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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Public capital in the 21st century: As productive as ever?*

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Abstract

The global financial crisis and the euro area sovereign debt crisis that followed induced a rapid deterioration in the fiscal positions of countries across the globe. In the ensuing fiscal adjustment process, public investments were severely reduced in many countries. How harmful is this for growth perspectives? Our main objective is to find out whether the importance of public capital for long run output growth has changed in recent years. We also aim to provide information on the relevance of international spillovers of public capital. To these ends, we expand time series on public capital stocks for 20 OECD countries as constructed by Kamps (2006) and estimate country-specific recursive VARs. Results show that the effect of public capital shocks on economic growth has not increased in general, although results differ widely between countries. This suggests that the current level of public investments generally does not pose an immediate threat to potential output. Of course, this could change if low investment levels are sustained for a long time. We furthermore provide some tentative evidence of positive spillovers of public capital shocks between European countries.

Keywords: Public capital stock, economic growth, spillovers.
JEL classifications: E22, E62, H54.

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1 Introduction

The global financial crisis and the euro area sovereign debt crisis that followed induced a rapid deterioration in the fiscal positions of many advanced economies. Governments reacted to this by increasing tax revenues and implementing expenditure cuts. In the process of expenditure adjustment, public investment bore a large share of the burden, in particular in countries under market pressure. General government gross fixed capital formation as percent of GDP in the EU28 was in 2015 more than 20% below its peak level in 2009, with the decline in, for example, Spain amounting to more than 50%.

The cuts in public investments in the aftermath of the crisis may be caused by economic or political factors. In an environment of low growth, the number of viable projects could well be low, whereas in some countries there might have been overinvestment in the years before the crisis. Moreover, financial market pressure and European fiscal rules urged countries to deliver budget balance improvements in the short run. In doing so, planned investment projects may - practically or politically - be more easily terminated or postponed than most types of current spending.

Cuts in public investments might come at a significant cost. Public investments, or public capital, have been shown to contribute to economic growth both in the short and the long run (see e.g. Núñez-Serrano and Velázquez, 2016; IMF, 2014; Pereira and Andraz, 2013; Romp and De Haan, 2007), although the effect varies greatly across regions, industries and types of investment (Bom and Ligthart, 2014b). Furthermore, due to international spillovers, investment cuts may harm the growth prospects in neighbouring countries (Bom and Ligthart, 2014b).

Despite the presumably positive effect of public capital on actual and potential output, the growth of public capital stocks in many countries already started slowing down during the eighties. As a percentage of GDP, public capital stocks are generally either flat or falling. This means governments spent too little on investments to sustain the existing capital stock. The question now is: is this something to worry about, do governments miss out on the opportunity to benefit from potentially high marginal returns to investments? And has the recent strong decline in public investments aggravated the situation? This need not be the case. Jong-A-Pin and De Haan (2008) show that the effect of a public capital shock on output has decreased over time, suggesting that marginal benefits of public capital have not increased. However, their sample ends in 2001 and hence sheds no light on developments in the early years of the 21st century.

We contribute to the literature in a number of ways. First of all, we expand existing series on public capital stocks for 20 OECD economies, as constructed by Kamps (2006), applying a common methodology. This provides us with capital stock series for the years 1960-2014. Secondly, we estimate recursive VAR-models - starting from the period 1960-2000, then expanding the sample period by one year at the time - to obtain some idea of the potentially changing relationship between public capital and other model variables, most notably economic growth. Lastly, by comparing the impulse responses from a VAR model for the euro area as a whole to the weighted impulse responses of VARs for individual euro area countries, we scrutinize the importance of spillovers between

European countries.

Our results show that the effect of a public capital shock on GDP growth differs widely between countries. The effect of public capital shocks on economic growth has not increased in general, leaving little ground to conclude that the current low level of public investments forms an immediate threat to potential output. Of course, if low investment levels are sustained for a long time, this could change. Furthermore, we provide some tentative evidence of the existence of positive spillovers of public capital between European countries.

In the empirical sections of this paper, when we use the term 'public investment', this refers to general government gross fixed capital formation as used in the National Accounts (NA). This has some implications for the economic meaning of the term 'public capital'. First of all, the economic and accounting concepts of what constitutes public capital are not always aligned. Private investors or state-enterprises not classified within the perimeter of the general government can and do invest in public good types of assets, such as roads. Secondly, expenditures on regular maintenance are counted in the NA as current expenditures rather than investments. However, maintenance spending obviously is important in sustaining the public capital stock (see e.g. Kalaitzidakis and Kalyvitis, 2005). Thirdly, other types of current spending which have characteristics of an investment, such as spending on education (other than educational structures) are not considered as government investment in the NA.

2 Related literature

Transport infrastructure, communication services, electricity and water are used in the production process of almost every sector (Romp and De Haan, 2007). In many countries, the capital stock providing these services is largely in public hands. Public capital thus represents the wheels – if not the engine – of economic activity, in the words of the World World Bank (1994).

But how exactly does public capital impact on output growth? In the short run, an increase in public investments creates positive demand effects. At the same time, public capital arguably enhances the economy's supply side. But additional public expenditures have to be financed, with potential detrimental consequences for output. This section gives a brief overview of empirical research on the relationship between public capital and output. For extensive reviews of the empirical literature on public capital and growth, we refer to Pereira and Andraz (2013), EC (2014) and Romp and De Haan (2007).

2.1 Partial equilibrium effects

One major branch of research focuses on partial effects of public capital, in particular on the contribution of public capital or investments to private sector output production. The empirical literature in this branch set off with the work of Aschauer (1989). Estimating a production function including public capital for the US, the author found strong positive effects of the public capital stock, and of core infrastructure in particular. The so-called production function approach, describing the technical relationship between production factors (or composite indices thereof) and output, was applied by many empiricists since (e.g. Calderón et al., 2015; Creel and Poilon, 2008; Kamps, 2006; Cadot et al., 2006).

Bom and Ligthart (2014b) summarize the empirical literature on production function estimates in a meta-analysis. Overall, it is difficult to draw strong conclusions on the economic importance of public capital. This is illustrated by Figure 1.[1] Figure 1 shows published estimates of public capital output elasticities, taken from 68 papers published between 1983 and 2008 (data are from Bom and Ligthart (2014b)).[2] Values run from a negative -1.7 to a positive 2.04, with the average output elasticity of public capital after correcting for publication bias at 0.106. Estimates vary considerably over time, location, level of aggregation, measure of public capital or estimation method.

Nevertheless, some lessons can be learned. The general picture emerging is that public capital supports the potential output level. The effect is typically stronger in the long run than in the short run. Bom and Ligthart (2014b) estimate the short run elasticity on average at 0.083 and the long run elasticity at 0.122 (this is confirmed in an even broader meta-analysis by Núñez-Serrano and Velázquez (2016), covering 145 empirical studies, who find values of 0.13 and 0.16, respectively). Furthermore, core infrastructure (roads, railways, telecommunications, etc.) seems to be relatively more important compared to other investments in physical capital (see also Figure 2, lhs).

2.2 General equilibrium effects

The production function approach provides useful information on the macroeconomic production process and firm behaviour, but only highlights the benefits of public investment or public capital. More is always better, as more public capital will increase output and lower costs, ceteris paribus. However, a government facing the decision whether to invest more or not has to trade off these extra investments against lower consumption expenditures, higher taxes or an increase in the debt level.

The second major branch of the literature therefore aims to provide a broader picture by taking into account feedback effects from higher public capital or investments on the rest of the economy. For example, if an increase in public investments is financed by raising tax rates, beneficial effects of extra public investments will be mitigated. Two common methods for incorporating feedback effects are the use of macroeconomic models and estimation of VAR-models.

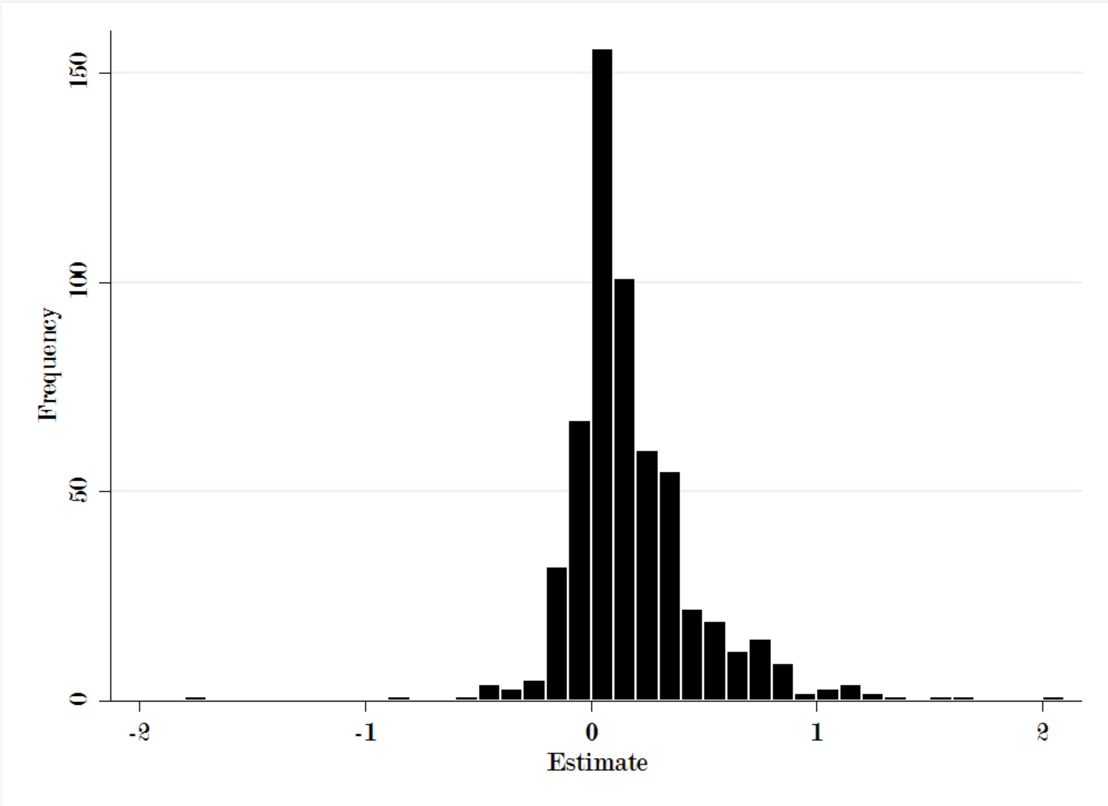
2.2.1 Macroeconomic models

In structural macroeconomic models public capital stock is often incorporated as an additional production factor, next to private capital stock and labour, by augmenting the production function (De Jong et al., 2017; Agénor and Neanidis, 2015; Bom and Ligthart, 2014a; Leeper et al., 2010; Baxter and King, 1993). Structural models provide a rich and

[1] We greatly thank Pedro Bom (University of Vienna) for sharing the data.

[2] Caution is warranted in interpreting the data in Figures 1-3, since data are not adjusted for publication bias.

Figure 1: Estimated output elasticities of public capital



Data are from Bom and Ligthart (2014b). Histogram shows published estimates of output elasticities; no correction for publication bias.

economically intuitive framework for analysing public investment effects, but at the cost of imposing restrictions on the data. Clearly, the predictions of a particular model would largely depend on specific, often somewhat subjective, modelling choices. As a result, in structural model simulations, public investments indeed (by construction) often outperform government consumption in terms of positive output effects (e.g. Leeper et al., 2010; Elekdag and Muir, 2014). There is, nevertheless, a growing literature attempting direct estimation of the relevant parameters. For example, in an extended version of the New Area-Wide Model for the euro area, while still largely calibrating public capital to be productive, Coenen et al. (2013) estimate the elasticity of substitution between the private and public capital stock. The estimation results point to a moderate complementarity between private and public capital stock. Ercolani and Valle e Azevedo (2014) estimate a RBC model using US data and find that the preferred model specification is the one where public investment is unproductive, i.e. public capital stock does not have direct supply-side effects.

An important consideration is that, in practice, it takes some time before investment plans are actually implemented. Leeper et al. (2010), in a closed-economy model, therefore allow for implementation delays in public investments. Implementation delays result in muted positive or potentially even negative responses in output and labour in the short run. Because it takes less time to build private capital, agents postpone investment until public capital significantly raises the productivity of private production inputs. Elekdag and Muir (2014) generalise the model of Leeper et al. (2010), employing a multi-region DSGE model and allowing for liquidity-constrained households and accommodative monetary policy. They confirm findings by Leeper et al. (2010) but show that accommodative monetary policy can overturn the short-run contractionary effects from an increase in public investments.

