PUBLIC CAPITAL IN THE 21ST CENTURY: AS PRODUCTIVE AS EVER?

Jasper De Jong,[*] Marien Ferdinandusse[**] and Josip Funda[***]

The global financial crisis and the euro area sovereign debt crisis that followed induced a rapid deterioration in the fiscal positions of many European countries. In the ensuing fiscal adjustment process, public investments were severely reduced. 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 insights on differences between countries and on international spill-overs. To this end, 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 stocks on economic growth has not increased in general, leaving little ground to conclude the current low level of public investments forms an immediate threat to potential output.

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 had a large share, in particular in countries under market pressure. General government gross fixed capital formation as percent of GDP in the EU28 was in 2013 almost 25 per cent below its peak level in 2009, with the decline in for example Spain amounting to more than 60 per cent.

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. Moreover, financial market pressure or European fiscal rules urged countries to deliver budget balance improvements in the short run. In doing so, planned investment projects may 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., 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.

Despite the presumable positive effect of public capital on economic potential, 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 spend 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

* De Nederlandsche Bank.

** European Central Bank.

*** Hrvatska Narodna Banka.

The views expressed in this paper are those of the authors and not necessarily the views of the European Central Bank (ECB). This paper was written while Jasper de Jong and Josip Funda were seconded to ECB. We thank Jakob de Haan, Cristophe Kamps, Vaclav Zdarek and national representatives in the Working Group on Public Finance (WGPF) for valuable comments and suggestions. We are furthermore grateful to members of the WGPF for providing us with national data on public capital stocks.

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 beginning 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 (2004), applying a common methodology. This provides us with data for the years 1960-2013. Secondly, we estimate recursive VAR-models – starting from the period 1960-1995, 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 notable economic growth. Lastly, by comparing the impulse responses from a VAR 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 public capital 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 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 this paper, when we use the term "public investment", this refers to general government gross fixed capital formation. However relevant, this does not include investment spending by public, but non-government organisations; expenditures on regular maintainance; or current expenditures which might actually have some characteristics of an investment, e.g., current spending on education.

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 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.

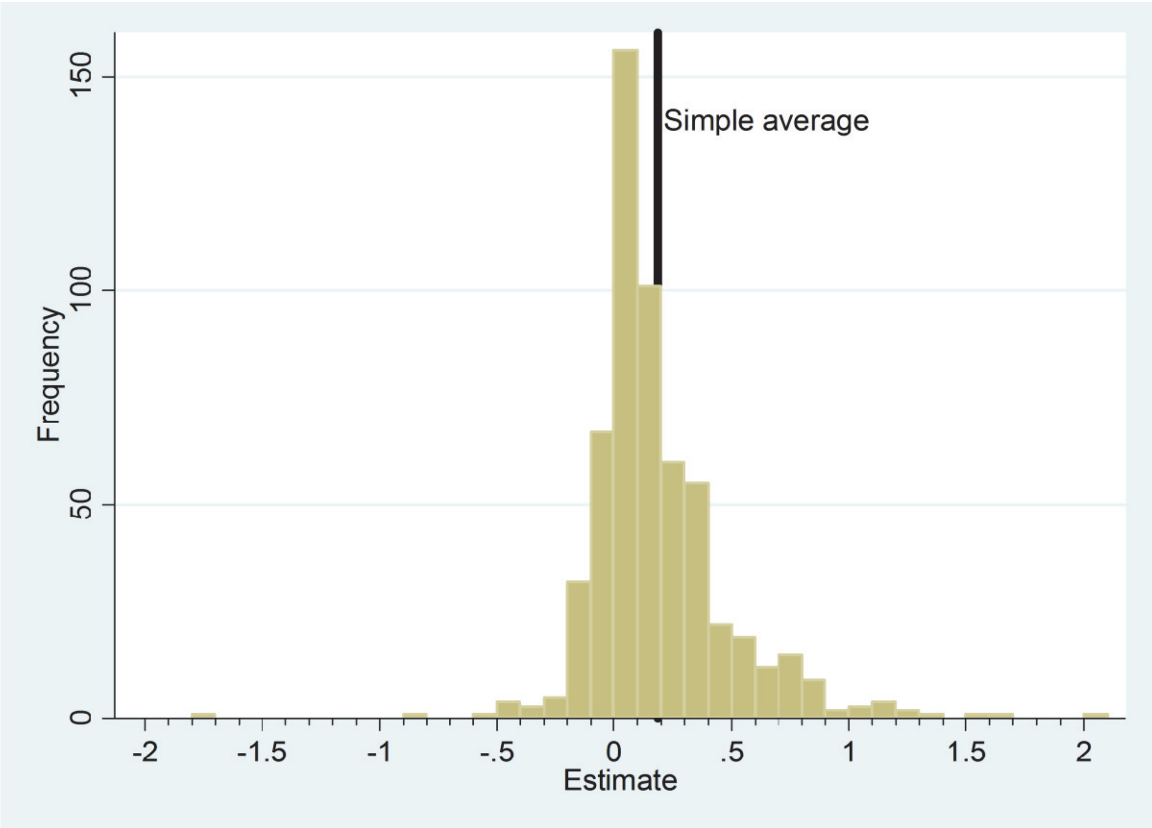
2.1 Partial equilibrium effects

There is a substantial, largely empirical literature aiming to quantify the economic importance of public capital (see Pereira and Andraz (2013), EC (2014) and Romp and de Haan (2007) for extensive reviews of the empirical literature on public capital and growth).

One major branch 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

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.

stock, and of core infrastructure in particular. The so-called production function approach, describing the technical relationship between production factors and output, was applied by many empiricists since (e.g., Kamps, 2006; Cadot *et al.*, 2006; Creel and Poilon, 2008).

Bom and Ligthart (2014b) summarize the empirical literature on production function estimates by carrying out 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 for New Zealand (Kamps, 2006) to 2.04 for Australia (Otto and Voss, 1994), 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. Core infrastructure (roads, railways, telecommunications, etc.) seems to be relatively more important compared to other investments in physical capital (see also Figure 2, lhs).

[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.

2.2 *General equilibrium effects*

The production and cost function approaches provide useful information on the macroeconomic production process and firm behaviour, but only highlight 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 consumptive 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 estimation of VAR-models and the use of calibrated general equilibrium models.

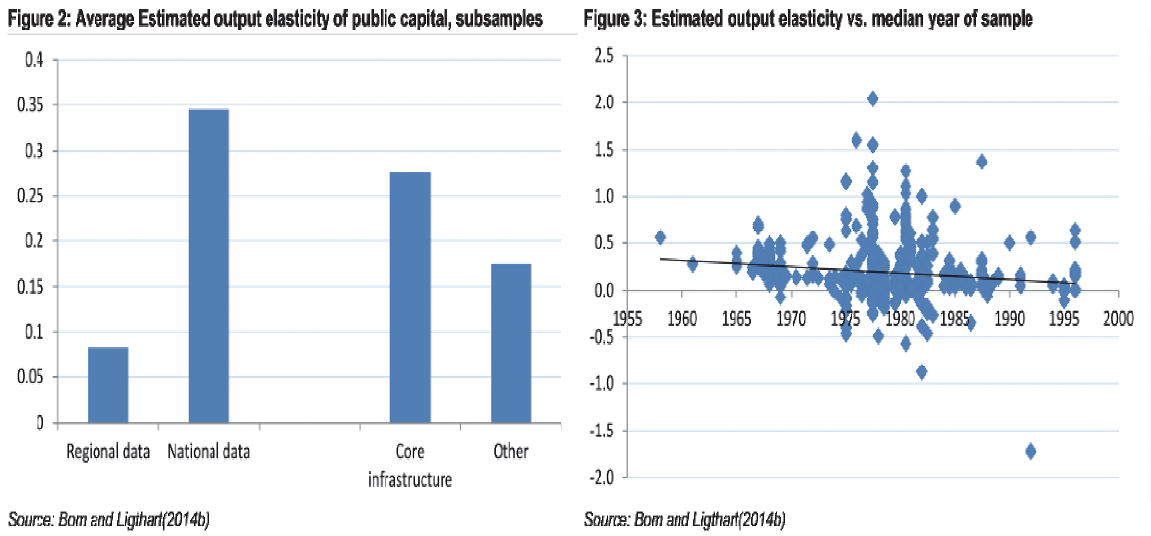
Calibrated or estimated macro-models provide the economist with a clear economic story, but at the cost of imposing restrictions on the data. A common way for incorporating public capital into a model is as a third production factor in a Cobb-Douglas production function, with constant or increasing returns to scale on private production factors (Leeper *et al.*, 2010; Bom and Ligthart, 2014a; Baxter and King, 1993). 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) that implementation delays in investment result in muted positive or potentially even negative responses in output and labour in the short run, but show that accommodative monetary policy can overturn the short run contractionary effects from an increase in public investments.

