The link between public capital and total factor productivity: A highway, a one-way street, or a blind alley?

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INCOMPLETE AND PRELIMINARY. NOT FOR QUOTATION

Abstract

While the impact of public capital on output has been studied extensively in the empirical literature, its indirect output impact through aggregate productivity has not received much attention. Similarly, the impact of productivity shocks on public capital, articulated in real business cycle models, has not been assessed empirically. To fill these gaps, we estimate the relationships between public capital and aggregate productivity using data from four large European countries. We find only weak evidence that productivity shocks drive public investment to adjust the public capital stock, and we find no evidence that public capital exert significant impact on aggregate productivity. These results cast doubt on the role of public investment in contributing to optimal adjustment following productivity shocks.

Keywords: Public capital, total factor productivity, VAR analysis.

JEL codes: H54, H11, O40, O52

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1 Introduction

Most empirical research on the macroeconomic impact of public capital has focussed on how it affects aggregate output (see Romp and de Haan (2005), and Jong-A-Pin and de Haan (2008), for comprehensive surveys). These studies have estimated the (average) output effect of public capital either through an aggregate production function or by specifying a vector autoregressive (VAR) model with GDP, a labour input variable, private capital and public capital.[1]

As explained by Romp and de Haan (2005), the theoretical underpinnings of the production function approach allow public capital to affect output both directly and indirectly through total factor productivity (TFP). Thus, public capital has been customarily considered either as another production factor or as a determinant of TFP. Either way, Sturm, Kuper and de Haan (1998) suggest that as long as a Cobb-Douglas –type of aggregate production function is estimated in log levels, one cannot disentangle the direct and indirect effects of public capital, as the empirical specification is similar in both cases.

Such "disentangling" of the direct and indirect output effects of public capital has, to the best of our knowledge, not been attempted to date; consequently, it remains unclear whether and how public capital affects TFP.

Perhaps even more surprising is the paucity of empirical work on the reverse link, that is, from TFP to public capital. It is surprising that researchers have not tackled that relationship because standard real business cycle models readily portray public capital as endogenously responding to TFP shocks.

This paper seeks to fill both gaps. The emphasis is on the link from TFP to public capital, as we first articulate a model specifying how exactly TFP shocks translate to public investment flows and changes in the public capital stock (section 2). This model helps us specify a VAR model to be estimated subsequently (section 3). However, as a by-product of that estimation we can also consider the reverse relationship (from public

[1] A small number of studies have also estimated the impact of public capital on private sector cost functions (Romp and de Haan (2005)).

investment and public capital to TFP).

Whether the causality runs from TFP to public capital or vice versa has profound implications for the economic role of public investment. If it is indeed the case that TFP shocks drive public investment to adjust the public capital stock to its new post-TFP shock optimal level, public investment should not really be regarded as a free policy tool; rather, it assumes a much more passive role as an endogenous variable whose main role is to facilitate adjustment to the new equilibrium. In contrast, if public capital has a significant impact on TFP, public investment should be regarded as an exogenous policy tool whose role it is to help keep TFP and aggregate output on their long-run growth paths.

2 A general equilibrium model with public capital

Consider a typical real business cycle model like that of Chari, Kehoe and McGrattan (2008) for example, but with public capital in the production function and a public investment rule along the lines of Marrero (2005). It differs from the simplest real business cycle (RBC) model in several respects. It is non-stationary since population grows at a constant rate n and the law of motion for the technology shocks follows a unit root. Public capital enters the production technology alongside labor and private capital to produce a final good that could be consumed by households or used to augment the private and public capital stocks. There are linear investment technologies in the public and private sector, i_t^g and i_t.

$$N_t i_t^g = N_{t+1} k_t^g - (1-\delta_g)\, N_t k_{t-1}^g, \tag{1}$$

$$N_t i_t = N_{t+1} k_t - (1-\delta)\, N_t k_{t-1}, \tag{2}$$

$$N_{t+1} = (1+n) N_t,$$

where k_{t-1}^g is the stock of public capital that is available in period t, k_{t-1} is the stock of private capital available in the same period, and N_t denotes current population.[2] Each

[2] The subscript on variables in this model refers to the period when they are decided. Since the level of capital stocks in period t is decided through investment in period $t-1$ we denote quantities that are

year the two capital stocks depreciate by constant depreciation rates specific to each type of capital – δ_g for public and δ for private.