2.2.2 VAR models

VAR-models, while lacking an explicit economic story, provide direct (reduced form) estimates of the dynamic relations between public capital and output growth. Moreover, they address some econometric objections to the structural approaches. A point of criticism towards the production function (and cost function) approaches outlined in the previous section is that they impose causal relationships between the variables. However, causality might well run in multiple directions. For example, next to finding that infrastructure positively affects income growth, it could be envisaged that with rising income the demand for adequate infrastructure rises. VAR models do not impose causal relationships between variables a priori, and allow for testing for the existence of causal relationships in either direction. VAR models have other advantages as well. They allow for indirect links between the variables in the model. In the VAR approach, the long-run output effect of a change in public capital results from the interaction of all the variables in the model. Furthermore, VARs offer more flexibility concerning the number of long-run relationships in the model; they do not assume there is at most one such relationship (Kamps, 2005). On the downside, a clear economic framework providing guidance in interpreting the outcomes is lacking (at least in an unrestricted VAR). Furthermore, data limitations often imply that the number of regressors should be kept relatively small.

Kamps (2005) estimates VARs or VECMs for 22 OECD countries. An essential ingredient to this research is the database on public capital stocks as constructed by Kamps (2006). Next to the net public capital stock, Kamps (2005) includes the net private capital stock, the number of employed persons and real GDP (in that order). Overall, an increase in public capital seems to contribute to economic growth, but less so than often found in production function estimates. This hints at the importance of taking into account feedback effects from output to public capital. Furthermore, public and private capital are found to be long-run complements in the majority of countries.

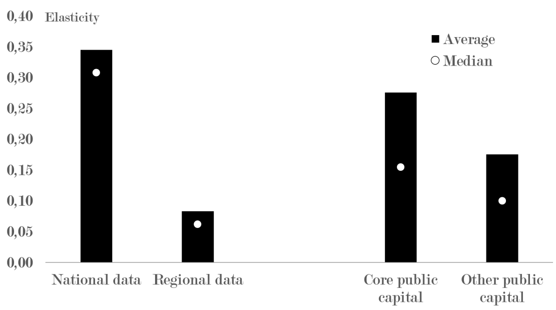
Results found in the empirical VAR-literature remain mixed though. Jong-A-Pin and De Haan (2008) extend the analysis by Kamps (2005), only partially confirming his findings. Using hours worked as a measure for labour input (which better captures labour supply than the number of employed persons) they find a positive effect of public capital on output in some, but by no means all countries. Sometimes the effect is even negative. Broyer and Gareis (2013) on the other hand, using data for 1995-2011, find very strong positive effects for infrastructure expenditures in the four largest euro area countries.

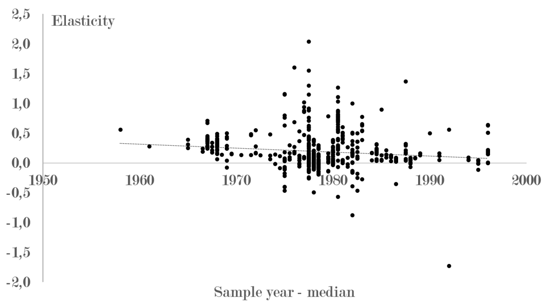
IMF (2014), directly estimating the relationship between public investments and output growth in a panel setting, also find strong positive effects (studying 17 advanced OECD economies, 1985-2013). Effects are particularly strong during periods of low growth and for debt-financed shocks, but are not significantly different from zero if carried out during periods of high growth or for budget-neutral investment shocks.

2.3 Has the impact changed over time?

An interesting question is whether the impact of public investments is constant over time. In many developed countries the public capital stock (as percentage of GDP) has been on a downward trend for a while (see figure 3). The question is: is this something to worry about, do governments miss out on the opportunity to benefit from high marginal returns to public capital?

Figure 2: Output elasticities, sub-samples (lhs) and variation over time (rhs)





Data are from Bom and Ligthart (2014b). The left-hand side figure shows the average and median elasticities found in different subsets of empirical studies used in the meta-analysis by Bom and Ligthart (2014b). The right-hand figure, based on the same dataset, plots the individual elasticities against the median year of the sample for which the respective elasticity was found.

This need not necessarily be the case, as Bom and Ligthart (2014b) in their meta-analysis find that estimated output elasticities of public capital are lower when more recent sample periods are used (see also Figure 2, rhs). This could support the idea that with the maturing of infrastructure networks in most developed countries, gains from additional roads, railway connections or power lines should be smaller than in the past. An alternative explanation is that early empirical studies sometimes ignored endogeneity or non-stationarity of the data, biasing estimates upwards, although Bom and Ligthart (2014b) in principle control for such issues. In the second part of their paper, Jong-A-Pin and De Haan (2008) estimate a rolling-window panel-VECM. The results indicate that between 1960 and 2001, the long-run impact of a shock in public capital to output declined in a number of countries, which was correlated with a declining public capital stock.

2.4 Cross country spillovers of public investment?

The effects of public capital are generally found to be lower for regions within countries than for countries as a whole, suggesting the presence of spillovers. Given the network characteristics of, for example, road and telecommunications infrastructure, positive spillovers between regions could emerge. Bom and Ligthart (2014b) in their meta-analysis find that using regional rather than national data generally results in lower estimates of the output elasticities of public capital, hinting at the importance of spillovers. Several studies find evidence for spillovers between U.S. states of public investments in infrastructure (Cohen and Paul, 2004) or infrastructure maintenance spending (Kalyvitis and Vellai, 2012); of public capital formation between Spanish regions (Pereira and Roca-Sagalés, 2003; Roca-Sagalés and Lorda, 2006) and of public transport infrastructure between Italian regions (Di Giacinto et al., 2013).

However, the evidence from regional studies on the existence of spillovers is far from uniform and the available evidence should be interpreted with caution. Some authors have pointed to the possibility of aggregation bias that results in high estimates when using aggregate data or did not find evidence for spillovers (see Creel and Poilon (2008) for an overview). De la Fuente (2010) in a survey finds that public capital variables are almost always significant in panel data specifications for the Spanish regions, and often insignificant in similar exercises conducted with US data, which could possibly be related to the difference in maturity of infrastructure networks in both countries.

3 Data

Data on public and private investments, as well as real GDP series, are obtained from OECD.[3] The data used follow the accounting standards from ESA95, as ESA2010 data are only available from 1995 onwards.[4] Total hours worked per annum are taken from the Total Economy Database.[5] All in all, our sample period runs from 1960 to 2013.

3.1 Construction of the data

We use the perpetual inventory method to construct government and private capital stocks. Here we provide a brief overview of the methodology. For a full description, see Kamps (2006) and references therein.

Assuming geometric depreciation, the net public capital stock evolves as follows:

$$K_{i,t+1} = (1 - \delta_t) K_{i,t} + I_t \qquad (1)$$

[3]The resulting series for public and private capital stocks, as well as data on real GDP, are available from the on-line appendix to this working paper. This document also provides an overview of the exact data source for each series.

[4]This way we also avoid including spending on military equipment in the investment series, which are assumed not to be important for the production process.

[5]The Conference Board Total Economy Database^{TM}, January 2014 version (downloaded early 2015), http://www.conference-board.org/data/economydatabase/

where K measures the capital stock at the beginning of the period, δ_t is the time-varying rate of depreciation and I denotes gross public investments.

From this, the public capital stock can be calculated as:

$$K_{t+1} = (1-\delta_t)^t K_1 + \sum_{i=0}^{t-1} (1-\delta_t)^i I_{t-i} \tag{2}$$

with K_1 denoting the initial capital stock. Data on investments are readily available, but one still has to determine the initial capital stock, as well as the depreciation rate to apply.

There is no official information on the magnitude of the initial capital stock for any country except the United States. Therefore, following Kamps (2006) (who in turn borrows the method from Jacob et al. (1997)) an artificial investment series for the period 1860–1959 is constructed. For each country, we assume that investment grew by 3.2 percent a year (the 1960-2013 average) during this period, finally reaching its observed level in 1960.

The depreciation rates used are the same for all countries but time-varying. In fact, they increase over time. This time dependence reflects findings from data provided by the US Bureau of Economic Analysis (BEA). The increase could follow from both a shift in composition of the capital stock towards assets with a higher depreciation rate, as well as a decrease in asset lives. Expanding the formula used in Kamps (2006), depreciation rates develop as follows:

$$\delta_t = \delta_{min}((\frac{\delta_{max}}{\delta_{min}})^{1/54})^{t-2014+54} \tag{3}$$

with δ_{min} fixed at 2.5% and δ_{max} equal to 4.8%. The underlying assumption of increasing depreciation rates of the total public capital stock is mirrored in national estimates of the public capital stock.

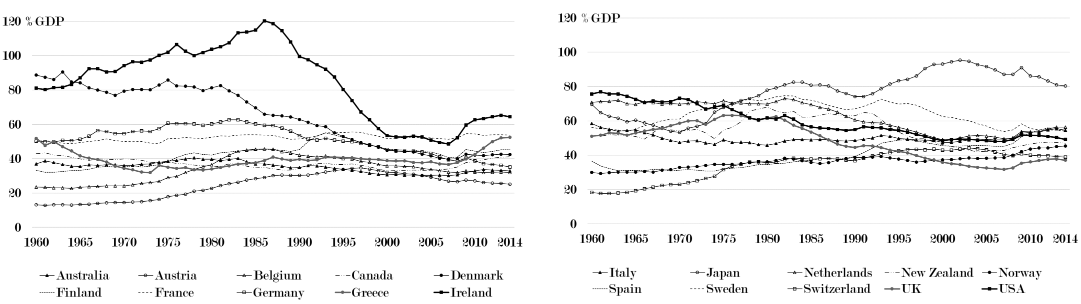
Regarding the private capital stock, we assume a constant depreciation rate of 1.5% for residential capital and a time-varying depreciation rate going from 4.25% in 1960 to 11% in 2013 for non-residential capital stock. These assumptions are, again, based on data by the US BEA. Differences in the composition of the capital stock are ignored due to lack of data.

Figure 3 presents the estimates of public capital stock for a sample of countries included in the analysis (see appendix A for private capital stocks). Two observations stand out. First, despite considerable cross-country differences, capital stocks seem to have converged in size internationally. In 2014, most countries had estimated public capital stocks between 25% and 65% GDP. Japan is a notable exception with the public capital stock of 80% of GDP. There is no apparent relation between the size of the public capital stock and GDP per capita. Secondly, in a number of countries public capital stocks have declined (as % of GDP) over the last two or three decades including the most recent period of global financial crises and its aftermath. Compared to 1980, the largest fall in public capital stock occurred in Ireland, Denmark and Germany, in all cases by more than 20%-points. UK, Sweden, New Zealand, the Netherlands and Belgium have recorded drops of more than 10%-points.

These developments reflect lower public investment rates than in the past. General government gross fixed capital formation as a percent of GDP has declined substantially over the recent period in some countries (figure 4). The largest reductions in public investment ratios since the turn of the century took place in countries with high initial public investment ratios, such as Japan and Ireland, as well as in a number of northern European countries, in particular Germany, Belgium and Finland, and Austria. Investments declined only more recently in countries that came under market pressure during the financial and euro crises, like Spain and Italy.

Furthermore, a fall in public capital stock ratios can to some extent also be the result of privatisations in the eighties and nineties, as well as a matter of valuation. Capital is valued at production costs, with its value subsequently adjusted for depreciation and price increases. Its true economic value, however, also depends on real income developments, but these are not accounted for. Therefore, assuming positive real GDP growth and constant production costs in percent of GDP, a road constructed in 1960 will be valued less today than a road constructed in 2000, even if maintenance spending prevented depreciation. In any case, it should be clear that these public capital stock measures are only proxies for the true public capital stock.