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 paragraph 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 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. Thirdly, 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, 2004). 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 the number of regressors should be kept relatively small.

Kamps (2004) 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 (2004) 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.

Figure 2

Output Elasticities: Sub-samples and Variation Over Time



Results found in the empirical VAR-literature remain mixed though. Jong-a Pin and de Haan (2008) extend the analysis by Kamps (2004), only partially confirming his findings. Using hours worked as a measure for labour input 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. 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?

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 spill-overs 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 spill-overs. Given the network characteristics of for example road and telecommunications infrastructure, positive spill-overs 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 spill-overs. Amongst many others, studies find evidence for spill-overs 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 spill-overs 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 spill-overs (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. Total hours worked per annum are taken from the Total Economy Database.[3] We have data for 1960 and later years.

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 (2004) and references therein.

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

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

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.

[3] The Conference Board Total Economy Database™, January 2014, http://www.conference-board.org/data/economydatabase/

There is no official information on the magnitude of the initial capital stock for any country except the United States. Therefore, following Kamps (2004) (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 time-varying. In fact, they increase over time. This reflects findings from a detailed analysis by the U.S. Bureau of Economic Analysis (BEA, 2001). 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 (2004), depreciation rates develop as follows:

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

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

Regarding private capital stock, we assume constant depreciation of rate 1.5 per cent for residential capital and time-varying depreciation rate going from 4.25 per cent in 1960 to 11 per cent in 2013 for non-residential capital stock. 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. The government capital stock data are constructed by applying a perpetual inventory method, described above.[4]

Two observations stand out. First, despite still considerable cross-country differences, capital stocks seem to have converged in size internationally. In 2013, all countries shown had estimated public capital stocks between 25 and 60 per cent GDP. Japan is a notable exception with the public capital stock of 80 per cent of GDP. There is no apparent relation between the size of the public capital and GDP per capita.

Secondly, in a number of countries public capital stocks have declined (as percent 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 was estimated for Denmark, Ireland, UK and New Zealand, in all cases above 20 per cent. US, Sweden and Netherlands all recorded a drop of more than 10 per cent.

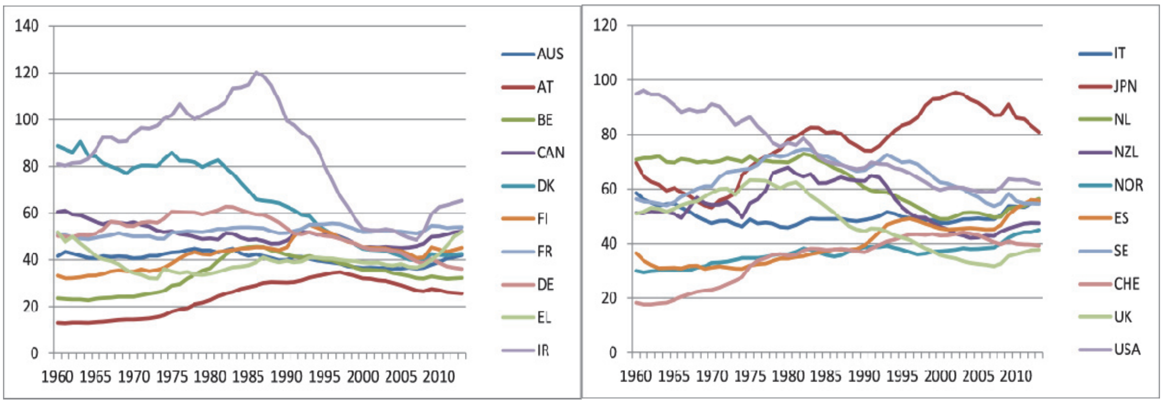
Such developments are reflecting a lower public investment rates than in the past. General government gross fixed capital formation as a percent of GDP has declined substantially over the recent period in some countries (Figure 4). The largest reductions in public investment ratios took place in countries with high initial public investment ratios, such as Japan and Ireland as well as in countries that came under market pressure (e.g., Spain, Greece, 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

[4] As the ESA2010 data on government investment are available only from 1995 or later, for this purpose ESA95 data with a reference year 2005 were used. In this way we also avoid including the military equipment in the investment which are assumed not to be important for the production process.

Figure 3

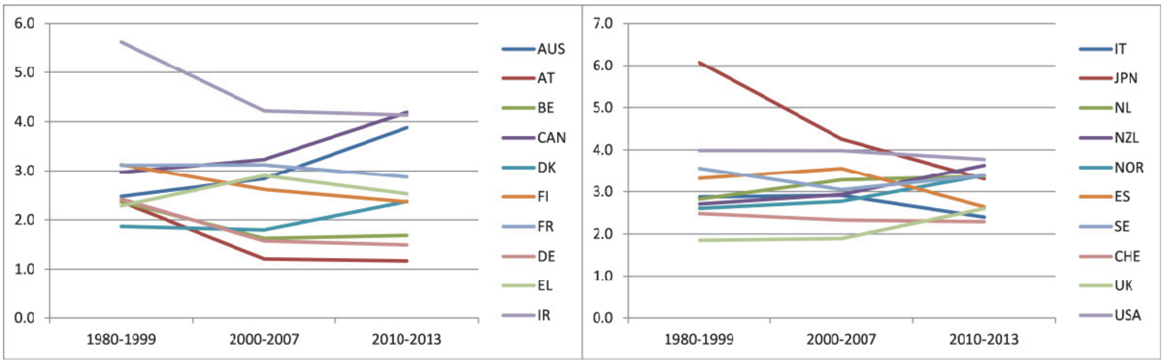
Public Capital Stock, 1960-2013
(percent of GDP, volume data)



Source: authors' calculations.

Figure 4

General Government Gross Fixed Capital Formation
(percent of GDP)



Source: OECD.

GDP, a road constructed in 1960 will be valued less today than a road constructed in 2000, even if maintenance spending actually prevented depreciation. In any case, it should be clear that these public capital stock measures are necessarily only proxies for the true public capital stock.

For an overview of the resulting public and private capital stocks, see Figures 9-15.

3.2 Statistical properties of the series:

First, we check for the order of integration of individual series. Out of many available testing procedures, we apply two of the most commonly used tests: the ADF-test and the KPSS-test. 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 1.

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 mixed results. In many cases, the ADF and KPSS-tests point in different directions, with capital stocks supposedly integrated of either order one or of 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 (2004) 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 9 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 (results not shown).[5] Still, the evidence remains inconclusive.

Since allowing for structural breaks does not change 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

Both the production function and the cost function approach impose quite strong restrictions on the data, by assuming a 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 income the demand for adequate infrastructure rises.

VAR-models form an attractive alternative to structural models. 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. Thirdly, 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, 2004). For these reasons, we estimate country-specific VAR-models.

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

4.1 Econometric approach

A k-th order VAR can be written as:

$$X_t = A_1X_{t-1} + ... + A_k X_{t-k} + \theta D_t + E_t \quad (4)$$

D_t captures any deterministic elements. Since our sample size is limited, we aim to estimate parsimonious models and keep the number of deterministic elements as low as possible.

A cointegration model can be written as:

$$\Delta X_t = \Pi X_t + \Phi_1 \Delta X_{t-1} + ... + \Phi_k \Delta X_{t-k} + \theta D_t + E_t \quad (5)$$

Since we are mainly interested is on the long run effects of public capital, we estimate an unrestricted VAR in levels as a first step. As Sims *et al.* (1990) show, 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. Our aim is to estimate a model as parsimonious as possible while preserving proper diagnostics, *i.e.* with normally distributed, homoskedastic residuals which are not serially correlated. 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).

As we are primarily interested in the IRFs, a second step is needed beyond estimating VARs in levels. To this end, we continue from the benchmark empirical model provided in the first step and investigate whether series are cointegrated. If there is cointegration, we revert to VECM estimation, further improving our model along the lines sketched above. If series are not cointegrated, we estimate a VAR in first differences. We thus end up with either a VECM, or a VAR in first differences for each country.

