A., & Webb, M. J. (2011). Military Spending and Economic Growth in South Asia: A Panel Data Analysis. *Defence and Peace Economics*, *22*(5), 545–554. https://doi.org/10.1080/10242694.2010.533905

WITS - Trade Statistics by Country. (2018). Retrieved March 1, 2018, from https://wits.worldbank.org/countrystats.aspx

World Bank. (2015). *World development indicators 2015*. Washington, DC. Retrieved from http://documents.worldbank.org/curated/en/795941468338533334/World-development-indicators-2015

Wu, Y. (1996). Are real exchange rates nonstationary? Evidence from a panel-data test. *Journal of Money, Credit and Banking*, *28*(1), 54–63.

Yakovlev, P. (2007). Arms Trade, Military Spending, and Economic Growth. *Defence and Peace Economics*, *18*(4), 317–338. https://doi.org/10.1080/10242690601099679

Ye, L., & Zhang, X. (2018). Nonlinear Granger Causality between Health Care Expenditure and Economic Growth in the OECD and Major Developing Countries. *International Journal of Environmental Research and Public Health*, *15*(9), 1953–1969. https://doi.org/10.3390/ijerph15091953

Yesilyurt, F., & Yesilyurt, M. E. (2019). Meta-analysis, military expenditures and growth. *Journal of Peace Research*, *56*(3), 352–363. https://doi.org/10.1177/0022343318808841

Yildirim, J., Sezgin, S., & Öcal, N. (2005). Military Expenditure and Economic Growth in Middle Eastern Countries: A Dynamic Panel Data Analysis. *Defence and Peace Economics*, *16*(4), 283–295. https://doi.org/10.1080/10242690500114751

Yin, Y., & Wu, S. (2001). Nonstationary Panels, Panel Cointegration, and Dynamic Panels Stationarity tests in heterogeneous panels. *Advances in Econometrics*, *15*, 7–51. https://doi.org/10.1016/S0731-9053(00)15010-8

Young, A. T., Higgins, M. J., & Levy, D. (2013). Heterogeneous Convergence. *Economics Letters*, *120*(2), 238–241. https://doi.org/10.1016/j.econlet.2013.04.017