2.1 Households

A representative household consumes each period an amount c_t and invests an amount i_t of the final good. Every year it supplies h_t hours of labor services to producers for an hourly wage of w_t. The capital stock maintained through annual investments is rented each year to producers for a unit rental rate of r_t. The representative household pays an investment tax τ_t^i, a payroll tax τ_t^l and receives lumpsum tax rebates each year, d_t.[3] The representative household is also the ultimate owner of production entities and receives the annual profits π_t, as a dividend. The budget constraint of the representative household is therefore,

$$c_t + \left(1+\tau_t^i\right) i_t \leq r_t k_{t-1} + \left(1-\tau_t^l\right) w_t l_t + \pi_t + d_t. \tag{3}$$

The representative household seeks to maximize the expected present value of lifetime utility and therefore,

$$\max_{\{c_t,k_t,h_t\}_{t=0}^{\infty}} \mathrm{E}_t \left\{ \sum_{t=0}^{\infty} \beta^t \frac{\left[c_t \left(1-h_t\right)^{\psi}\right]^{(1-\sigma)}}{1-\sigma} \right\}. \tag{4}$$

2.2 Producers

Producers own a production technology that combines labor, private and public capital to produce a single consumption-investment good.

$$F\left(K_{t-1}, k_{t-1}^g, Z_t L_t\right) = K_{t-1}^{\theta_1} K_{t-1}^{g,\theta_2} \left(Z_t L_t\right)^{1-\theta_1-\theta_2}, \text{where}$$

$$K_t = N_{t+1} k_t,\ k_t^g = N_{t+1} k_t^g, \text{ and } L_t = N_t l_t.$$

productive in period t with subscript $t-1$.

[3] Chari, Kehoe and McGrattan (2007) argue that the payroll and labor taxes introduce wedges in the household's decision problem that allow to replicate salient features of the business cycle. For this reason we introduce them here without the intention to treat the shocks to taxes as structural.

Total labor demanded by producers in period t is denoted by L_t, while l_t is the number of hours per employee. The technology is exogenous and evolves according the following law of motion:

$$Z_t = \mu_z + Z_{t-1} + z_t,\ z_t \sim N\left(0, \sigma_z\right). \tag{5}$$

Producers' optimality conditions imply that they equalise factor payments and marginal factor products.

$$w_t = \left(1 - \theta_1 - \theta_2\right) k_{t-1}^{\theta_1} k_{t-1}^{g,\theta_2} \left(Z_t l_t\right)^{-\theta_1-\theta_2} N_t Z_t, \tag{6a}$$

$$r_t = \theta_1 k_{t-1}^{\theta_1 - 1} k_{t-1}^{g,\theta_2} \left(Z_t l_t\right)^{1-\theta_1-\theta_2} \tag{6b}$$

The profits of production entities aggregate to

$$\pi_t = (1 - \theta_1 - \theta_2) F\left(k_{t-1}, k_{t-1}^g, l_t\right).$$

2.3 Government

The government in this model is there to maintain the public capital stock. It does so using an investment rule that aims to keep the ratio of public investment and output constant provided that the ratio of public and private capital stays on its balanced growth path (BGP) value. Marrero (2005) uses this rule to study US public investment in a deterministic endogenous growth model.

$$\ln\left(\frac{i_t^g}{y_t}\right) = \ln\left(\bar{x}\right) + \eta \ln\left(\frac{\hat{k}_{g,t-1}}{k_{gss}}\right), \tag{7}$$

where y_t is output, $\hat{k}_{g,t-1}$ is the ratio of public to private capital in some year, t, and k_{gss} is the same ratio on BGP. The target value of the ratio of investment to output is denoted by $\bar{x}$.