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 cointegration relation among variables is confirmed for all countries, we estimate VEC-models. In principle 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 (see also Figures 9-15) to account for specific events. 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 and the 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, 2004). 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

Table 1

Selected Models

Country	Sample period	Model type	# Lags	# Cointegr. Rel.	Johansen model type	Deterministic terms	Test-statistics Trace	Test-statistics Max. Eigenval	Diagnostics J-Bera	Diagnostics 1st order ac
AUS	1962-2013	VECM	1	2	4	-	2	2	8.53	8.54
AT	1963-2013	VECM	2	2	4	dummy 75-13, dummy 98-13	2	3	5.00	20.78
BE	1962-2013	VECM	1	1	4	dummy 66, dummy 1972	1	1	10.24	12.33
CAN	1962-2013	VECM	2	2	3	dummy 82	2	2	7.44	25.47*
DK	1962-2013	VECM	1	1	3	dummy 90, dummy 81-13, dummy 2009-13	1	1	30.55***	8.38
FI	1964-2013	VECM	3	1	3	dummy 90-93, dummy 09, dummy 93-13	1	1	6.86	13.38
FR	1962-2013	VECM	1	2	4	dummy 73, dummy 75, dummy 84-13	2	1	4.18	19.80
DE	1963-2013	VECM	2	2	4	dummy 90-13, dummy 09-13	2	2	17.67	7.59
EL	1962-2013	VECM	1	2	4	dummy 74-13, dummy 09-13	2	2	3.69	22.79
IR	1965-2013	VECM	1	1	4	dummy 94-13, dummy 08-13	1	1	13.58*	25.93*
IT	1963-2013	VECM	2	1	4	dummy 68, dummy 69, dummy 09	1	1	4.18	20.52
JPN	1963-2013	VECM	2	1	5	dummy 91-13, dummy 09	1	1	12.84	16.12
NL	1962-2013	VECM	1	1	4	dummy 09	1	0	4.43	7.61
NZL	1963-2013	VECM	2	1	4	-	2	0	5.40	15.81
NOR	1962-2013	VECM	1	2	4	dummy 09-13	2	0	7.23	19.99
ES	1964-2013	VECM	3	2	3	dummy 09	2	2	4.97	22.36
SE	1962-2013	VECM	1	2	4	dummy 91-93, dummy 09	2	3	8.27	23.33
CHE	1962-2013	VECM	1	1	4	dummy 75	1	0	13.00	17.50
UK	1962-2013	VECM	2	1	4	dummy 73, dummy 09-13	1	1	12.81	24.55*
USA	1962-2013	VECM	1	1	3	-	1	1	14.32*	17.18

*Johansen model types refer to: 3 = model with intercept in cointegration relation and in VAR; 4 = intercept and trend in cointegration relation, intercept in VAR. Dummies with a single number are equal to 1 in the year mentioned, 0 otherwise. Dummies with two numbers added are 1 from the first year mentioned onwards, 0 before. Columns Trace' and 'Max. Eigenval.' show selected number of cointegration relations from Johansen cointegration tests, either according to the trace statistic or the maximum eigenvalue statistic. The Jarque-Bera statistic tests for normality of residuals, with as null hypothesis that residuals are multivariate normal, 8 degrees of freedom. The serial correlation LM statistic tests for first order autocorrelation, with a null of no autocorrelation. * significant at 10%, ** significant at 5%, *** significant at 1%.*

four-variable framework anyway, we need to resort to formal testing. We apply Johansens cointegration test, Table 1 shows the test results. In about half of the cases, the trace and maximum eigenvalue statistics agree on the number of contegration relations. For countries where both tests return different results, we generally follow the outcomes of the trace test as this test is more robust to nonnormality (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.

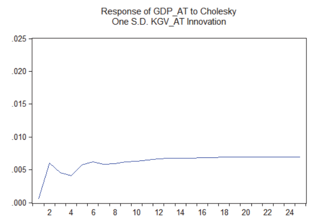
4.2.2 Results

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

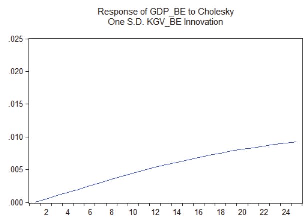
Figure 5

Impulse Responses of GDP to a one s.d. Public Capital Shock, Euro Area

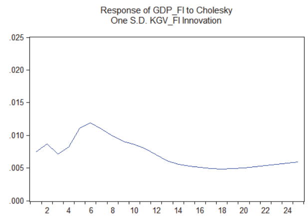
(a) Austria



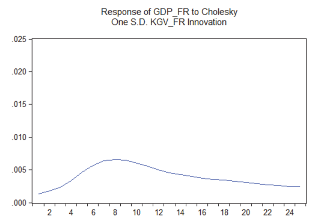
(b) Belgium



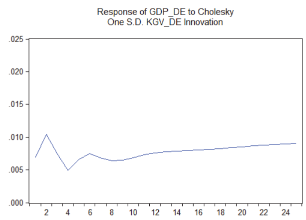
(c) Finland



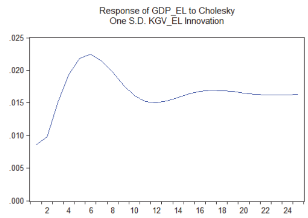
(d) France



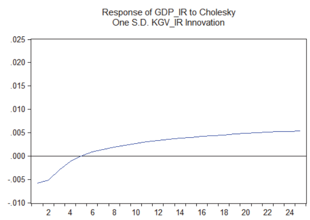
(e) Germany



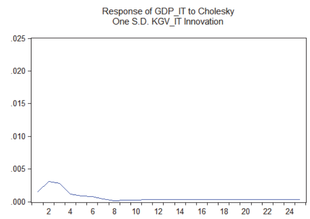
(f) Greece



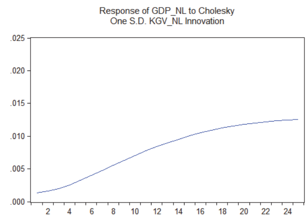
(g) Ireland



(h) Italy



(i) Netherlands



(j) Spain

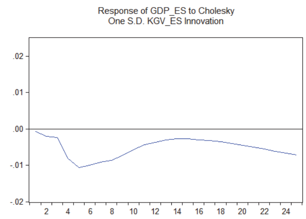
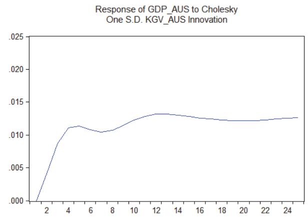


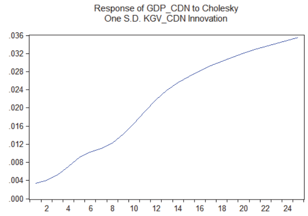
Figure 6

Impulse Responses of GDP to a one s.d. Public Capital Shock, Non-Euro Area

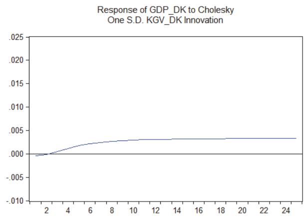
(a) Australia



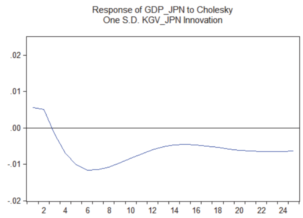
(b) Canada



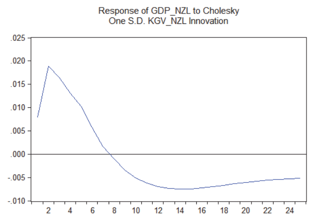
(c) Denmark



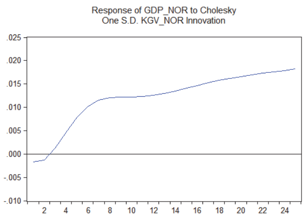
(d) Japan



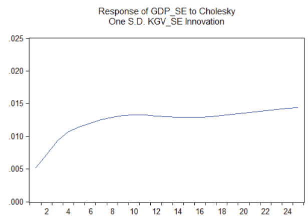
(e) New Zealand



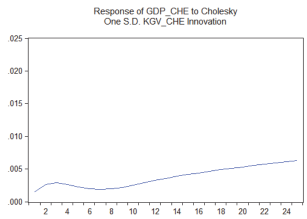
(f) Norway



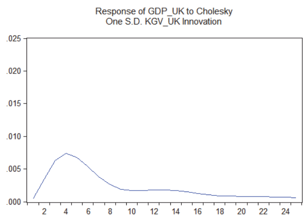
(g) Sweden



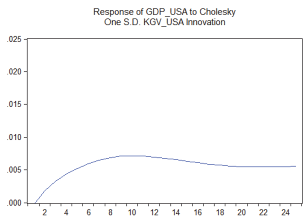
(h) Switzerland



(i) United Kingdom



(j) United States



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.[6]

Overall, similar to Kamps (2004), 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. A notable exception is Spain where, similar to Jong-a Pin and de Haan (2008), the effect is found to be negative for all periods while for Japan and New Zealand the initial positive impact is followed by negative effects. The results for Japan might be seen as expected since Japan has by far the highest level of public capital among the countries in the sample so after initial positive demand effect this additional capital has an adverse impact on output. In the case of Ireland (second largest capital stock in the sample) and Norway an initial negative effect turns positive after several periods. 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 other endogenous variables included in the analysis (see Figures 13 and 14), private and public capital are found to be complements (positive response of private capital to a shock in public capital) in Austria, Belgium, Greece, Finland, France, Netherlands, Norway, New Zealand and Sweden, already in the short run. In the case of Australia, Canada and Germany complementarity holds only in the long run while in the short to medium run public capital shock has a negative effect on the private capital. As Baxter and King (1993) suggest, there are two forces determining the response of the private capital stock to a shock in public capital. 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. One might expect the first one to dominate in the short run while in the long run the second one should dominate, albeit probably only up to a certain level of public capital stock.