Figure 3: Public capital stock, in % of GDP, 1960-2014



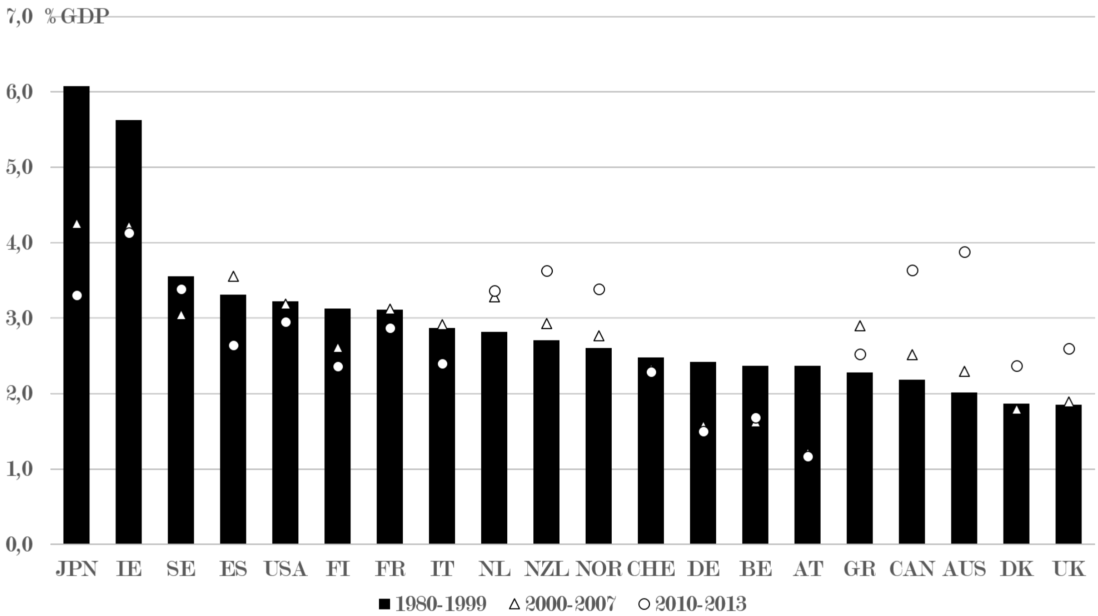
Source: Author's calculations.

3.2 Statistical properties of the time series

First, we check for the order of integration of individual series in logs. Out of many available testing procedures, we apply two of the most commonly used tests: the ADF test and the KPSS test by Kwiatkowski et al. (1992). These tests have different null hypotheses. The ADF test has a unit root as its null, while the KPSS starts from the premise of stationary series. The relevant test statistics and outcomes are presented in table 4 in appendix B.

Series for GDP and total hours worked generally turn out to be integrated of order one and we therefore maintain this as our working assumption. The same can not be said for capital stock data. Formal tests for the order of integration of capital stocks show

Figure 4: General government gross fixed capital formation, average by period, % GDP



Source: OECD

mixed results. In many cases, the ADF and KPSS-tests point in different directions, with capital stocks supposedly integrated of either order one or order two. In some cases, both tests point in the direction of I(2). Both results, I(1) and I(2)-ness of capital stocks, are actually found in the empirical literature (e.g. Jong-A-Pin and De Haan (2008) conclude capital stocks are I(1), Everaert (2003) and Kamps (2006) find evidence for I(2) capital stock series).

However, from equation 1 we know that the capital stock in a year consists of two elements, namely last years' capital stock minus depreciation and the investment series. By construction, the first part has a root very close to, but surely below one. This part of the capital stock series is therefore I(0). The investment series turn out to be I(1) in many/all countries. In theory this means capital stocks must be I(1) as well.

So, how should we interpret the I(2) findings? It is well known that unit root tests (such as ADF) have low power to distinguish between unit root and near unit root processes (Enders, 1995), i.e. a false null hypothesis is relatively unlikely to be rejected. The problem is furthermore aggrevated in case of small samples. As Mahadeva and Robinson (2004) state, practically speaking it is often close to impossible to differentiate difference stationary series from a highly autoregressive one. Clearly, slowly depreciating capital stocks are by nature highly autoregressive.

However, before jumping to conclusions, we investigate another potential cause of our I(2) results. A look at the data in figure 10 in appendix A suggests there may be structural breaks in the capital stock series. Perron (1989) showed that failure to account for a structural break leads to a reduction in the ability to reject a false unit root null hypothesis. Therefore, we perform Zivot-Andrews and Philips-Perron testing allowing for a break in the intercept and the deterministic trend where appropriate.[6] However, also with these tests the evidence remains inconclusive (results not shown).

Since allowing for structural breaks does not change our overall results and since by deduction we concluded that capital stocks must be I(1), we interpret the outcomes of the unit roots tests mainly as evidence for the low power of these tests for near unit root processes. In the empirical sections below, we assume capital stocks are I(1).

4 Empirical approach and results

VAR-models form an attractive alternative to structural models of production function estimates. VAR-models do not impose causal relationships between variables a priori, and allow for testing for the existence of causal relationships in whatever direction. VARs furthermore allow for indirect links between the variables in the model. In a VAR-approach, the long-run output effect of a change in public capital results from the interaction of all the variables in the model. Finally, VARs offer more flexibility concerning the number of long-run relationships in the model; they do not assume there is at most one such relationship as is the case in the production function approach (Kamps, 2005). For these reasons, we estimate country-specific VAR-models.

4.1 Econometric approach

A k-th order VAR, ignoring deterministic elements, can be written as

$$z_t = A(L)z_{t-1} + \epsilon_t \tag{4}$$

where z_t is a vector of endogenous variables and $A(L)$ a matrix of a polynomial order (number of lags) p. ϵ_t is a vector of reduced form i.i.d. residuals, with $\mathrm{E}(\epsilon_t)=0$, $\mathrm{E}(\epsilon_t {\epsilon'}_t)= \Omega$ and $\mathrm{E}(\epsilon_t {\epsilon'}_s) = 0$ for $s \neq t$, with Ω a (k$\times$ k) symmetric positive definite matrix, k denoting the number of endogenous variables in vector z_t.

In order to gauge the long-run effects of public capital, it is sufficient to estimate an unrestricted VAR in levels. The OLS estimator for the autoregressive coefficients in such a model is consistent and asymptotically normally distributed, even in the case where some variables are integrated or cointegrated. Therefore, a VAR in levels can be used to investigate the properties of the data and construct a valid empirical model. However, the consistency of estimates for the autoregressive coefficients does not carry over to impulse response functions (IRFs) obtained from unrestricted VARs in levels. IRFs are inconsistent at long horizons if non-stationary variables are included (Phillips, 1998).

To this end, we use that a VAR model of order p can always be written in the form of a VECM:

$$\Delta z_t = \Gamma(L)\Delta z_t + \Pi z_{t-1} + \epsilon_t \tag{5}$$

[6] In both cases, we set the trimming parameter to 0.10

where $\Gamma(L) \equiv -\sum_{i=j+1}^{p} A_i$ and $\Pi \equiv -I_k + \sum_{i=1}^{p} A_i$ are matrices of coefficients. If matrix Π has a rank of $0 <$ r$<$ k, r linearly independent cointegrating vectors exist. In this case, a VECM is estimated. If the rank of $\Pi = 0$, the non-stationary variables (in levels) are not cointegrated and a VAR in first differences is considered. If the rank of $\Pi =$ k, all series are stationary in levels (i.e., I(0)) and a VAR in levels is considered.

4.2 VAR models

4.2.1 Selected models

Table 1 provides an overview of the selected empirical models, as well as some diagnostic checks on these models. As at least one cointegration relation among variables is confirmed for all countries, we estimate VEC-models (with all variables in logs). In most cases we include a trend in the cointegration relation, as well as a constant in both the cointegration relation and the VAR.

In most models, we included some deterministic elements. We often have to allow for breaks in trends or to correct for observations in specific years to account for specific events (see also the charts in Appendix A). These specific events include, for example, moving some entities from the general government to the private sector in Austria from 1998 onwards, the reunification of Germany in 1990, the Swedish financial crisis in the early nineties, the fall of the Soviet Union affecting Finland, and - in many countries - the oil crises of the seventies and the severe economic crisis of 2009 and later years.

The number of lags is chosen with an economic use of degrees of freedom in mind. Usually we choose the model with the lowest number of lags that is not suffering from too strong autocorrelation.

The number of cointegration relations is a priori unknown (Kamps, 2005). Economic theory suggests constancy of the great ratios. Therefore, public capital to output and private capital to output could well form cointegrating relations. Furthermore, if technology behaves as a trend-stationary process, the macro-economic production function describes another cointegrating relation. With potentially up to three cointegrating relations, which is the maximum in our four-variable framework anyway, we need to resort to formal testing. We apply Johansen's cointegration test; table 1 shows the test results. In about one third of the cases, the trace and maximum eigenvalue statistics agree on the number of contegration relations. For countries where both tests give different results, we generally follow the outcomes of the trace test as this test is more robust to non-normality (Cheung and Lai, 1993).

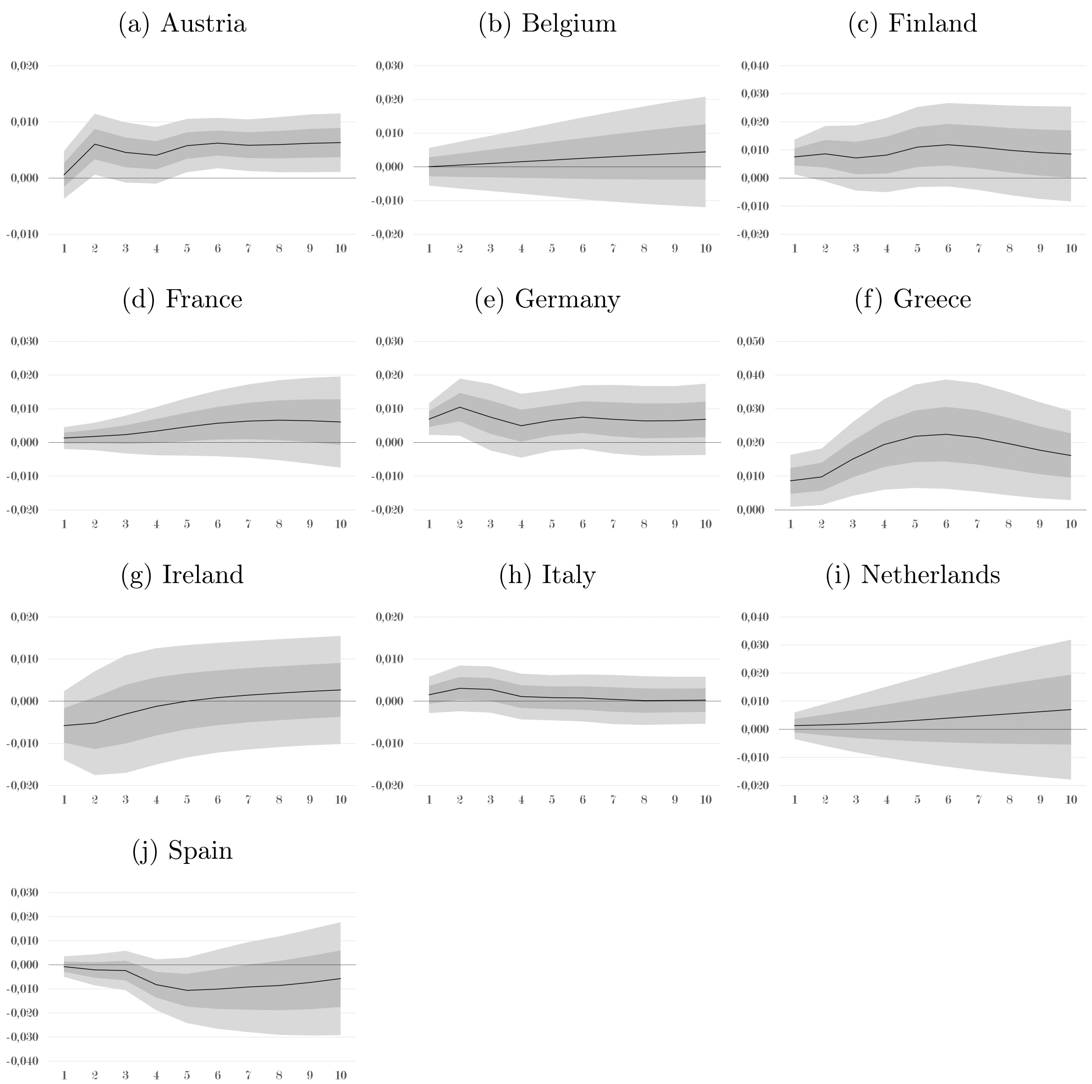
The residuals of the selected models are well-behaved. Normality of residuals cannot be rejected in nearly all cases with Denmark being a notable exception. Furthermore, there is no strong evidence for first order autocorrelation or heteroskedasticity in the residuals of any model.