Taxes paid by households finance public investment, public consumption and lumpsum transfers to households. Taxes and public consumption are assumed to follow stochastic laws of motion as described by the following system:

$$\tau_t^i = \bar{\tau}^i + \rho^i \tau_{t-1}^i + \epsilon_t^i,\ \epsilon_t^i \sim N\left(0, \sigma^i\right) \tag{8a}$$

$$\tau_t^l = \bar{\tau}^l + \rho^l \tau_{t-1}^l + \epsilon_t^l, \epsilon_t^l \sim N\left(0, \sigma^l\right) \tag{8b}$$

$$\ln(g_t) = \bar{g} + \rho^g \ln(g_{t-1}) + \epsilon_t^g, \epsilon_t^g \sim N\left(0, \sigma^g\right). \tag{8c}$$

The government budget constraint (normalized by current period population N_t) is thus,

$$g_t + i_t^g + d_t = \tau_t^l w_t h_t + \tau_t^i i_t. \tag{9}$$

2.4 Competitive equilibrium

The competitive equilibrium in this model is characterised by sequences of prices $\{w_t,\, r_t\}_{t=0}^{\infty}$ *and quantities* $\{k_t,\, k_t^g,\, c_t,\, l_t,\, i_t,\, i_t^g\}_{t=0}^{\infty}$ *that solve the representative household's problem* (4) *subject to* (3)*, satisfy producers optimality conditions* (6)*, the budget constraint of the government* (9) *and its investment rule* (7)*. Goods and labor markets clear, i.e.*

$$y_t = c_t + i_t + i_t^g + g_t + d_t,$$
$$h_t = l_t.$$

The private production technology, taxes and public consumption follow the laws of motion specified by (5) *and* (8)*.*

2.5 Calibration and solution

We solve the model numerically by log-linear approximation around the steady state. The model described above is non-stationary and therefore its steady state is not defined. We make the model stationary dividing K_{t-1}, $K_{g,t-1}$, Z_t by $N_t Z_{t-1}$. Further, we divide c_t, i_t, i_t^g by $N_t Z_t$. The solution is of the form:

$$X_t = AX_{t-1} + Bw_t,$$

$$Y_t = CX_{t-1} + Dw_t,$$

where state variables are collected in the vector $X_t = [k_t,\, k_t^g,\, \tau_t^i,\, \tau_t^l,\, g_t]^T$, control variables are in Y_t and fundamental shocks in the system are collected in $w_t = [z_t,\, \epsilon_t^i,\, \epsilon_t^l,\, \epsilon_t^g]^T$.

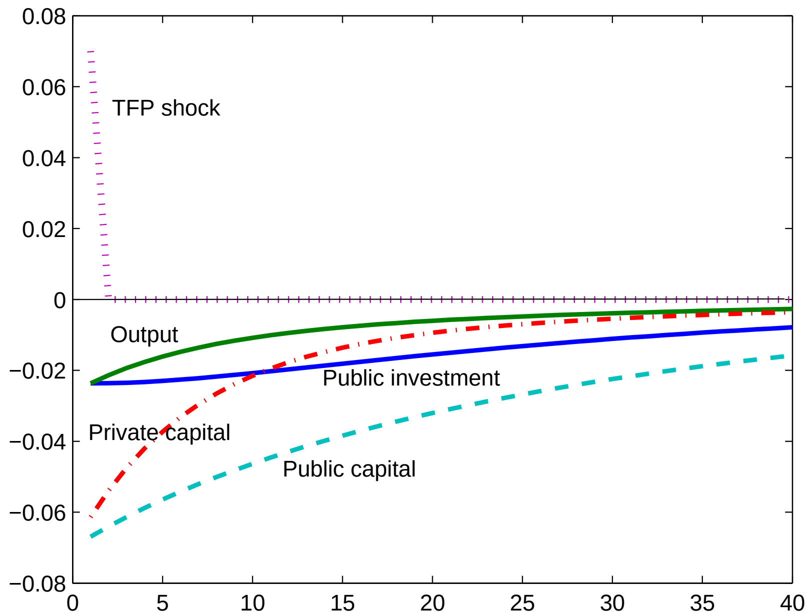
With our numerical solution we study the optimal response of public investment to TFP shocks and map the model to the data in order to examine its plausibility. Since we do not use the model for quantitative evaluation we have calibrated it using parameter estimates typically employed in studies for the US economy. All calibrated values can be found in table A7.1 in Annex 7.

We ask how policy makers should react to structural shocks in the economy, in particular to TFP shocks? The answer in the framework of this model, is of course conditional on the chosen public investment rule. In other words, given that policy makers have preference to keep a constant investment to output ratio in the long-run what is their optimal reaction to TFP shocks?

A positive productivity shock in this economy raises the marginal productivity of all production inputs and as a result investment in private capital stock rises. If the government is to follow its rule (7) public investment should rise above the target $\bar{x}$ so that public capital stock can catch up with private capital. In other words a shock to productivity increases the needs for public investment (in productive capital) above the usual "target" ratio.