The reaction of total hours worked as a measure of the labour input is in most cases negative in the long run suggesting that additional public capital wouldn't be beneficial for employment. While there are several European countries where this effect is positive even in the long run it is always very close to zero and statistically insignificant. Exceptions are Greece, and Canada and New Zealand (in the short and medium run) where the shock to public capital leads to a rather sizable increase in employment. As Kamps (2004) 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 though.

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:

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

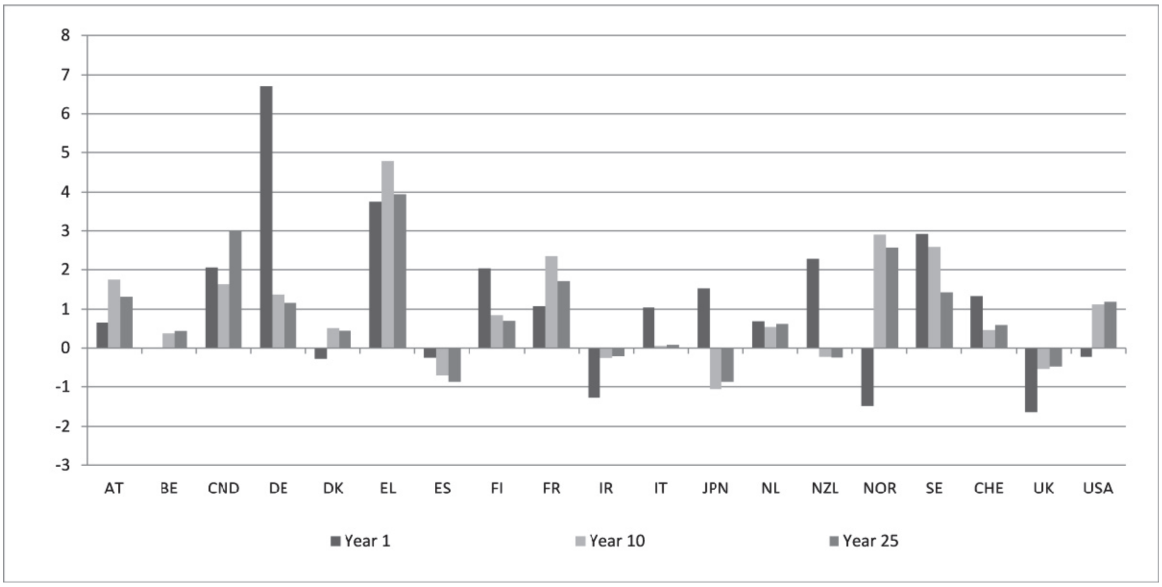
In words, a 1 percent of GDP shock in public capital results in an M_n^{KGV} percent increase in GDP in period *n*.

---

[6] 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.

Figure 7

General Government Capital Multipliers at Different Horizons



Source: Authors' calculations

Figure 7 shows the estimates of the general government capital multipliers for different time horizons.[7] 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. Surprisingly, the medium and long run the public capital multiplier is found to be negative for the UK, Ireland, Japan and Spain. 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.

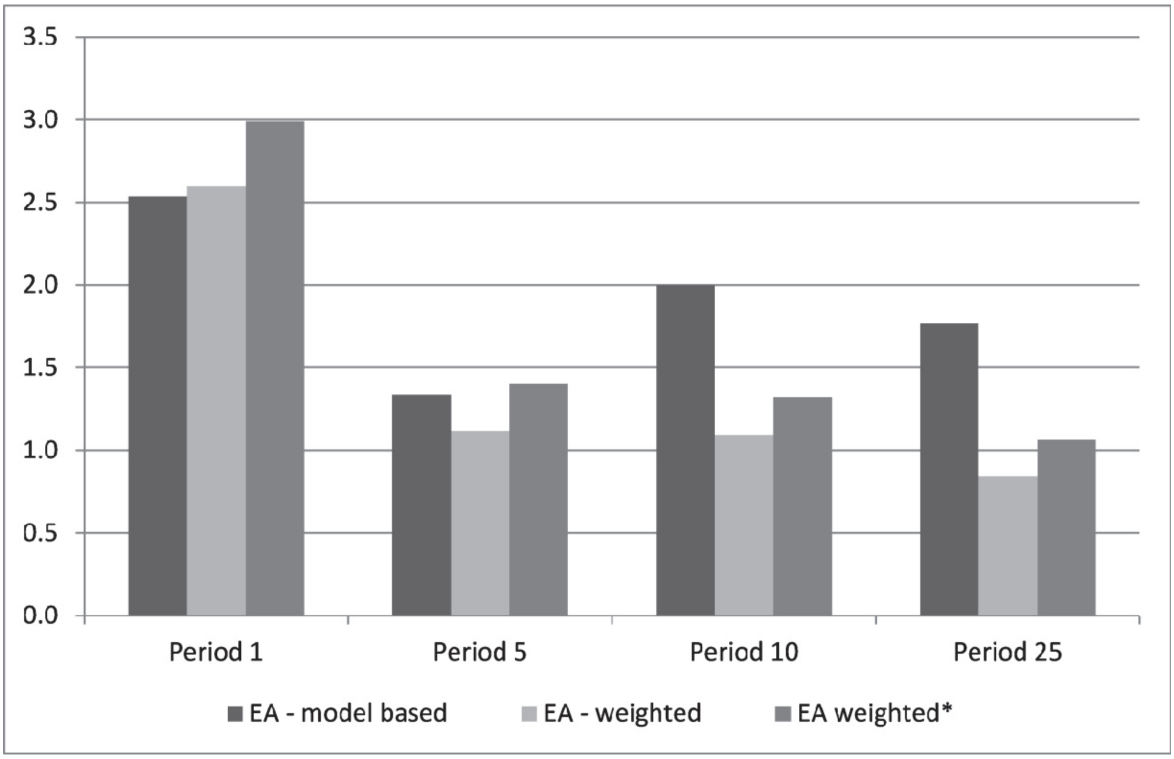
4.2.3 Spillovers

This section investigates further the issue of potential spillover effects across euro area countries included in the sample. Both theoretical and empirical literature has shown that policy actions in one country may have a significant effect on economic outcomes of other countries (Auerbach and Gorodnichenko, 2012). The literature on fiscal spillovers identifies several channels for the transmission of fiscal shocks among countries. For example, the trade channel captures the extent to which increase in public spending (including investment spending) in one country has a positive output effects in other countries either through direct purchase of foreign products by the government (usually found to be small) or/and by stimulating the domestic economy which in turn increases imports from other countries (Giuliodori and Beetsma, 2004). The latter cause is found to be more important, but depends on the size of domestic multipliers and trade linkages among countries. The interest rate channel and the exchange rate channel are also potentially relevant. However, in a monetary union a fiscal stimulus in one country should not, in theory, affect the

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

Figure 8

Fiscal Multipliers at Different Horizons Compared



Note: Euro area* includes only countries where a positive multiplier was found in the country model Source: Authors' calculation.

short-term interest rate at the union level. Yet, if the country engaging in expansionary fiscal policy is sufficiently large, upward pressure on area-wide inflation might appear, leading to a monetary policy tightening with adverse effects on other countries in the union (Hebous and Zimmermann, 2013). Increases in the short-term interest rate may also result in upward pressure on long-term interest rates, thereby crowding out private investment. Finally, in the context of public investment, the long-term effects on output might be larger than just the country which undertakes the investment, e.g., in the case of cross country infrastructure networks. Accordingly, studies that focus on small(er) geographical areas might not be able to capture the full pay-off of public investment.

We address the issue of spillovers among countries in our sample that share a common currency (euro area)[8] in two ways.

First, we calculate a weighted multiplier for the euro area where shares in the aggregate output are used as weights (see Figure 8). These individual country multipliers ignore spillovers to other countries. We compare this weighted multiplier to a multiplier calculated from a model estimated for the euro area leve as a whole. This euro area aggregate model should in principle incorporates positive spillovers. The impact multiplier (period 1) is similar for all estimates which is in line with the literature conclusions that direct purchases of foreign products by the domestic government are usually insignificant and their effects on foreign outputs are negligible. After three

8 Our sample includes Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands and Spain. These countries account for more than 95 per cent of the overall euro area output.