Table 1: Selected models

Country	**Sample period**	**# Lags**	**# Coint. relations**	**Johansen model type**	**Deterministic elements**	**J-Bera**	**Auto-correlation**	**Trace**	**Max. eigenvalue**
AT	1963-2013	2	2	4	D_75to14 D_98to14	5.00	20.78	2	3
AUS	1962-2013	1	2	4		5.19	13.49	1	1
BE	1965-2013	1	1	4	D_66 D_72	10.24	12.33	1	1
CAN	1963-2013	1	2	3	D_82	12.38	21.06	2	2
CHE	1962-2013	1	1	4	D_75	13.00	17.50	1	0
DE	1965-2013	2	2	4	D_90to14 D_09to14	7.59	17.67	2	2
DK	1966-2013	1	1	3	D_90to93 D_09to14	1.65	18.36	2	1
ES	1964-2013	3	2	3	D_09	4.97	22.36	2	2
FI	1964-2013	3	1	3	D_90to93 D_09 D_93to14	6.86	13.38	1	1
FR	1962-2013	1	2	4	D_73 D_75 D_84to14	4.18	20.51	2	2
GR	1962-2013	1	2	4	D_74to14 D_09to14	3.69	22.79	2	2
IE	1965-2013	1	1	4	D_94to14 D_08to14	13.58	25.93	1	1
IT	1963-2013	2	1	5	D_68 D_75 D_09	5.79	24.59	1	1
JPN	1963-2013	2	1	5	D_91to14 D_09	12.84	16.12	1	1
NL	1962-2013	1	1	4	D_09	4.43	7.61	1	0
NOR	1962-2013	1	2	4	D_09to14	7.23	19.99	2	0
NZL	1962-2013	1	1	4		5.44	25.21	1	0
SE	1962-2013	1	2	4	D_91to93 D_09	8.27	23.33	2	3
UK	1962-2013	2	1	4	D_73 D_09to14	12.81	24.55	1	0
USA	1962-2013	1	1	3		13.13	16.78	1	1

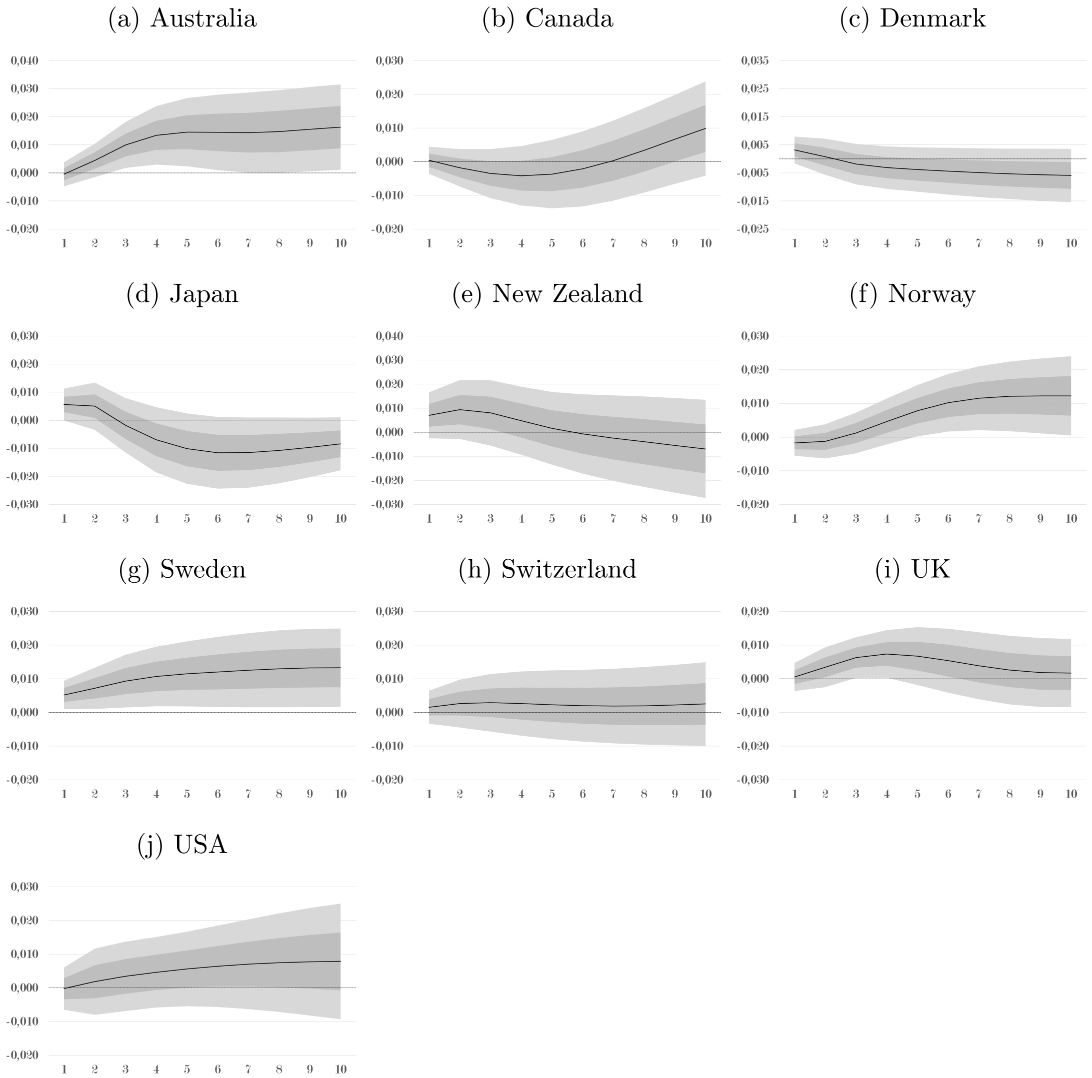
Johansen model types refer to: 3 = model with intercept in cointegration relation and in VAR; 4 = intercept and trend in cointegration relation, no intercept in VAR; 5 = intercept and trend in cointegration relation, intercept in VAR. Dummies with a single number are equal to 1 in the year mentioned and 0 otherwise. Dummies with two numbers are 1 from the first year mentioned onwards, 0 before. Columns 'Trace' and 'Max. eigenvalue' show the selected number of cointegration relations from Johansen cointegration tests, either according to the trace statistic or the eigenvalue statistic. The Jarque-Bera statistic tests for normality of residuals, with a null hypothesis of multivariate normal residuals, 8 degrees of freedom. The serial correlation LM-statistic tests for first order autocorrelation, with a null of no autocorrelation. *Significant at 5%, **significant at 1%.

Figure 5: Impulse responses of GDP to a one s.d. public capital shock, euro area



Numbers on the vertical axis indicate the percentage deviation from the baseline. Confidence intervals are based on bootstrapped standard errors (1000 replications). The dark (light) grey shaded areas indicate 1 (2) standard deviation bands around the central estimate.

Figure 6: Impulse responses of GDP to a one s.d. public capital shock, non euro area



Numbers on the vertical axis indicate the percentage deviation from the baseline. Confidence intervals are based on bootstrapped standard errors (1000 replications). The dark (light) grey shaded areas indicate 1 (2) standard deviation bands around the central estimate.

4.2.2 Results

Figures 5 and 6 plot the impulse response functions for GDP to a shock in the net real public capital stock. To orthogonalize shocks, a Cholesky decomposition of the residual covariance matrix is applied. The variables are ordered as follows: net real public capital, net real private capital, total hours worked and real GDP. This particular ordering implies that we assume that public capital contemporaneously influences other variables, but is not contemporaneously influenced by the others. Government investment is largely considered to be unrelated to current changes in the business cycle as there are considerable implementation time lags related to capital projects in the public sector. Similar reasoning holds for private capital, although we assume the private sector is in general able to react quicker. While labour market developments are found to be highly pro-cyclical they tend to lag output developments. Therefore, employment is ordered third, and real GDP is ordered last in our specification.[7]

Overall, similar to Kamps (2005), public capital seems to be productive for most of the countries included in the sample as the long run impact of a one standard deviation shock in public capital on GDP seems to be positive. As in previous studies, these effects are shown to be significant in the case of only several countries.[8] Notable exceptions to these positive responses are Spain, where similar to Jong-A-Pin and De Haan (2008) the effect is found to be negative for all periods, and Denmark, Japan and New Zealand, where an initial positive impact is followed by negative effects. The results for Japan might be as expected since Japan has by far the highest level of public capital among the countries in the sample, so after an initial positive demand effect additional capital may have an adverse impact on output. In the case of Canada, Ireland (second largest capital stock in the sample) and Norway an initial negative effect turns positive after several periods, albeit only significantly so in the latter case. In general, we do find a small negative correlation between the response of GDP to the shock to public capital and the level of the public capital itself, especially in the long run.

Regarding the response of the private capital stock to a shock in public capital, there are two opposing forces at work (Baxter and King, 1993). First, a crowding out effect of additional government investment (that results in an increase in public capital stock) leading to a reduction in the resources available for financing private sector projects. Second, a public capital shock could increase the marginal productivity of private capital leading to an increase in private investment. It is a priori not clear which effect dominates. Empirical results are mixed, but in most countries private and public capital are found to be complements (i.e., the response of private capital has the same sign as the shock in

[7]Of course, these are quite strong assumptions. We therefore performed a robustness check with different ordering of the variables but this does not affect results much. The impulse response functions for different ordering of the variables are available on request.

[8]Charts 5 and 6 report one standard deviation (dark grey) and two standard deviation (light grey) bands around the central estimate. Confidence intervals for impulse responses from VAR-models are notoriously wide (see e.g. Runkle, 1987), as the uncertainty on each model parameter translates into uncertainty around the impulse response. Therefore Kamps (2005), e.g., following up on Sims and Zha (1999), presents 68%-confidence intervals.

public capital) in both the short and long run.[9] In the case of Canada, Germany, Ireland and the USA complementarity holds only in the long run while in the short to medium run a public capital shock coincides negatively with private capital. For Spain, Italy and Japan private and public capital are found to be substitutes (for Japan: not in the short run).

The reaction of employment (total hours worked) is in most cases negative in the long run, suggesting that additional public capital would not be beneficial for employment. Exceptions are Greece, Canada and Spain (in latter case only in the long run) where the shock to public capital leads to a substantial increase in employment. As Kamps (2005) suggests, the reaction of labour might depend on the way the new public investment are financed (distortionary versus non-distortionary taxes). The small sample size makes it difficult to include additional variables in our models however.

The response of GDP and other variables to a public capital shock endogenously causes public capital to change over time itself. Therefore, the IRF of GDP cannot be interpreted as an estimate of the public capital multiplier. To obtain this multiplier, additional calculations are needed. The period n multiplier of public capital can be calculated as:

$$M_n^{KGV} = \frac{\Delta log(GDP)}{\Delta log(KGV)} / \frac{KGV}{GDP} \tag{6}$$

In words, a public capital shock of 1% of GDP results in an M_n^{KGV} % increase in GDP in period n.