Figure 1 plots the impulse response of the model economy, stationarised as described above, to a one standard-deviation shock to TFP. Let us recall what exactly the plotted variables are. Public investment is a logarithmic transformation of the ratio of per-capita public investment and TFP. In addition the variables have been expressed in (log) deviations from steady state. In the steady state, therefore the plotted variables are all zero. The size and the sign of the deviation depends on the relative size and sign of

Figure 1: Impulse response to a one standard-deviation shock to TFP. Deviations from steady state.



the two variables in the ratio. In other words, the the bigger the response (in the chart, the closer the log-ratio to zero) the stronger the response of the variable relative to the TFP shock. In the chart above, a one-standard-deviation shock increases TFP by 0.07 but affects public investment by less. Hence the deviation of their ratio from its steady state value is less than 1 and its logarithmic transformation – less than zero. In sum the model predicts that on a positive TFP shock, output increases the most but returns most quickly to steady state. Public investment jumps as much as output to keep the ratio constant but takes much more to return to steady state. The reason is that the optimal ratio of public to private capital has changed and the economy should adjust to the new level. Public and private capital react much less to TFP. Public capital takes much longer to return to steady state because its depreciation rate is lower than that of private capital.

3 Empirical analysis

The model presented above gives us a stylized framework for conceptualising the relationship between TFP and public capital – our key interest in this paper. With this framework in mind, we now turn to an empirical analysis of the link between TFP and public capital in the European context.

3.1 Data and sample properties

The variables in the empirical analysis include Total Factor Productivity (TFP), public investment (volume), and the ratio of the public capital stock (volume) to the private non-residential (productive) capital stock (volume). For the purpose of the analysis, we take natural logarithms of all variables.

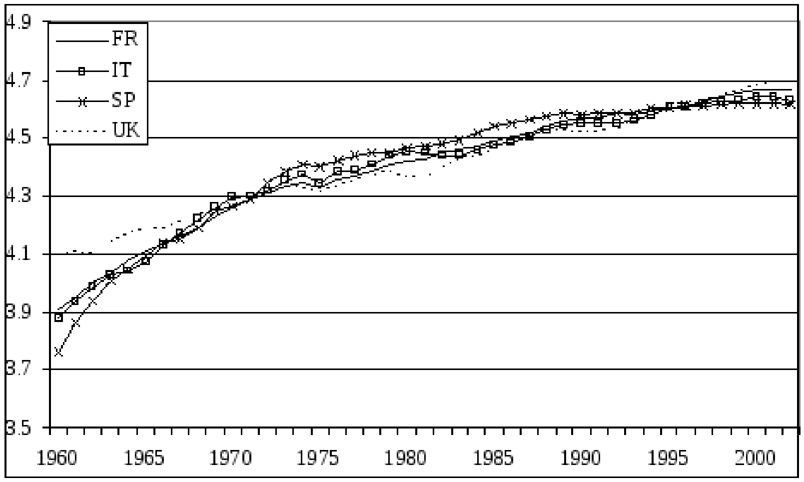
Data on TFP originate from the annual macroeconomic (Ameco) database of the European Commission.[4] The data on public investment and capital stocks are obtained from the database on capital stocks in OECD countries at the Kiel Institute for the World Economy (see also Kamps (2005)).[5]

As is customary, the TFP data in our source has been derived as a Solow residual from an estimated aggregate production function. In that production function private capital and public capital have simply been added up, implicitly assuming that they are perfect substitutes. In most economic models including the one presented in this paper, however, public and private capital are considered complements . If the production function had assumed complementarity instead of substitutability, the Solow residual would have been different. Thus, our TFP data (or any other TFP data that we are aware of) contain undesired noise.

The initial country sample included the four large Western European countries (France, Germany, Italy and the United Kingdom) plus the largest cohesion country (Spain). Germany was dropped from the final sample, as no satisfactory specification of the empirical model could be found. The sample period covers 42 annual observations starting

[4] http://ec.europa.eu/economy_finance/indicators/annual_macro_economic_database/ameco_en.htm.
[5] http://www.ifw-kiel.de/forschung/datenbanken/netcap.

Figure 2: TFP (natural logarithm)



Source: Ameco database, own transformation.

in 1960 and ending in 2001-02.