Table 2

Long-run GDP Response to a Shock in Public Capital

	'60-'00	'60-'01	'60-'02	'60-'03	'60-'04	'60-'05	'60-'06	'60-'07	'60-'08	'60-'09	'60-'10	'60-'11	'60-'12	'60-'13
Austria	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
Belgium	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
Finland	-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
France	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
Germany	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
Greece	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
Ireland	-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
Italy	-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
Netherlands	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
Spain	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
Australia	2.2	1.9	1.9	1.9	2.0	2.0	2.0	1.9	1.9	2.3	2.1	2.5	1.5	1.3
Canada	3.0	4.2	4.1	4.8	4.9	4.6	4.7	4.7	4.4	4.4	3.7	3.7	5.1	5.7
Denmark	1.0	1.1	1.1	1.3	1.3	1.2	1.2	0.7	0.6	0.6	0.7	0.5	0.4	0.3
Japan	-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
New Zealand	-0.2	-0.4	-0.3	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.5	-0.5	-0.6	-0.5
Norway	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
Sweden	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
Switzerland	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
United Kingdom	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
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

Numbers denote the long-run (period 100) response of GDP to a Cholesky one standard deviation innovation in public capital.

years a positive differential appears which further increases in the long run. This could point to the existence of positive spillovers within the euro area. These results should however be interpreted with caution – and for more precise estimates of the size of the spillover effects more detailed modeling of trade-linkages would be necessary.

Recently, calls have emerged for Germany to increase its public spending, claiming this would have a beneficial effects also for the other countries in the euro area. Germany is the largest economy in the euro area and arguably has the fiscal space to increase spending. Therefore, we additionally re-estimate the model for Germany, but now also include GDP of one other European country at the time. This allows us to test whether a public capital shock in Germany exerts a positive effect on the output of the other country. Figure 15 gives impulse response functions. Positive effects of a shock in German public capital were found for Italy and (marginally) for Spain. Surprisingly, no significant effect was found for Germany's neighbouring countries France, Austria or Netherlands, despite significant trade linkages. These results suggest that international spill-overs from an increase in German investment spending would be rather limited.

4.3 Recursive VARs

We are interested in the development of the relationship between public capital and economic growth over time. To this end, we estimate models starting from the sample 1960-2000 up to 1960-2013, each time adding one year to the estimation period. 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 is as depicted in Table 1.

Table 3

Long-run Multiplier, Different Subsamples

	'60-'00	'60-'01	'60-'02	'60-'03	'60-'04	'60-'05	'60-'06	'60-'07	'60-'08	'60-'09	'60-'10	'60-'11	'60-'12	'60-'13
Austria	-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
Belgium	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
Finland	-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
France	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
Germany	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
Greece	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
Ireland	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
Italy	-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
Netherlands	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
Spain	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
Australia	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.1	1.0	0.9	0.9
Canada	1.6	1.7	1.9	2.0	2.2	2.4	2.9	3.3	3.2	3.2	3.1	3.1	3.3	3.4
Denmark	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.6	0.6	0.6	0.6	0.5	0.4
Japan	-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
New Zealand	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.3	-0.3	-0.3	-0.2
Norway	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
Sweden	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
Switzerland	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
United Kingdom	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
USA	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.5	1.3	1.3	1.2	1.2	1.2

Numbers denote the long-run (period 100) public capital multiplier as defined in equation 6.

From Table 2 a rather diffuse picture emerges. The long-run GDP response (here we simply take the value from period t=100) to a one standard deviation innovation in public capital increases over time in a number of, mainly euro area, countries. To take into account the fact that public capital itself also responds to a shock in public capital, Table 3 also shows the "public capital multiplier" as defined in equation 6 above. Our conclusions do not change much. Experiences differ by country, there is no general tendency for public capital to become more, or less, productive over time.

5 Concluding remarks

The recent cuts in public investment in many advanced economies as part of the budgetary corrections following the financial crisis have raised the question if there is public underinvestment, which through its effect on the public capital stock will harm long-term growth prospects. The public capital-to-GDP ratio has been on a long-term downward trend in many countries, for which various explanations have been offered in the literature. The first relates the evolution of the public capital stock to changing economic needs, such as less importance of physical capital in more service oriented economies and saturation effects once infrastructure networks have been built. The second puts more emphasis on political considerations during consolidation episodes, with public investment considered to be among the easier to cut public expenditures.

This paper examines whether the relationship between public capital and output has changed on the basis VAR/VECM estimates of an expanded data series of public capital stocks for 20

OECD economies for the years 1960-2013. We find that public capital seems to be productive for most of the countries in our sample, but that these results are heterogeneous across countries, as in earlier studies. We also find a small negative correlation between the effect of public capital on output and the level of public output in the long run. However, we do not find that the effect is much larger than in previous studies.

We also estimate recursive VAR-models – starting from the period 1960-2000, then expanding the sample period by one year at the time – to see if the relationship between public capital and economic growth has changed in recent years. We do not find systematic evidence that this has been the case. Our results do not suggest that there is general lack of public investment or that its marginal use has increased in recent years. Of course, the need for public investment should be considered carefully on case-by-case basis, in which other consideration, such as the expected interest rates relevant for investment decisions, can play an important role.

Finally, we compare the impulse responses from a VAR for the euro area as a whole to the weighted impulse responses of VARs for individual euro area countries and include the GDP growth of other euro area countries in the VAR for Germany as a tentative way to consider the importance of investment spill-overs in Europe. The first approach yields some evidence for the relevance of spill-overs, evidence from the latter is not conclusive.