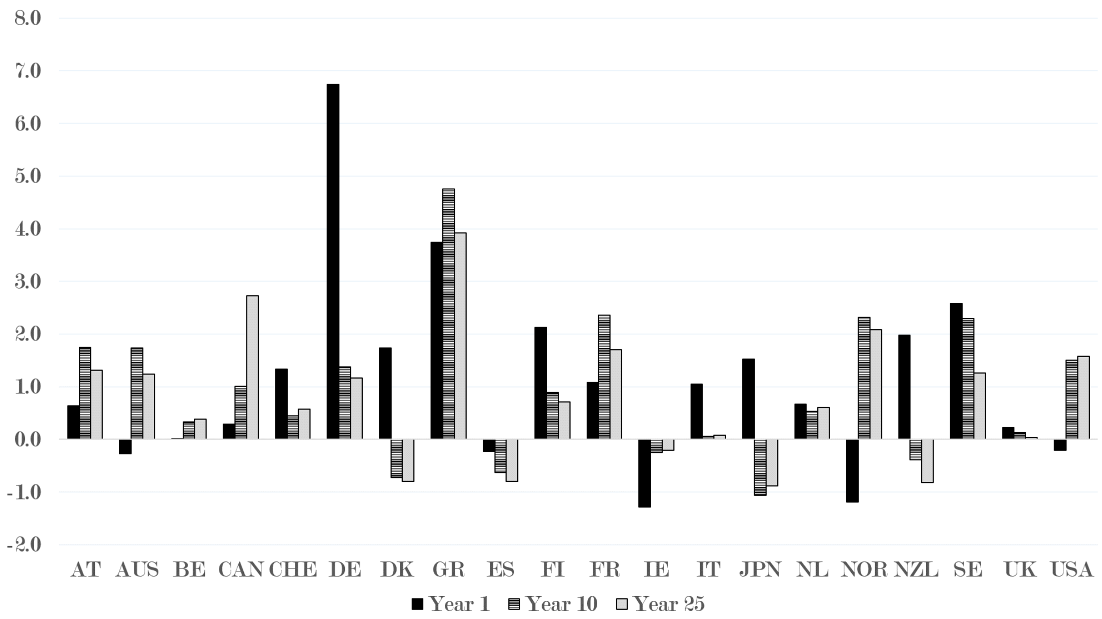
Figure 7 shows the estimates of the general government capital multipliers for different time horizons.[10] Generally, multipliers seem rather high given that they represent the change in a flow (real GDP) in response to a change in a stock (real public capital). This could reflect that shocks in public capital in practice closely resemble shocks in public investments, which means that we might be finding estimates for the investment multiplier rather than for the 'true' capital multiplier. Another explanation - for countries where the multiplier is found to be positive - could be that changes in public capital positively correlate with other growth-supporting policy measures.

The highest multiplier is found for Greece where the strong reaction of GDP to a public capital shock is supported by the complementarity of private and public capital as well as a positive reaction of total hours works to this shock. Large long-run multipliers (around 3) are also found for Canada and Norway. The medium and long-run public capital multiplier is found to be negative for Japan, Spain, New Zealand, Denmark and Ireland, i.e. by and large the same countries as those with negative long-run GDP impulse responses. For all other countries the multipliers are positive and fall in the long run (after 25 periods) roughly in the range between 0.5 and 2.

[9] Results not shown, but available upon request

[10] The very high impact multiplier for Germany should be interpreted with caution as it reflects a very small initial reaction of public capital (the denominator) to its own shock and already after two periods it takes the value much closer to those found for other countries.

Figure 7: General government capital multipliers at different horizons



Numbers depict the general government capital multipliers, calculated according to equation 6, at different time horizons.

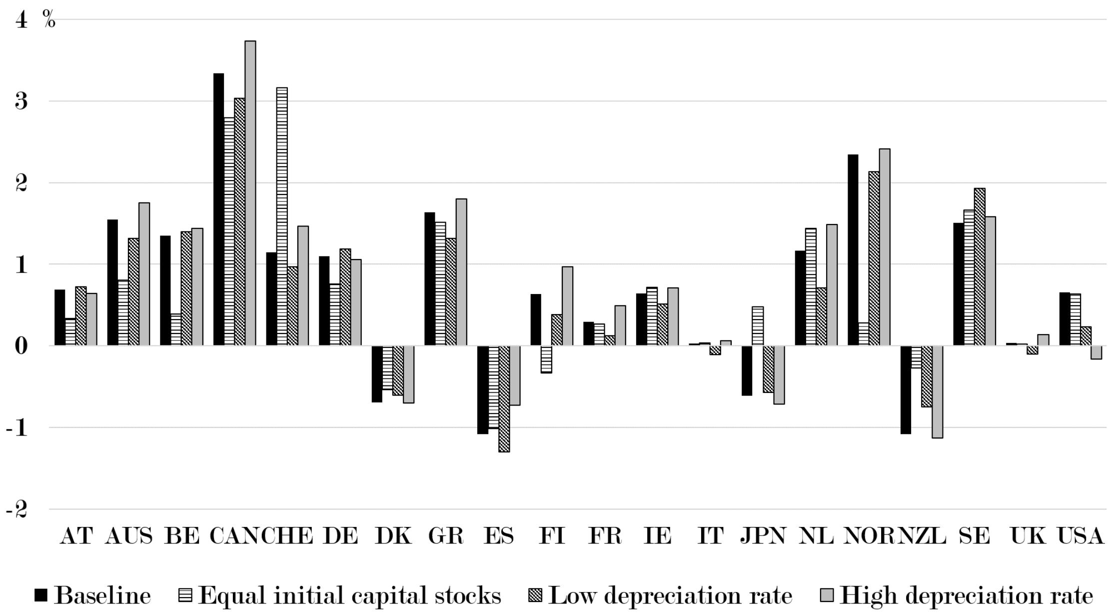
4.2.3 Robustness

The assumptions underlying the capital stock calculations, in particular those on the level of initial capital stock and the depreciation rates, are strong. Therefore, we scrutinize the sensitivity of our baseline results to alternative assumptions.

As a first robustness check, we assume that all countries had the same initial public and private capital-to-GDP ratio. This ratio is determined as the unweighted average of the values following from the country-specific calculations. As a result, all countries are assumed to have a public capital-to-GDP ratio of 49.5% in 1960 and a private capital-to-GDP ratio of 250.5%. This alternative assumption mainly influences the capital stock estimates for the early part of the sample (see figures 14 and 15 in Appendix A). After all, under the baseline assumptions for the depreciation rates, the 1960 public capital stock has roughly been depreciated by half in 1980, while the private non-residential capital stock has already been depreciated by two thirds. Estimating our VEC-models using the same empirical models as before generally confirms our earlier findings (see figure 8).

Secondly, we test how sensitive results are to the discount rates applied in constructing the capital stock series. To this end, we vary the assumptions for δ_{max} (see equation 3). We set δ_{max} equal to respectively 50% and 150% of its original value. This means that the public capital depreciation rate either decreases from 2.5% in 1960 to 2.4% in 2013, or increases to 7.2% in 2013. Private non-residential capital now alternatively depreciates by 5.5% or 16.5% in 2013. Arguably, these are quite extreme assumptions, but we use these extreme values to obtain an idea of the maximum impact on our estimates. Figures

Figure 8: GDP response to a public capital shock, sensitivity analysis



Numbers depict the long run percentage response of real GDP to a one standard deviation shock in the real net public capital stock. The underlying empirical models are described in table 1. Results in the first column correspond to the baseline model (and therefore coincide with the final column of table 2). In the second column, all countries are assumed to have the same initial, 1960 capital stock equal to the unweighted average of the 20 countries. In column 3 (4), the government capital stock depreciation rate falls to 2.4% (increases to 7.2%) in 2014, while the non-residential private capital depreciation rate falls to 5.5% (increases to 16.5%) in 2014.

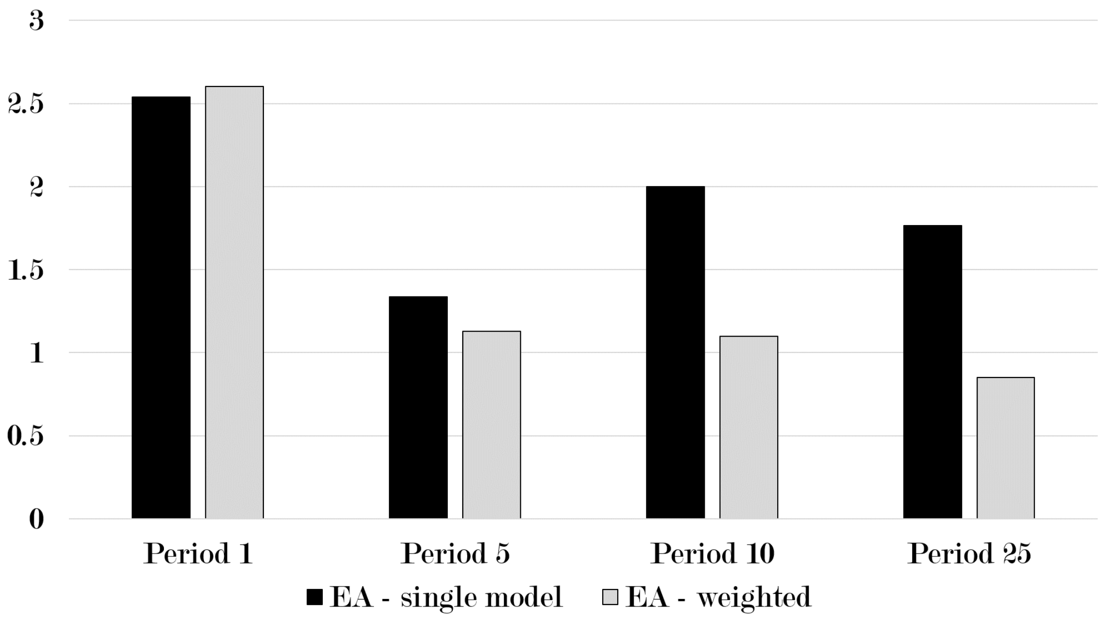
14 and 15 in Appendix A show the resulting alternative capital stocks. Estimating our baseline models with these alternative capital stock series does affect the magnitude of the effect found for some countries, but not the overall direction (figure 8).

Finally, the sensitivity of our findings to the time period under consideration can be gauged from the recursive VARs, as estimated below in section 4.4 (with results in table 2). We will discuss this in more detail in paragraph 4.4.

4.3 Spillovers

This section investigates the issue of potential spillover effects across euro area countries included in the sample. Fiscal policy actions in one country, such as an increase in public investments, could impact economic conditions in other countries via several channels. The most direct channel is via the effect on trade and exports. An increase in public spending could positively affect output in other countries through direct purchases of foreign products by the government or, indirectly, by stimulating the domestic economy, which in turn increases imports from other countries. For countries in a monetary union, fiscal stimulus by fellow member countries could theoretically also have adverse consequences. If a country engages in expansionary fiscal policy, upward pressure on area-wide inflation might appear, leading to a monetary policy tightening. Generally, positive (trade) effects seem to dominate (Hebous and Zimmermann, 2013; Auerbach and Gorodnichenko, 2013; Giuliodori and Beetsma, 2004; Beetsma et al., 2006; Degiannakis et al., 2016). Furthermore, specific to the context of public investment and public capital, positive supply side effects may materialize in other countries than just the country which undertakes the investment, e.g. in the case of cross country infrastructure networks. Accordingly, studies that focus on large(r) geographical areas generally find larger positive effects of public investments (Bom and Ligthart, 2014b).

Figure 9: Fiscal multipliers and international spillovers



Numbers depict the general government capital multipliers at different time horizons. Black bars show results in case a single VAR model is estimated for the euro area as a whole. Multipliers are calculated by using equation 6. Grey bars show the GDP weighted average of individual euro area country multipliers.

We look for the existence of both short and long run spillovers among the countries that currently share a common currency, i.e. the euro area member states.[11] To this end, first, a euro area multiplier for different horizons is calculated as the weighted average of the country specific multipliers presented in the previous section, using shares in aggregate output as weights. These individual country multipliers ignore spillovers to other countries, however. In a second step, we therefore estimate a model for the euro area as a whole. This euro area aggregate model in principle incorporates positive spillovers.[12]

[11] Our sample thus includes Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands and Spain. These countries account for more than 95% of the overall euro area output.

[12] The model for the euro area as a whole is a VECM, estimated over the period 1962–2013, with one lag and two cointegrating vectors. The cointegration relation contains an intercept and a trend, while the VAR has an intercept (Johansen model type 4). Dummies for 1973 and 1975 are included. Both the trace and the maximum eigenvalue statistic point in the direction of two cointegrating vectors. Normality

We do not find evidence for positive spillovers in the short run. The impact multiplier is similar under both approaches (see figure 9), suggesting that either direct government purchases abroad are small, the indirect effect via domestic stimulation is small, or that negative interest rate and exchange rate spillovers undo positive (in)direct effects to a large extent. After some while though, a positive difference builds up. In the long run, the euro area model incorporating spillovers points to a markedly higher multiplier than the model ignoring spillovers. This could point at the importance of positive supply side spillovers.

4.4 Recursive VARs

We are interested in the development of the relationship between public capital and economic growth over time. We follow the approach of Jong-A-Pin and De Haan (2008) and estimate so-called recursive VAR-models. That is, for each country we estimate a model for the sample period 1960-2000; subsequently we extend the end date of the sample period by one year at a time and re-estimate the model, until we reach 2013, the final year of our dataset. For each subsample, we impose the country-specific model for the whole period as specified in the previous section. That is, the number of cointegration relations and the number of lags chosen is as shown in table 1.