Turning then to the sample properties, the graphs below illustrate the three variables (TFP, public investment, and the ratio of public to private capital stocks).

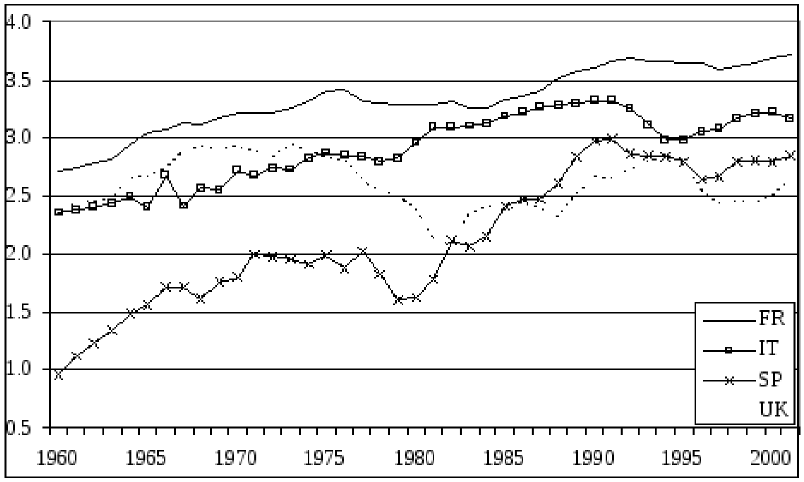
To characterise the time series properties of our sample, Annexes 1-3 contain the results of unit root, VAR order and cointegration tests.[6]

To start with, Annex 1 shows the results of the Augmented Dickey-Fuller (ADF) unit root test for the variables in (log) levels and first differences. We also performed the KPSS and Philips-Perron unit root tests, but as the results were qualitatively the same across the different tests, we only show the ADF test results. To summarise Tables A1.1 and A1.2, it can be concluded that the variables are as a rule neither level nor trend stationary, but they are predominantly difference stationary.

Annex 2 covers the order selection for the unrestricted VAR (variables in levels), together with diagnostic test results of the residuals from the unrestricted VARs. The order selection is based on three common information criteria (Aikake, Schwarz and Hannan-Quinn), complemented by the Wald test for lag exclusion. Whenever two of

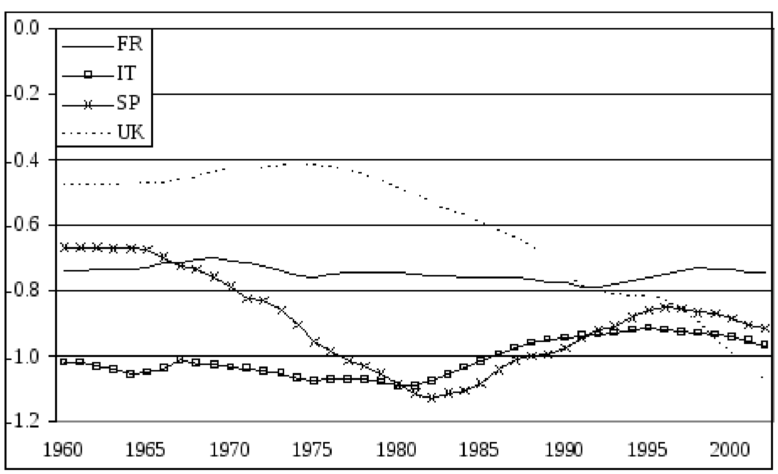
[6] The results presented in Annexes 1 – 3 have been obtained using Eviews 6.0.

Figure 3: Public investment (volume, natural logarithm)



Source: Kamps (2005), own transformation

Figure 4: The ratio of public to private non-residential capital stocks (volume, natural logarithm).



Kamps (2005), own transformation.

the information criteria agree, that order is subjected to the lag exclusion test. Otherwise the median of the three is subjected to the lag exclusion test. As the residuals are predominantly well-behaved, we use the order thus chosen in the subsequent analyses.

Annex 3 shows the results of the Johansen cointegration tests (both trace and maximum eigenvalue tests), assuming all trends to be stochastic. The conclusions about the number of cointegrating relationships are the same even if deterministic trends are allowed for. In all four sample countries at least one cointegrating relationship can be found among the three variables.