Figure 9

Log Real Net Government Capital Stocks, 1960-2013

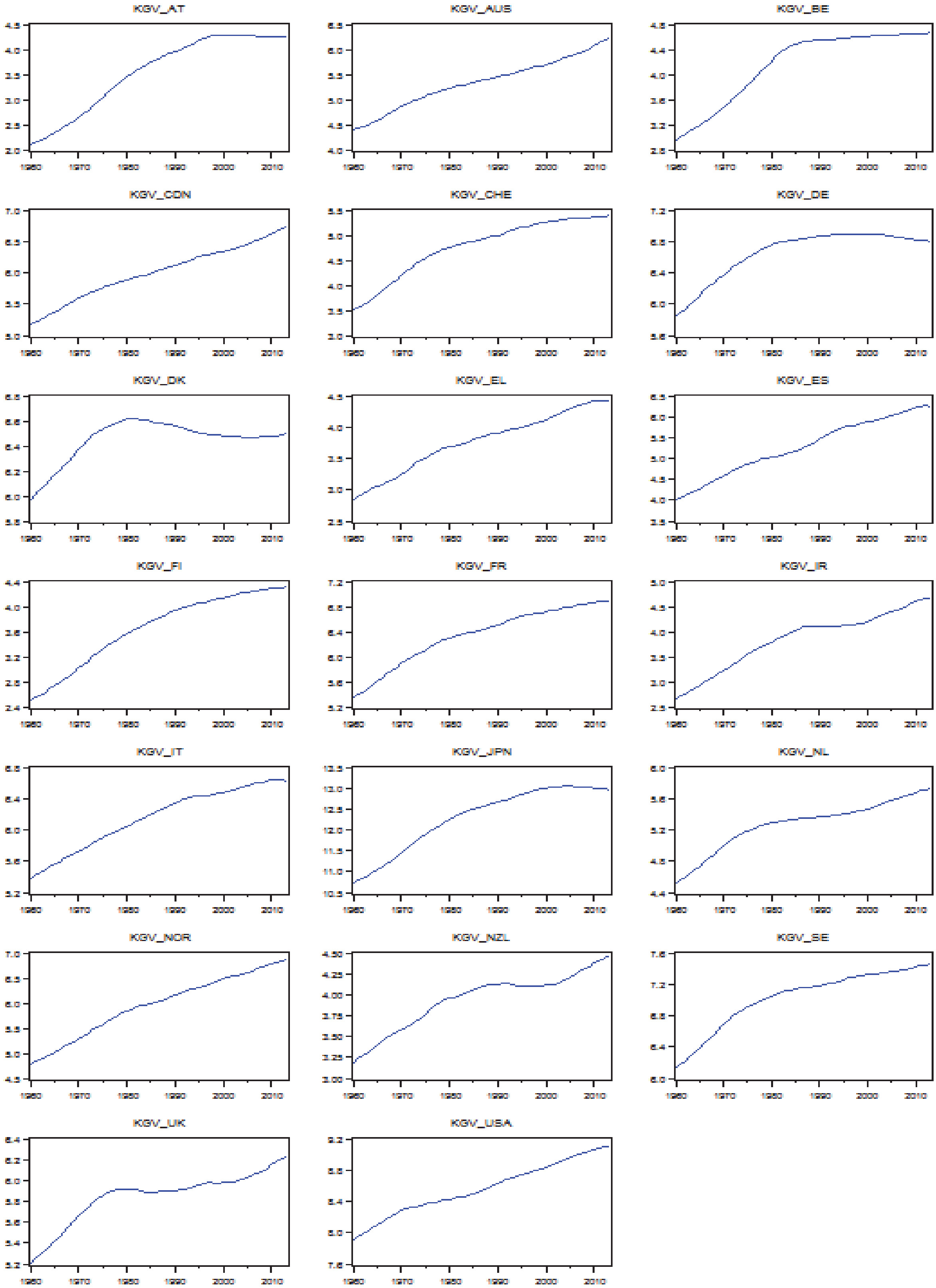


Figure 10

Log Real Net Private Sector Capital Stocks, 1960-2013

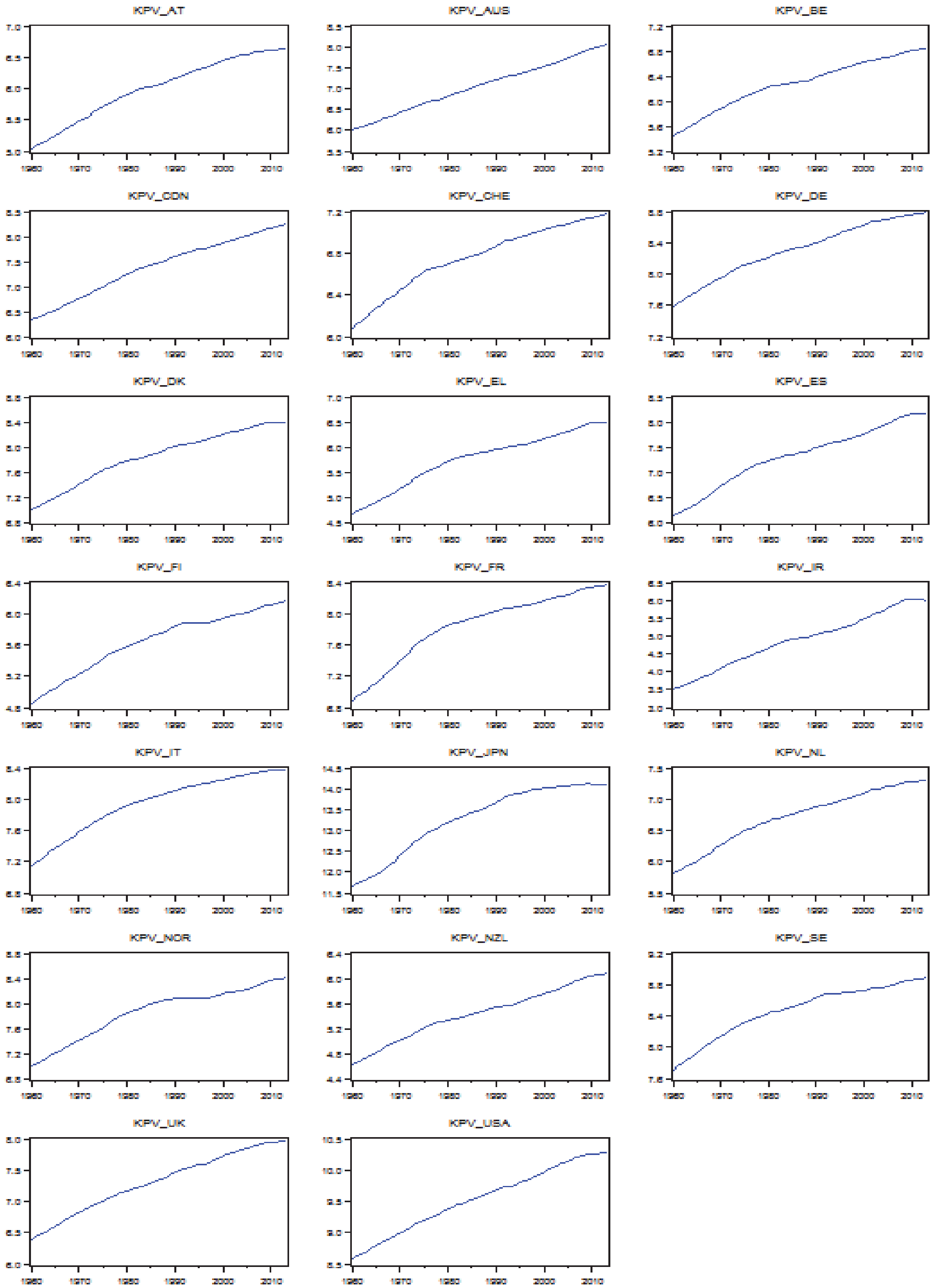


Figure 11

Log Total Hours Worked, 1960-2013

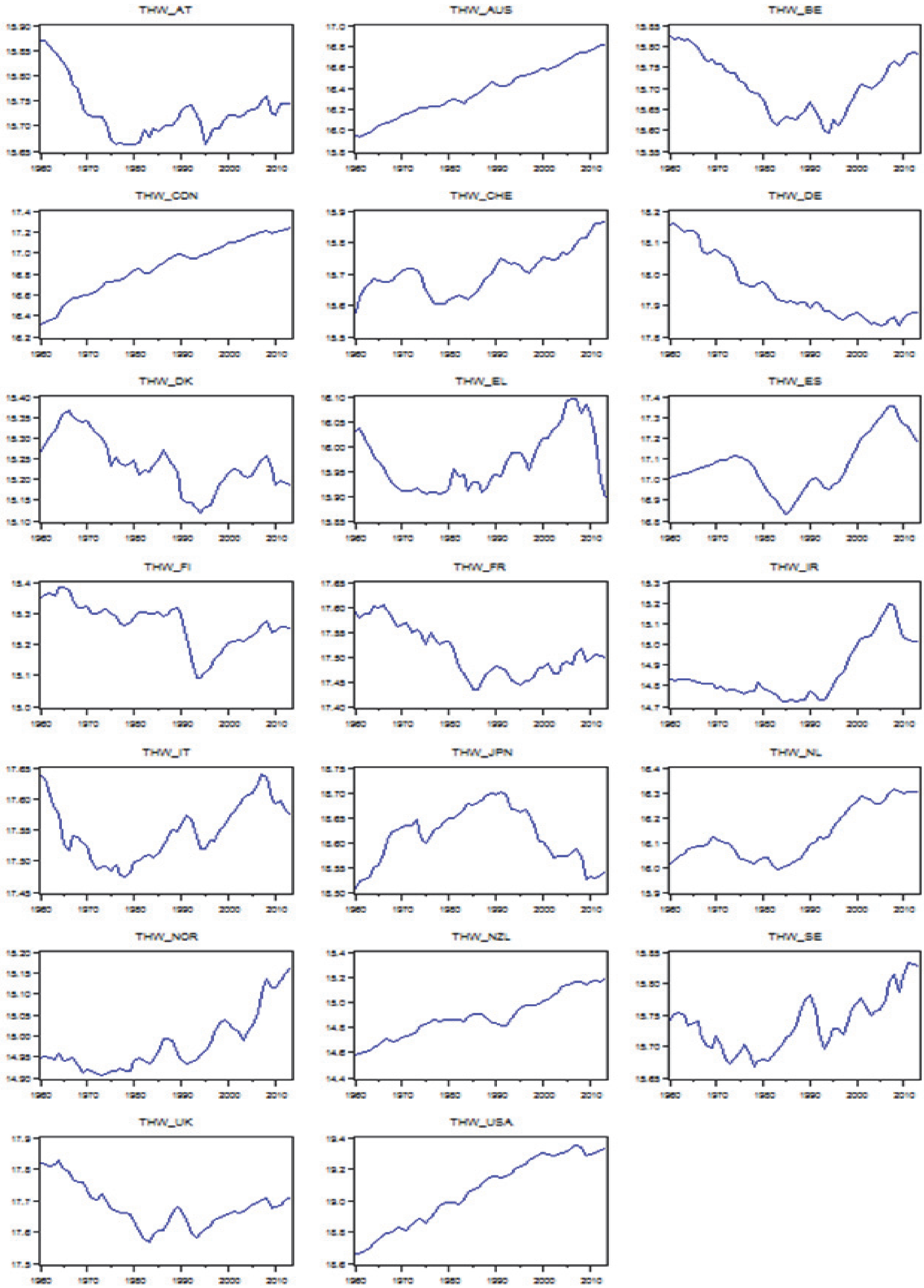


Figure 12

Log Real GDP, 1960-2013

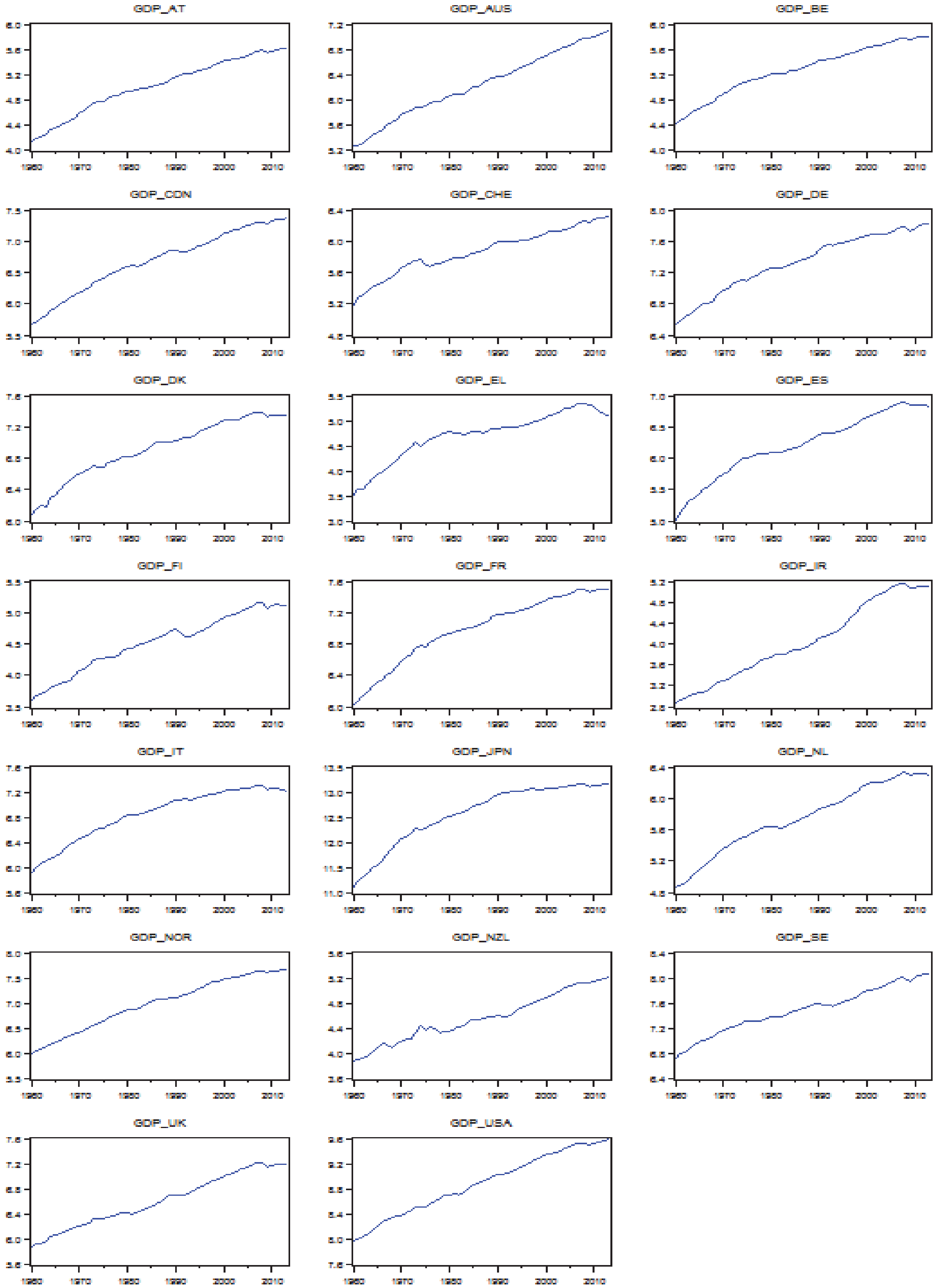
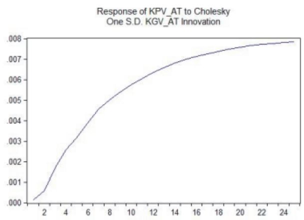


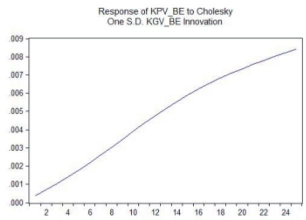
Figure 13

Impulse Responses of the Net Real Private Capital Stock to a one s.d. Public Capital Shock, Euro Area

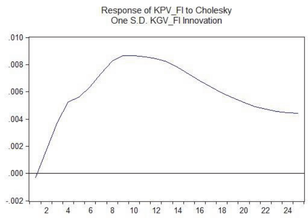
(a) Austria



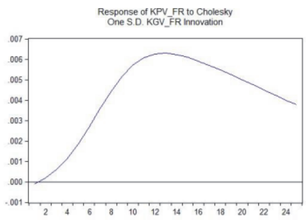
(b) Belgium



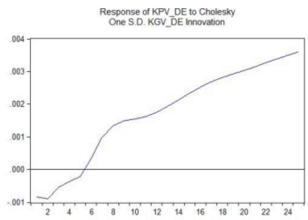
(c) Finland



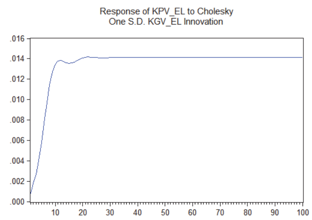
(d) France



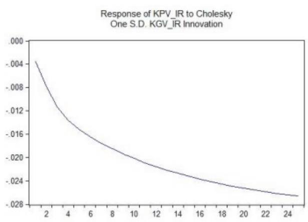
(e) Germany



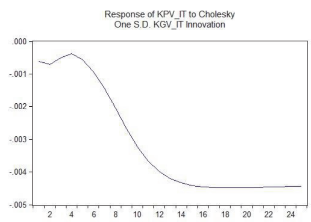