Results for this recursive analysis are presented in table 2. The final column of the table indicates the direction of a simple time trend in the estimated recursive GDP responses. A rather diffuse picture emerges. The long-run GDP response (for simplicity we take the value from period n=100) to a one standard deviation innovation in public capital indeed seems to have increased in a number of countries, most notably Austria, Belgium, Finland and Italy. However, in a number of other countries the positive effects of a public investment shock on growth declined over time, e.g. in Denmark, the Netherlands, Switzerland, Sweden and the USA.

Compared to Jong-A-Pin and De Haan (2008), who analyse changes in the GDP response to public capital between the periods 1960-1989 and 1960-2001, trends seem to have reversed in Ireland, Italy and Switzerland. For the first two countries, we find an increase over time in the impact of public capital on GDP whereas Jong-A-Pin and De Haan (2008) concluded that public capital investments became less effective over time in those countries. The opposite holds for Switzerland. For Finland, Denmark, the USA and France trend developments present in the nineties of the previous century have continued in the 21st century.

The analysis does not allow us to draw strong conclusions on what is driving trend developments, as we have only 20 observations on trend directions and causality will often run in multiple directions. For example, one might expect the GDP-impact of public capital shocks to decline over time as the public capital stock increases, due to diminishing marginal returns. However, if for a certain reason the impact of public capital shocks increases over time, one might expect countries to invest more and thus see the

and absence of first order autocorrelation of residuals cannot be rejected at the 10% significance level. In chart 9, the GDP response is expressed relative to the public capital stock response and scaled by the capital-to-GDP ratio.

Table 2: Long-run GDP response to a shock in public capital, recursive estimates

End year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Trend
AT	0.0	0.3	0.5	0.4	0.4	0.2	0.3	0.3	0.4	0.6	0.6	0.6	0.7	0.7	I
AUS	2.1	1.8	1.8	1.7	1.9	1.9	1.9	1.9	1.8	1.8	1.9	1.9	1.6	1.5	D
BE	0.0	0.9	0.4	1.1	0.5	0.5	0.4	0.3	0.5	1.5	1.3	1.3	1.3	1.3	I
CAN	4.3	4.1	3.8	3.8	4.1	3.9	3.6	3.5	3.5	3.5	3.6	5.5	3.4	3.3	N
CHE	3.2	5.4	6.5	6.2	3.8	5.1	3.2	1.9	1.8	3.5	2.0	1.0	1.6	1.1	D
DE	0.9	0.9	0.9	0.9	0.9	0.9	1.2	1.2	1.1	1.1	1.6	1.3	1.3	1.1	I
DK	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	D
ES	0.5	1.9	2.2	-0.6	-0.9	-1.0	-1.2	-1.2	-1.1	-1.1	-0.8	-0.9	-1.1	-1.1	D
FI	-0.1	-0.3	-0.2	-0.3	-0.2	-0.1	-0.1	-0.3	0.0	0.0	0.0	0.4	0.4	0.6	I
FR	3.0	2.8	0.6	0.3	0.4	0.4	0.6	0.5	0.4	0.3	0.4	0.3	0.3	0.3	D
GR	1.4	1.6	1.6	1.7	1.8	1.8	1.8	1.7	1.6	1.6	1.6	1.6	1.7	1.6	N
IE	-1.1	-0.5	-0.2	0.1	0.6	0.7	0.8	0.8	0.8	0.8	0.8	1.0	0.8	0.6	I
IT	-0.6	-0.5	-0.4	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.2	-0.1	0.0	I
JPN	-0.7	-0.7	-0.7	-0.6	-0.5	-0.6	-0.8	-0.8	-0.8	-0.8	-0.8	-0.6	-0.6	-0.6	N
NL	5.0	4.6	4.6	4.3	4.2	2.5	2.1	2.3	2.3	2.3	1.9	1.5	1.2	1.2	D
NOR	1.5	1.1	1.2	2.8	0.5	2.2	3.5	3.2	4.0	4.0	2.7	1.9	2.0	2.3	N
NZL	-0.5	-0.5	-0.5	-0.4	-0.5	-0.5	-0.5	-0.4	-0.5	-0.5	-0.8	-1.0	-1.0	-1.1	D
SE	3.0	2.9	2.8	2.7	2.8	2.7	2.7	2.5	2.0	2.0	2.2	2.2	2.0	1.5	D
UK	0.6	0.9	0.8	0.9	0.8	0.7	0.5	0.6	-0.3	-0.3	0.2	0.0	0.0	0.0	D
USA	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.2	0.8	0.9	0.8	0.7	0.6	D

Country-specific models and initial sample periods as specified in table 1. Numbers denote the long-run (period 100) response of GDP to a Cholesky one standard deviation innovation in public capital. Column 'trend' denotes the sign of the coefficient of a linear time trend in a regression of the GDP response on a constant and a time trend. I = positive (i.e effect increases) and significant at 5%, D = negative (decrease) and significant at 5%, N = no significant trend.

public capital stock rising. It is therefore no surprise that the data do not show a clear relationship between e.g. changes in the public capital stock as a percentage of GDP or changes in the public to private capital stock ratio on the one hand, and the direction of trend in the GDP impact of public capital shocks on the other.

For the sake of completeness, table 3 shows the public capital multiplier as defined in equation 6 above to take into account the fact that public capital itself also responds to a shock in public capital. Overall, conclusions do not change much, although for Australia, Denmark and Ireland the trend direction reverses. Apparently, the endogenous response of public capital to a public capital shock has developed differently over time from the GDP response to such a shock in these countries. Generally speaking though there is no clear tendency for public capital to become more or less productive over time.

5 Concluding remarks

The public capital-to-GDP ratio has been on a long-term downward trend in a number of countries. In combination with recent cuts in public investment in many advanced economies, this observation raises the question of whether there is public underinvestment, which through its effect on the public capital stock could harm long-term growth prospects. In this paper we examine the relationship between public capital and output, and investigate whether it has changed over time. We find that a positive shock

Table 3: Long-run multiplier, recursive estimates

Sample end year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Trend**
AT	-0.2	0.5	0.6	0.5	0.6	0.4	0.4	0.5	0.7	0.9	0.9	1.0	1.2	1.2	I
AUS	1.2	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.2	1.2	1.2	1.3	1.2	1.2	I
BE	0.0	0.2	0.1	0.3	0.2	0.2	0.2	0.1	0.2	0.4	0.4	0.4	0.4	0.4	I
CAN	2.2	2.1	2.4	2.4	2.7	3.0	3.1	3.1	3.1	3.0	3.2	4.6	3.0	3.0	I
CHE	1.3	1.3	1.3	1.3	1.2	1.1	1.0	0.7	0.7	0.9	0.7	0.6	0.7	0.6	D
DE	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	I
DK	-1.1	-1.3	-1.4	-1.6	-1.6	-1.2	-1.0	-0.7	-1.0	-1.0	-0.9	-0.9	-0.9	-0.8	I
ES	0.4	1.0	1.1	-0.6	-0.9	-1.0	-1.3	-1.4	-1.2	-1.2	-0.9	-1.1	-1.4	-1.4	D
FI	-1.0	-0.9	-0.4	-0.4	-0.5	-0.1	-0.1	-0.4	0.0	0.0	0.0	0.5	0.5	0.8	I
FR	2.4	2.4	2.4	1.8	1.6	1.6	1.9	1.9	1.9	1.9	1.9	1.8	1.9	1.9	N
GR	3.8	3.5	3.6	3.6	3.3	3.1	3.7	3.6	3.3	3.3	3.3	3.3	3.7	4.0	N
IE	0.1	0.1	0.0	0.0	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.4	-0.3	-0.2	D
IT	-1.0	-1.0	-0.7	-0.7	-0.8	-0.8	-0.9	-1.0	-1.0	-1.0	-0.8	-0.6	-0.2	0.1	I
JPN	-0.8	-1.2	-1.0	-0.9	-0.8	-0.9	-1.9	-2.3	-1.5	-1.5	-2.0	-0.9	-0.8	-0.8	N
NL	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	D
NOR	0.9	0.6	0.8	1.2	0.6	1.4	1.7	1.9	2.2	2.2	2.2	2.1	2.1	2.1	I
NZL	-0.2	-0.3	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.6	-0.9	-0.9	-0.7	D
SE	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.1	1.1	1.1	1.1	N
UK	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	-0.3	-0.3	0.1	0.0	0.0	0.0	D
USA	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.8	1.9	1.6	1.6	1.5	1.6	1.6	D

Country-specific models and initial sample periods as specified in table 1. Numbers denote the long run (period 100) public capital multiplier as defined in equation 6. Column 'trend' denotes the sign of the coefficient of a linear time trend in a regression of the GDP response on a constant and a time trend. I = positive (i.e effect increases) and significant at 5%, D = negative (decrease) and significant at 5%, N = no significant trend.

to public capital increases output in the short and long run in most countries in our sample, although there is heterogeneity across countries, as in earlier studies. We do not find a systematic tendency for public capital to become more or less productive over time, suggesting we cannot speak of an across-the-board 'investment gap' in all countries. Whether there are investment needs at the current juncture therefore needs to be judged on a country-by-country basis. Finally, for euro area countries, our research provides some tentative evidence for the existence of international investment spillovers, supporting the case for international coordination in drawing up an investment agenda.

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Appendices

A Charts and figures

Figure 10: Real net government capital stocks, log of billions of national currency or (for euro area countries) euros, 1960-2014

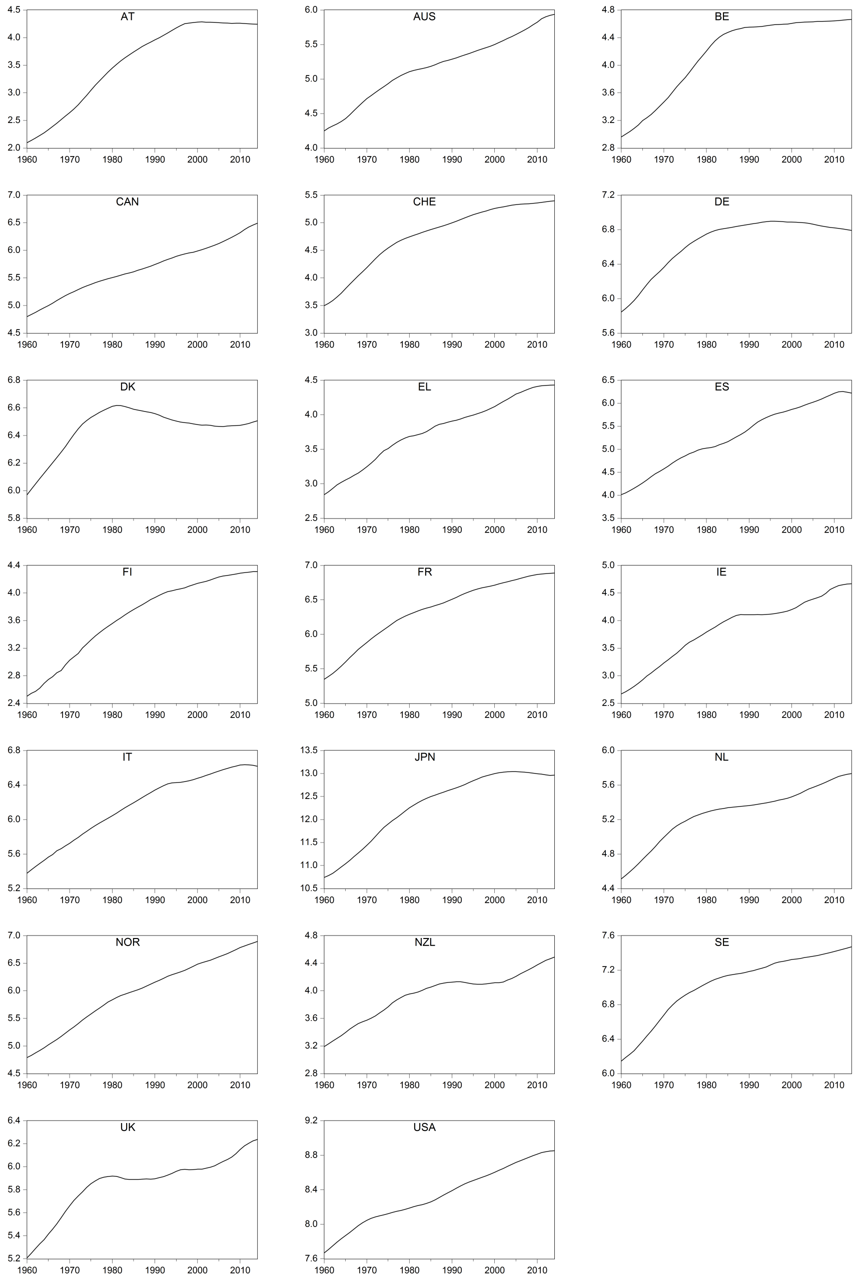


Figure 11: Real net private sector capital stocks, log of billions of national currency or (for euro area countries) euros, 1960-2014