3.2 Methodology

We estimate a Vector Error Correction Model (VECM) for all countries using the number of cointegrating relationships from Annex 3. That is, we estimate

$$\Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{p-1} \varphi_i \Delta y_{t-i} + \varepsilon_t. \qquad (10)$$

Where y is a vector containing our 3 variables (TFP, public investment and the ratio of public to private capital). The first term on the right hand side denotes the error-correction term, with Π specifying both the (long run) cointegrating relationships between the variables and the speed of adjustment to deviations from them. With our 3 variables, the rank of Π must be 1 or 2 for the variables to be non-stationary and cointegrated (rank zero would indicate no cointegration and rank 3 would indicate that all variables are individually stationary). The second term collects the short-term relationships among the variables and their lagged values. ε_t is vector of white noise processes. Note that we do not include a term with deterministic elements (intercept, deterministic trends, dummies) in the ECM (but we do include an intercept term in the cointegrating relationship, embedded in Π).

The exact model specification for each country is summarised in Annex 4. No deterministic (linear) trends are assumed present; however, the results do not change materially even if a deterministic trend is assumed. The residuals are predominantly well-behaved.

To test for model stability, the Chow breakpoint and sample-split tests were performed for all four countries (results not reported). Only for Spain was there some evidence of a breakpoint in the early 1980s, otherwise the null of stability could not be rejected.

3.3 Results: Impulse responses

While the stylised theoretical model presented in Section 2 does not provide us with structural identification restrictions for estimating the model and deriving impulse response functions, we can use it to derive an ordering of our variables that, in turn, allows us to use Choleski decomposition to identify our model. As is obvious from Section 2, the most exogenous variable is TFP (by assumption), followed by public investment and, finally, the ratio of public to private capital stocks (which is endogenous to public investment by construction).[7]

Given the well-known sensitivity of the results to the ordering assumption imposed, we also derive generalised impulse response functions (Pesaran and Shin (1998))—that are robust to any ordering assumptions—as a robustness check. Both sets of impulse response functions are presented in Annex 5. (Note that the vertical scales do not always coincide).

The two sets of impulse response functions are in general quite close in magnitude and shape. That the impulse response functions are not very sensitive to the underlying ordering assumption is also suggested by the relatively low cross-correlations among the residuals (contemporaneous cross-correlations are generally $< |0.35|$). That being the case, we focus the subsequent discussion on the ones derived from a Choleski decomposition, as we have confidence bands for them only.

Considering first the impulse responses of TFP to public investment shocks (denoted PINV–>TFP in the graphs), we observe that they are negative but insignificant throughout. For the UK the upper confidence band crosses the zero line eventually; however, the 95 percent confidence band would include zero as well.

[7] The results in Annex 4 have been obtained using Eviews 6.0, as have the generalised impulse response functions in Annex 5. All other results in Annexes 5 and 6 have been obtained using JMulTi softaware, available in www.jmulti.de.

The reverse impulse responses – of public investment to TFP shocks (TFP–>PINV) – are less clear cut. For Spain and the UK they are flat and clearly insignificant. However, for France and Italy they slope up; for France the response is clearly significant, for Italy less so.

3.4 Results: Long-rum dynamics

The following tables present the estimated long-run elasticities of TFP with respect to public investment shocks (Table 1) and of the ratio of public to private capital with respect to TFP shocks (Table 2). The elasticities give the long-run percentage change in TFP (ratio) per one percent long-run change in public investment (TFP), accounting for any dynamic interactions among the three variables.

Table 1: Long run elasticities of TFP with respect to public investment shocks

	LR accumulated response of TFP to public investment (a)	LR accumulated response of public investment to itself (b)	LR elasticity of TFP with respect to public investment (a)/(b)
FR	-4.219360	17.11581	-0.24652
IT	-2.480360	35.16054	-0.07054
SP	-2.818301	-5.186084	0.543435
UK	-1127.760	1516.041	-0.74388

Note: Response horizon set at 500.

Table 2: Table 2. Long run elasticities of the ratio of public to private capital with respect to TFP shocks

	LR accumulated response of ratio to TFP (a)	LR accumulated response of TFP to itself (b)	LR elasticity of ratio w. r. t. TFP (a)/(b)
FR	-4.824240	9.662912	-0.49925
IT	-6.2361	-8.638950	0.721859
SP	-2.109036	13.07341	-0.16132
UK	164.2882	-114.6993	-1.43234

Note: Response horizon set at 500.