(f) Greece



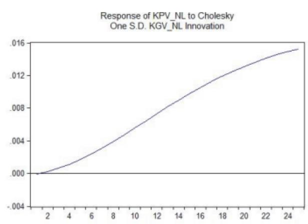
(g) Ireland



(h) Italy



(i) Netherlands



(j) Spain

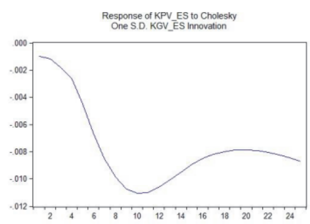
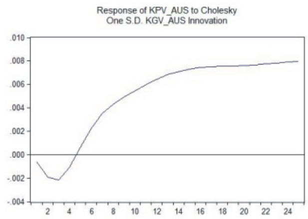


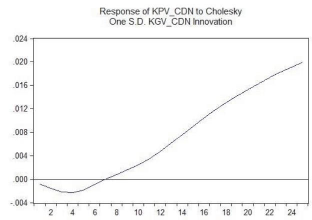
Figure 14

Impulse Responses of the Net Real Private Capital Stock to a one s.d. Public Capital Shock, Non-Euro Area

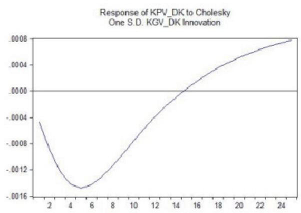
(a) Australia



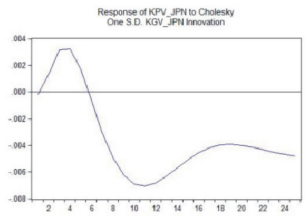
(b) Canada



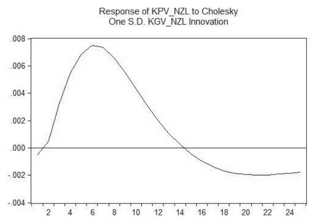
(c) Denmark



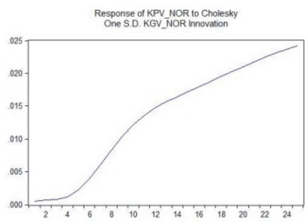
(d) Japan



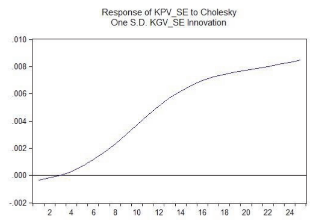
(e) New Zealand



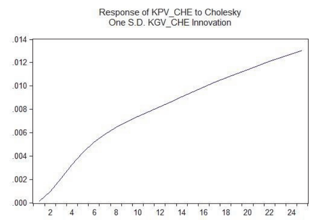
(f) Norway



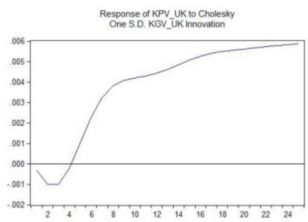
(g) Sweden



(h) Switzerland



(i) United Kingdom



(j) United States

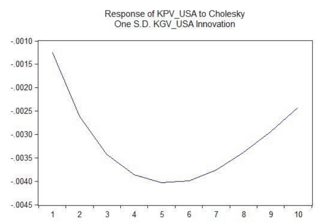
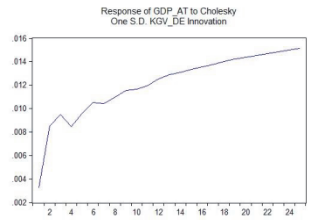