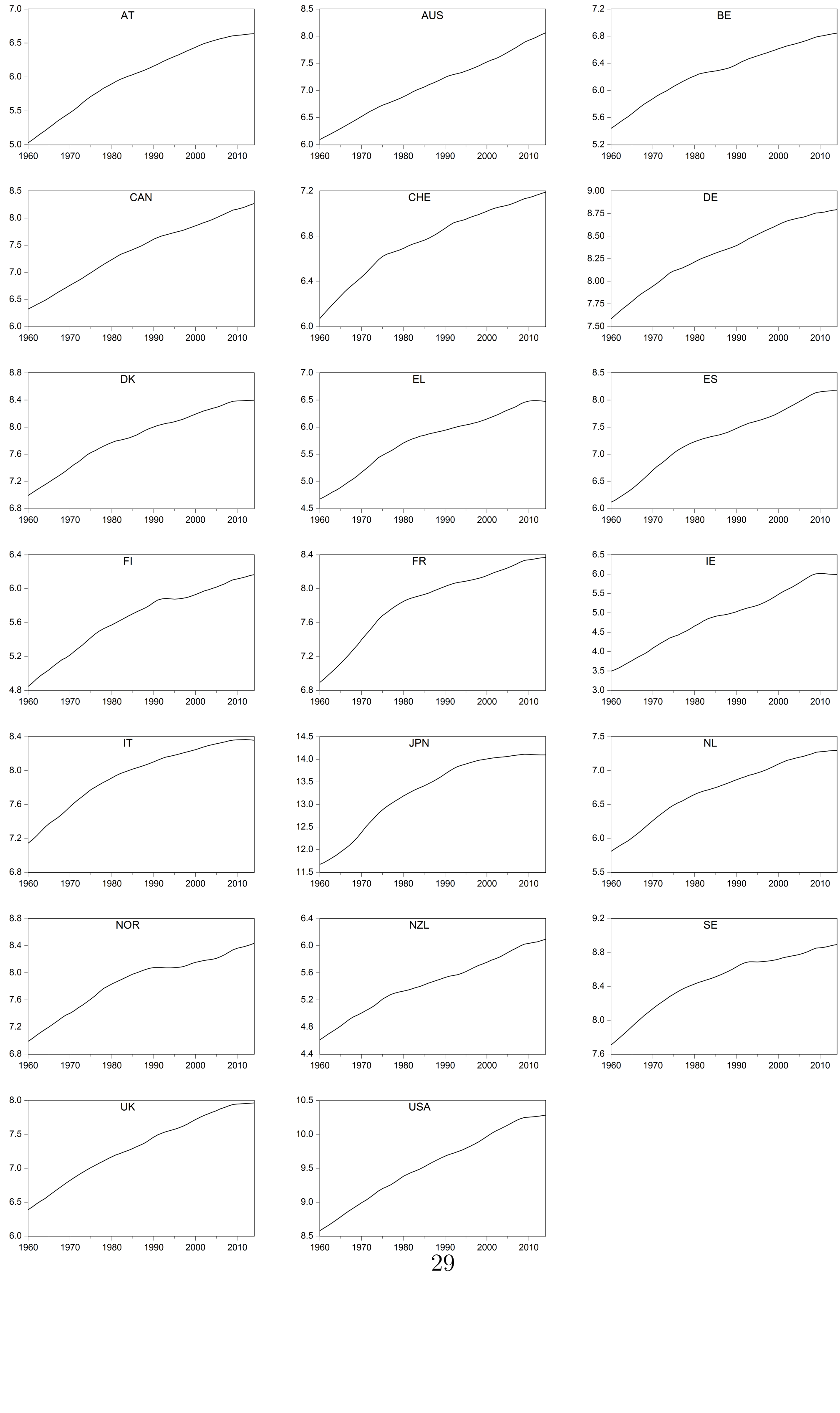


Figure 12: Total hours worked, log of thousands of hours worked, 1960-2013

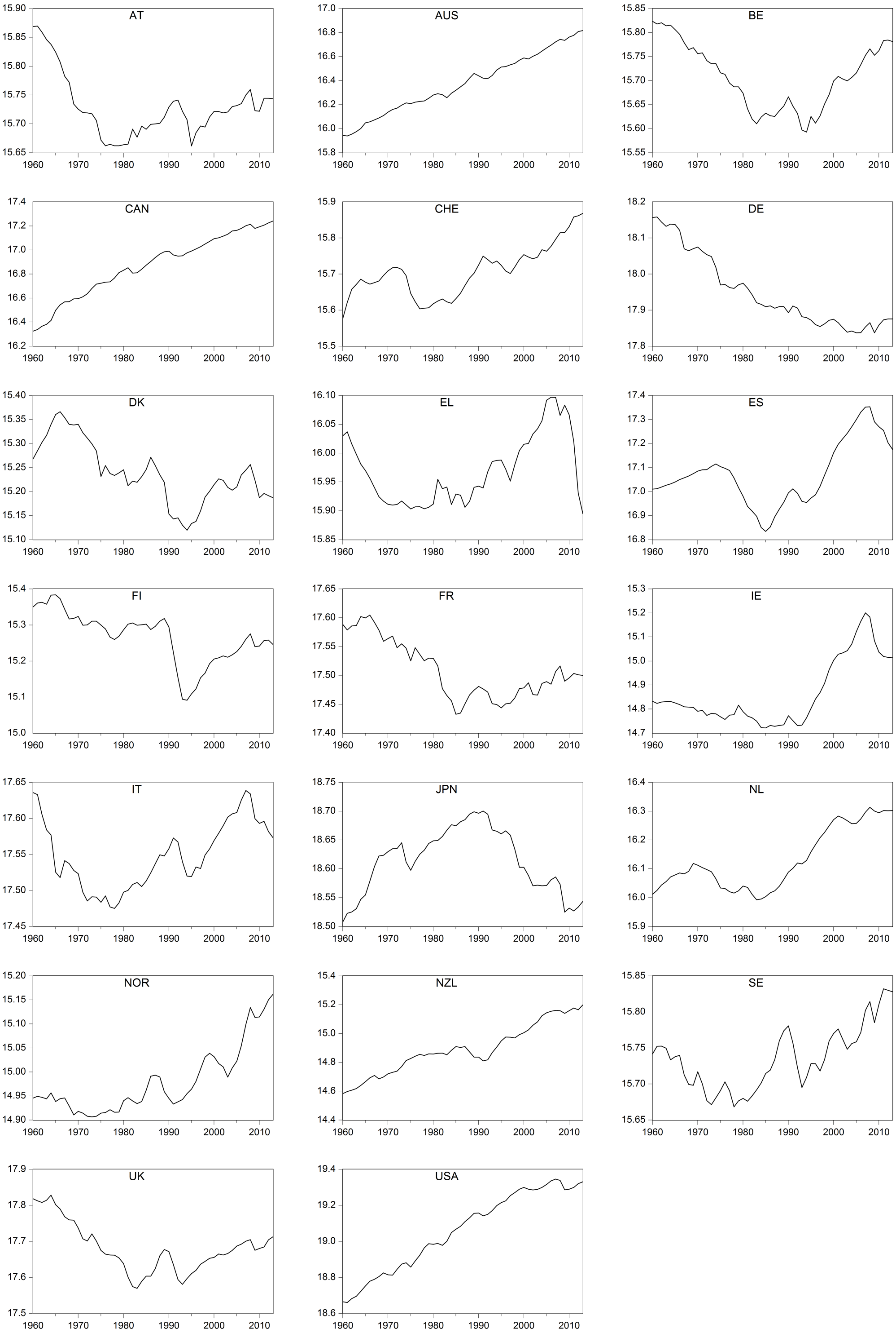


Figure 13: Real GDP, log of billions of national currency or (for euro area countries) euros, 1960-2014

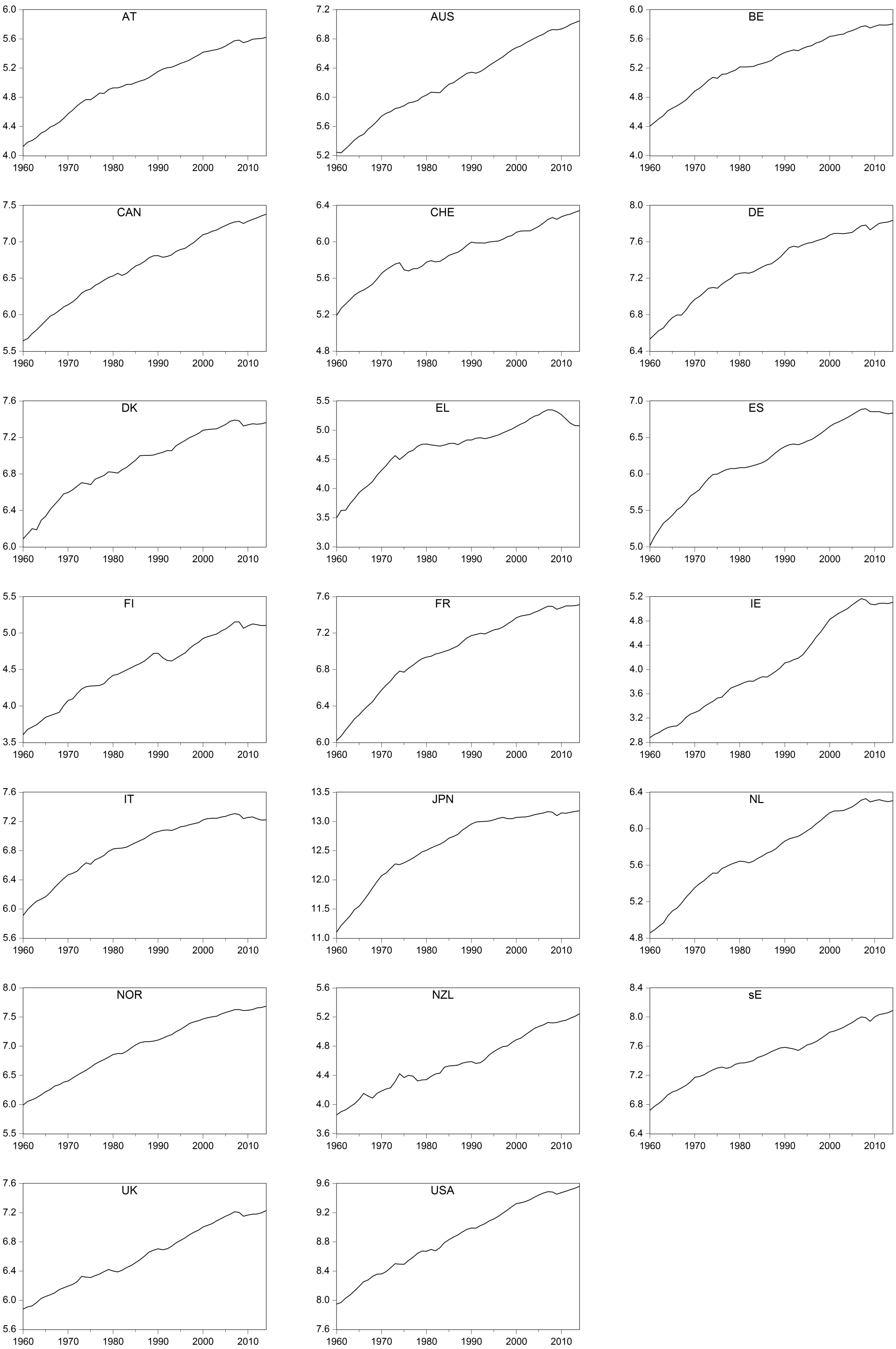
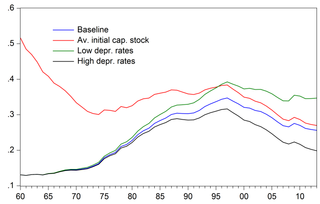
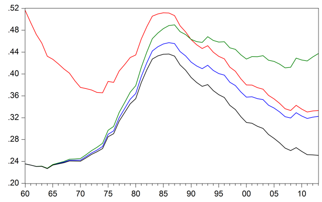