We conclude from Table 1 that the long-run elasticities of TFP with respect to public investment shocks are negative, except for Spain and well below unity. Note, however, that the estimated elasticities may not be statistically significantly different from zero.

Table 2 suggests that the ratio of public to private capital tends to fall in the long term in response to TFP shocks, except in Italy. The elasticities are again well below unity, except in the UK. The remark concerning statistical significance applies.

4 Interpretation of the results

We set out to articulate the impact of TFP on public capital as well as to estimate both that link and the reverse relationship from public capital to TFP. Our results based on data from four large European countries suggest that TFP shocks have a positive but statistically insignificant impact on public investment, except in France, where that impact is statistically significant. In contrast, the impact of public investment on TFP (accounting also for the impact of public investment on public and private capital stocks) is negative and insignificant in all sample countries.

In other words, we found only very weak evidence of public investment and capital responding endogenously to TFP shocks. At face value, this could be seen as evidence against the relevance of the kind of a real business cycle model that underlie the analysis. However, the fact that we were unable to find a significant relationship from public investment and capital to TFP casts equal doubt on the validity of alternative (production function) models, considering public investment as an exogenous policy tool to keep TFP and aggregate output on their long run growth paths.

There are other, more plausible, explanations for the absence of strongly significant relationships both ways. First, public investment reacts to not only TFP shocks but to a number of other economic variables (Mehrotra and Välilä (2006)), and it is also subject to political influences (Sturm (1998)). Second, as a direct consequence, TFP shocks do not trigger optimal public investment responses; indeed, they hardly trigger any significant response at all. As a consequence, to the extent that the optimal propagation of TFP shocks thorough the economy would indeed require adjustment in public capital, the observed adjustment is clearly suboptimal.

Put differently, our findings suggest that public investment and capital are neither endogenously responding to TFP shocks, nor are the exogenous policy instruments to steer the evolution of TFP. Instead, they respond to a number of influences, casting doubt on the role of public investment in contributing to optimal adjustment following productivity shocks.

References

Chari, V.V., Patrick J. Kehoe, and Ellen R. McGrattan, "Business cycle accounting," *Econometrica*, 2007, *75* (3), 781–836.

____ , ____ , and ____ , "New Keynesian Models: Not Yet Useful for Policy Analysis," Working Paper 14313, National Bureau of Economic Research September 2008.

Jong-A-Pin, R. and J. de Haan, "Time-varying impact of public capital on output: New evidence based on VARs for OECD countries," *EIB Papers*, 2008, *13* (1), 56 – 81.

Kamps, C., "New Estimates of Government Net Capital Stocks in 22 OECD Countries 1960–2001," Staff Paper 53:1, International Moneary Fund 2005.

Marrero, Gustavo A., "An Active Public Investment Rule and the Downsizing Experience in the US: 1960-2000," *Topics in Macroeconomics*, 2005, *5* (1).

Mehrotra, A. and T. Välilä, "Public investment in Europe: Evolution and determinants in perspective," *Fiscal studies*, 2006, *27* (4), 443–471.

Pesaran, M. H. and Y. Shin, "Impulse Response Analysis in Linear Multivariate Models," *Economics Letters*, 1998, *58*, 17–29.

Romp, W. and J. de Haan, "Public capital and economic growth: a critical survey," *EIB Papers*, 2005, *10* (1), 40–70.

Sturm, J-E, *Public capital expenditure in OECD countries: the causes and impact of the decline in public capital spending*, Cheltenham: Edwar Elgar, 1998.

____ , G. H. Kuper, and J. de Haan, "Modelling government investment and economic growth on a macro level: A review," in S. Brakman, H. van Ees, and S. K. Kuipers, eds., *Market behaviour and macroeconomic modelling*, London, UK: MacMillan Press Ltd, 1998.