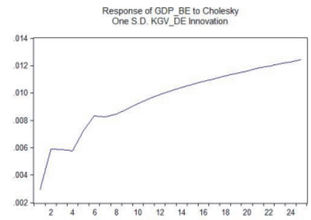
Figure 15

Impulse Responses of Real GDP to a Shock to General Government Capital Stock in Germany

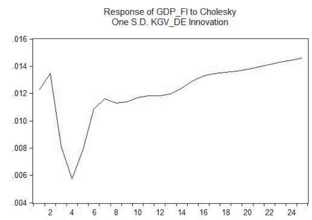
(a) Austria



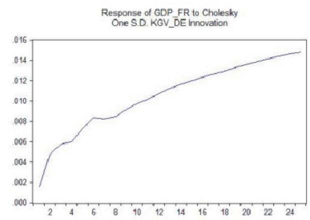
(b) Belgium



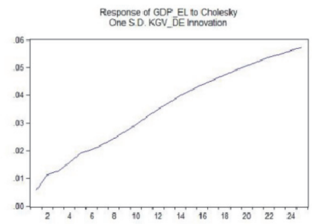
(c) Finland



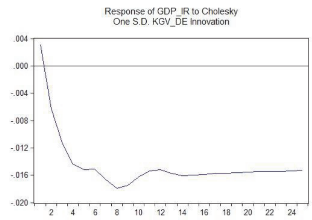
(d) France



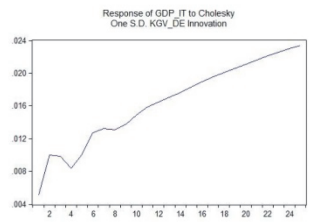
(e) Greece



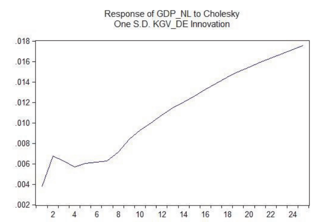
(f) Ireland



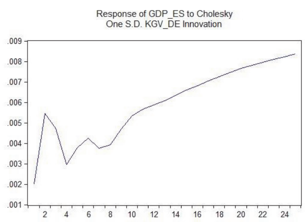
(g) Italy



(h) Netherlands



(i) Spain



REFERENCES

Aschauer, D. (1989), "Is Public Expenditure Productive?", *Journal of Monetary Economics*, Vol. 23, No. 2, pp.177-200.

Auerbach, A. and Y. Gorodnichenko (2012), "Measuring the Output Responses to Fiscal Policy", *American Economic Journal: Economic Policy*, Vol. 4, No. 1, pp. 1-27.

Bank, W. (1994), *Annual Report*, Washington (D.C.).

Baxter, M. and R. King (1993), "Fiscal Policy in General Equilibrium", *American Economic Review*, Vol. 83, No. 3, pp. 315-34.

Bom, P. and J. Ligthart (2014a), "Public Infrastructure Investment, Output Dynamics, and Balanced Budget Fiscal Rules", *Journal of Economic Dynamics and Control*, No. 40, pp. 334-354.

—————(2014b), "What Have We Learned from Three Decades of Research on the Productivity of Public Capital?", *Journal of Economic Surveys*, Vol. 28, No. 5, pp. 889-916.

Broyer, S. and J. Gareis (2013), "How Large is the Infrastructure Multiplier in the Euro Area?", *Flash Economics by Natixis,* No. 227, p. 40.

Cadot, O., L. Roller and A. Stephan (2006), "A Political Economy Model of Infrastructure Allocation: An Empirical Assessment", *Journal of Public Economics*, No. 90, pp. 1133-53.

Cheung, Y. and K. Lai (1993), "Finite-sample Sizes of Johansen's Likelihood Ratio Tests for Cointegration"; *Oxford Bulletin of Economics and Statistics*, Vol. 55, No. 3, pp. 313-28.

Cohen, J. and C.M. Paul (2004), "Public Infrastructure Investment, Interstate Spatial Spillovers, and Manufacturing Costs", *Review of Economics and Statistics*, No. 86.

Creel, J. and G. Poilon (2008), "Is Public Capital Productive in Europe?", *International Review of Applied Economics*, No. 22, pp. 673-91.

De la Fuente, A. (2010), "Infrastructures and Productivity: An Updated Survey", Barcelona Economics, Working Paper, No. 475.

Di Giacinto, V., G. Micucci and P. Montanaro (2013), "Network Effects of Public Transport Infrastructure: Evidence on Italian Regions", *Regional Science*, Vol. 91, No. 3, pp. 515-41.

EC (2014), "Infrastructure in the EU: Developments and Impact on Growth", *European Economy*, Occasional Paper, No. 203.

Elekdag, S. and D. Muir (2014), "Das Public Kapital: How Much Would Higher German Public Investment Help Germany and the Euro Area?", IMF, Working Paper, No. 14/227.

Enders, W. (1995), *Applied Econometric Time Series,* John Wiley & Sons, Ney York (NY).

Everaert, G. (2003), "Balanced Growth and Public Capital: An Empirical Analysis With I(2) Trends in Capital Stock Data", *Economic Modelling*, No. 20, pp. 741-63.

Giuliodori, M. and R. Beetsma (2004), "What Are the Spill-overs from Fiscal Shocks in Europe? An Empirical Analysis", ECB, Working Paper, No. 325.

Hebous, S. and T. Zimmermann (2013), "Cross-border Effects of Fiscal Consolidations: Estimates Based on Narrative Records", CESifo, Working Paper, No. 4311.

IMF (2014), "Is it Time for an Infrastructure Push? The Macroeconomic Effects of Public Investment", *World Economic Outlook*, October.

Jacob, V., S. Sharma and R. Grabowski (1997), "Capital Stock Estimates for Major Sectors and Disaggregated Manufacturing in Selected OECD Countries", *Applied Economics*, Vol. 29, No. 5, pp. 563-79.

Jong-a Pin, R. and J. de Haan (2008), "Time-varying Impact of Public Capital on Output: New Evidence Based on VARs for OECD Countries", EIB Papers, Vol. 13, No. 1, pp. 56-81.

Kalyvitis, S. and E. Vellai (2012), "On the Productivity Effects of Public Capital Maintenance: Evidence for U.S. States", European University Institute, Working Paper, No. 2014/04.

Kamps, C. (2004), "The Dynamic Effects of Public Capital: VAR Evidence for 22 OECD Countries", *International Tax and Public Finance*, Vol. 12, No. 4, pp. 533-58.

————— (2006), "New Estimates of Government Net Capital Stocks for 22 OECD Countries", IMF, Staff Papers, Vol. 53, No. 1, pp. 120-50.

Leeper, E., T. Walker and S.C. Yang (2010), "Government Investment and Fiscal Stimulus", *Journal of Monetary Economics*, No. 57, pp. 1000-12.

Mahadeva, L. and P. Robinson (2004), "Unit Root Testing to Help Model Building", *Handbooks in Central Banking*, No. 20.

Otto, G. and G. Voss (1994), "Public Capital and Private Sector Productivity", *Economic Record*, No. 70, pp.121-32.

Pereira, A. and J. Andraz (2013), "On the Economic Effects of Public Infrastructure Investment: A Survey of the International Evidence", The College of William and Mary, Working Paper, No. 8.

Pereira, A. and O. Roca-Sagalés (2003), "Spillover Effects of Public Capital Formation: Evidence from the Spanish Regions", *Journal of Urban Economics*, Vol. 53, No. 2, pp. 238-56.

Perron, P. (1989), "The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis", *Econometrica*, Vol. 57, No. 6, pp. 1361-401.

Phillips, P. (1998), "Impulse Response and Forecast Error Variance Asymptotics in Nonstationary VARs", *Journal of Econometrics*, Vol. 83, No. 1-2, pp. 21-56.

Roca-Sagalés, O. and H.S. Lorda (2006), "Efectos Desbordamiento de la Inversión en Infraestructuras en las Regiones Españolas", *Investigaciones Regionales*, No. 8, pp. 143-61.

Romp, W. and J. de Haan (2007), "Public Capital and Economic Growth: A Critical Survey", *Perspektiven der Wirtschaftspolitik*, Vol. 8(S1), pp. 6-52.

Sims, C., J. Stock and M. Watson (1990), "Inference in Linear Time Series Models with Some Unit Roots", *Econometrica*, Vol. 58, No. 1, pp. 113-44.