Figure 14: General government capital stock, % GDP, alternative assumptions, euro area

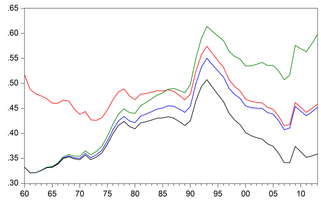
(a) Austria



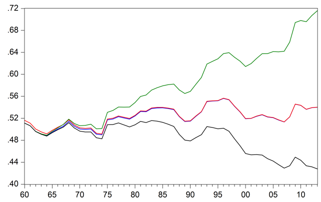
(b) Belgium



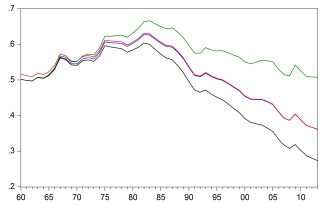
(c) Finland



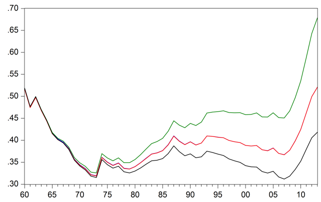
(d) France



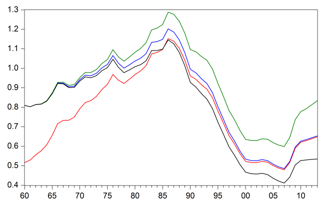
(e) Germany



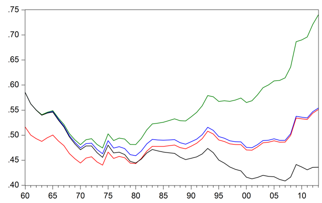
(f) Greece



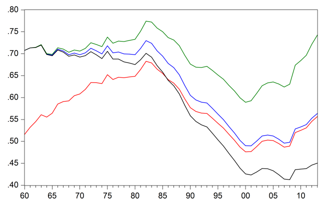
(g) Ireland



(h) Italy



(i) Netherlands



(j) Spain

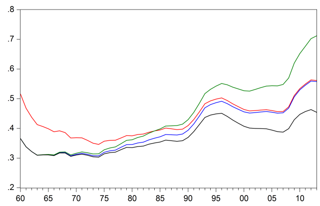
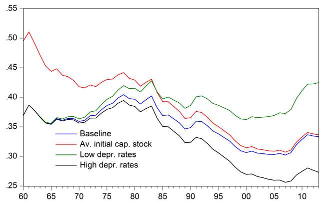
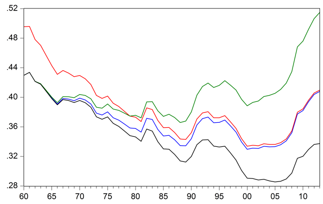


Figure 15: General gov. capital stock, % GDP, alternative assumptions, non-euro area

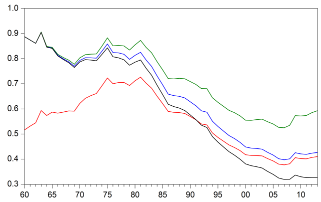
(a) Australia



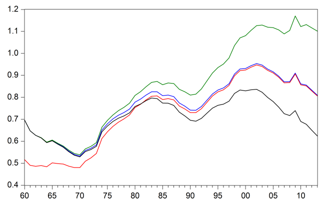
(b) Canada



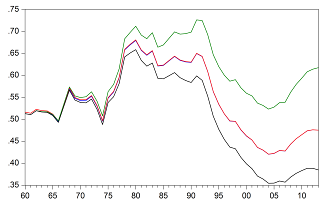
(c) Denmark



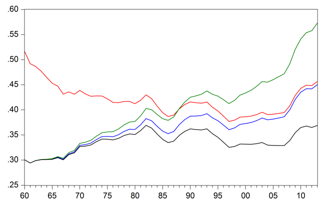
(d) Japan



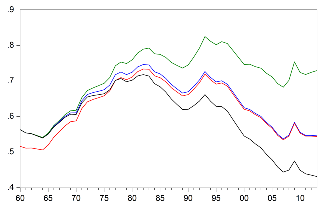
(e) New Zealand



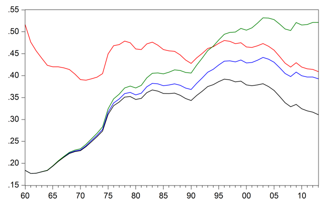
(f) Norway



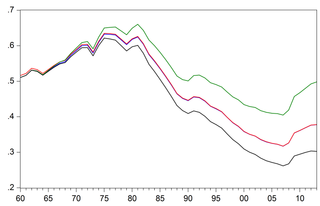
(g) Sweden



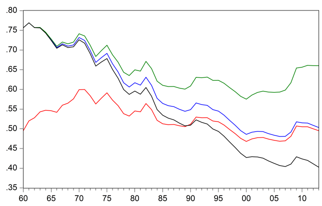
(h) Switzerland



(i) UK



(j) USA



B Testing for unit roots

Table 4: Unit root testing

		ADF Level	ADF I(1)	ADF I(2)	KPSS Level	KPSS I(1)	KPSS I(2)
Critical value (5%)		-3.50	-3.50	-3.50	0.15	0.15	0.15
Country	**Variable**			**Test-statistics**			
	KGV	-1.81	-2.96	-5.64	0.25	0.18	0.12
Austria	KPV	-0.62	-2.72	-7.21	0.25	0.07	0.07
	THW	-1.59	-6.45	-8.07	0.21	0.09	0.34
	GDP	-1.38	-6.39	-9.38	0.22	0.08	0.05

Table 4 continued: Unit root testing

		ADF Level	ADF I(1)	ADF I(2)	KPSS Level	KPSS I(1)	KPSS I(2)
Critical value (5%)		-3.50	-3.50	-3.50	0.15	0.15	0.15
Country	**Variable**			**Test-statistics**			
	KGV	-2.95	-2.09	-6.51	0.22	0.12	0.17
Belgium	KPV	-2.80	-2.22	-6.68	0.23	0.14	0.05
	THW	-0.03	-5.61	-6.80	0.25	0.13	0.24
	GDP	-2.01	-6.76	-7.04	0.22	0.11	0.21
	KGV	-4.43	-2.29	-4.87	0.26	0.16	0.13
Germany	KPV	-1.45	-4.03	-6.46	0.23	0.13	0.16
	THW	-0.46	-6.06	-6.41	0.25	0.13	0.50
	GDP	-1.73	-6.71	-8.59	0.24	0.20	0.16
	KGV	-3.92	0.25	-4.82	0.23	0.23	0.12
Denmark	KPV	-1.26	-3.13	-6.03	0.24	0.08	0.05
	THW	-2.32	-5.32	-5.71	0.15	0.09	0.07
	GDP	-1.76	-6.87	-8.56	0.20	0.09	0.38
	KGV	-1.78	-2.69	-7.16	0.22	0.08	0.06
Greece	KPV	-1.72	-1.88	-5.79	0.23	0.10	0.10
	THW	-1.99	-4.49	-7.97	0.17	0.17	0.15
	GDP	-1.13	-4.95	-8.13	0.19	0.11	0.08
	KGV	-0.81	-2.29	-4.94	0.17	0.06	0.10
Spain	KPV	-1.99	-2.33	-4.06	0.20	0.11	0.11
	THW	-2.43	-2.44	-6.67	0.19	0.09	0.05
	GDP	-1.59	-3.73	-7.96	0.17	0.13	0.10
	KGV	1.19	-5.25	-8.39	0.26	0.14	0.50
Finland	KPV	-1.38	-3.64	-5.24	0.25	0.10	0.06
	THW	-3.00	-3.99	-8.60	0.11	0.07	0.16
	GDP	-1.74	-4.88	-8.05	0.19	0.05	0.50
	KGV	-3.47	-2.64	-5.27	0.25	0.12	0.09
France	KPV	-3.24	-2.09	-5.24	0.24	0.14	0.11
	THW	-0.94	-6.66	-9.98	0.23	0.08	0.01
	GDP	-2.36	-5.20	-7.91	0.24	0.13	0.34
	KGV	-2.21	-2.60	-5.24	0.20	0.14	0.09
Ireland	KPV	-3.06	-2.61	-5.51	0.15	0.07	0.08
	THW	-2.00	-3.81	-8.20	0.21	0.10	0.50
	GDP	-1.98	-3.32	-7.99	0.11	0.12	0.16
	KGV	0.68	-2.65	-11.04	0.26	0.08	0.07
Italy	KPV	-1.86	-3.84	-4.94	0.26	0.16	0.14
	THW	-2.88	-5.21	-8.99	0.19	0.14	0.09
	GDP	-0.63	-6.75	-8.57	0.25	0.09	0.19
	KGV	-5.02	-1.00	-5.38	0.20	0.21	0.13
Nether-	KPV	-1.66	-2.67	-5.65	0.24	0.09	0.06
lands	THW	-1.70	-3.51	-6.91	0.18	0.11	0.50
	GDP	-1.66	-4.66	-7.84	0.16	0.10	0.11
	KGV	-4.60	-1.29	-4.99	0.24	0.16	0.11
Sweden	KPV	-3.01	-2.96	-5.12	0.25	0.15	0.05
	THW	-1.40	-6.47	-8.91	0.19	0.08	0.20
	GDP	-3.12	-5.36	-8.22	0.13	0.17	0.25
	KGV	-3.92	-1.48	-5.39	0.18	0.20	0.08
UK	KPV	-0.26	-2.93	-5.90	0.24	0.07	0.06
	THW	-1.03	-5.39	-6.32	0.24	0.05	0.22
	GDP	-2.30	-4.88	-8.08	0.07	0.13	0.50
	KGV	-2.98	-1.72	-5.43	0.19	0.17	0.07
Australia	KPV	-2.86	-3.20	-6.50	0.16	0.15	0.09
	THW	-3.74	-5.83	-6.48	0.11	0.14	0.24
	GDP	-3.47	-5.19	-4.21	0.13	0.07	0.14
	KGV	-3.29	-1.55	-5.42	0.14	0.20	0.06
Canada	KPV	-1.61	-2.57	-6.13	0.22	0.10	0.06
	THW	-2.42	-5.11	-8.92	0.22	0.10	0.33
	GDP	-2.77	-5.51	-9.54	0.22	0.08	0.50
	KGV	-4.27	-2.56	-5.03	0.24	0.10	0.13
Switzer-	KPV	-3.08	-3.57	-4.99	0.24	0.15	0.04
land	THW	-2.72	-3.64	-7.36	0.17	0.10	0.09
	GDP	-3.22	-4.79	-7.76	0.13	0.13	0.18

Table 4 continued: Unit root testing

		ADF Level	ADF I(1)	ADF I(2)	KPSS Level	KPSS I(1)	KPSS I(2)
Critical value (5%)		-3.50	-3.50	-3.50	0.15	0.15	0.15
Country	**Variable**	**Test-statistics**					
Japan	KGV	-0.62	-3.59	-5.23	0.25	0.12	0.14
	KPV	-0.38	-4.10	-3.64	0.25	0.09	0.10
	THW	-2.03	-5.46	-8.09	0.24	0.07	0.48
	GDP	-2.69	-5.54	-8.71	0.25	0.10	0.03
Norway	KGV	-2.33	-2.65	-6.58	0.22	0.10	0.08
	KPV	-2.41	-2.45	-5.45	0.21	0.14	0.06
	THW	-1.68	-4.74	-8.43	0.21	0.04	0.31
	GDP	-0.11	-4.46	-6.16	0.23	0.05	0.28
New Zealand	KGV	-2.65	-1.67	-6.36	0.19	0.17	0.07
	KPV	-2.86	-3.16	-5.76	0.18	0.14	0.04
	THW	-1.64	-4.90	-5.18	0.11	0.07	0.03
	GDP	-2.36	-6.29	-5.19	0.12	0.06	0.03
USA	KGV	-2.40	-3.01	-3.54	0.08	0.13	0.11
	KPV	-0.66	-3.88	-5.97	0.23	0.08	0.14
	THW	-1.49	-5.67	-6.78	0.20	0.12	0.18
	GDP	-2.34	-5.63	-6.36	0.16	0.08	0.50

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