Annex 1. Unit root tests

Table A1.1: ADF test, variables in levels

ADF		Log public investment		Log ratio pub/priv capital		Log tfp	
		Intercept	Trend and int.	Intercept	Trend and int.	Intercept	Trend and int.
FR	T stat	-2.248430	-3.859818**	-1.769	-2.619	-2.681*	-2.462
	prob	0.1931	0.0239	0.390	0.275	0.086	0.344
IT	T stat	-1.628672	-1.358619	-1.3371	-1.3439	-3.11**	-3.0988
	prob	0.4592	0.8570	0.603	0.863	0.034	0.120
SP	T stat	-1.768243	-2.165192	-1.8427	-2.6951	-3.61**	-2.1675
	prob	0.3905	0.4945	0.355	0.244	0.010	0.494
UK	T stat	-2.813910	-2.951178	1.1234	-0.3138	-0.5953	-2.8592
	prob	0.0658	0.1589	0.997	0.988	0.861	0.186

Table A1.2: ADF test, variables in first differences

ADF		D(Log public investment)		D(Log ratio pub/priv capital)		D(Log tfp)	
		Intercept	Trend and int.	Intercept	Trend and int.	Intercept	Trend and int.
FR	T stat	-2.99714**	-2.824739	-3.738***	-3.7043**	-2.0156	-3.2169*
	prob	0.0444	0.1980	0.007	0.034	0.279	0.096
IT	T stat	-3.38893**	-3.62342**	-1.7449	-1.4125	-1.6598	-2.7742
	prob	0.0178	0.0414	0.401	0.841	0.443	0.215
SP	T stat	-2.653543*	-2.576343	-1.2213	-1.4505	-3.2717**	-4.347***
	prob	0.0918	0.2926	0.655	0.829	0.023	0.007
UK	T stat	-3.23572**	-3.049920	-1.8443	-3.7076**	-4.043***	-3.9867**
	prob	0.0257	0.1331	0.354	0.034	0.003	0.018

Note: Number of lags based on AIC (max 3).
The null (unit root) is rejected at * 10%, ** 5% level of confidence.

Annex 2. VAR order

Table A2.1: VAR order selection and residual diagnostics (variables in levels)

	AIC	SC	HQ	Chosen VAR order	Autocorrelation (LM, order 1)	Heteroscedasticity (White)	Normality (Lütkepohl)
FR	4	2	2	2	0.3591	0.9730	0.5007
IT	4	2	4	3	0.9582	0.1256	0.1754
SP	4	2	4	4	0.6080	0.3595	0.0221**
UK	4	2	3	3	0.4840	0.8618	0.5770

Note 1: AIC = Aikake Information Criterion, SC = Schwarz Criterion,
HQ = Hannan-Quinn Criterion.
Note 2: Wald lag exclusion test is performed to complement the information criteria.
Note 3: p-values reported for the residual diagnostic tests.
Null rejected at ** 5% level of significance .

Annex 3. Cointegration tests

Table A3.1: Johansen cointegration test (all trends stochastic)

	Trace test			Max Eigenvalue test		
	None	At most 1	At most 2	None	At most 1	At most 2
FR	66.05212	17.03372	3.671342	49.0184	13.36238	3.671342
p-value	0.0000	0.1313	0.4633	0.0000	0.1200	0.4633
IT	55.70648	19.39742	3.775363	36.30906	15.62206	3.775363
p-value	0.0001	0.0654	0.4466	0.0003	0.0551	0.4466
SP	49.75308	24.62763	7.961805	25.12545	16.66582	7.961805
p-value	0.0007	0.0117	0.0842	0.0196	0.0378	0.0842
UK	46.11103	19.25462	6.587285	26.85641	12.66734	6.587285
p-value	0.0023	0.0683	0.1500	0.0108	0.1505	0.1500

Note: Lag length selection based on the underlying VAR (see Annex 2). Unrestricted intercepts in the cointegrating equation. MacKinnon-Haug-Michelis p-values.

Annex 4. Model specification

Table A4.1: Selected model specification and residual diagnostics.

	Order	CI rank	Auto-correlation (LM, order 1)	Heteroscedasticity (White)	Normality (Lütkepohl)	Adj. R^2
FR	1	1	0.0943*	0.6071	0.8926	0.18 – 0.84
IT	2	1	0.3995	0.0201**	0.4420	0.18 – 0.85
SP	3	2	0.6394	0.5255	0.0563*	0.25 – 0.91
UK	2	1	0.7268	0.7464	0.7751	0.09 – 0.92

Note: p-values reported for the residual diagnostic tests.
Null rejected at ** 5%, * 10% level of significance.

Annex 5. Impulse response functions

Figure A5.1: France (Choleski decomposition with ordering: TFP, public investment, ratio)

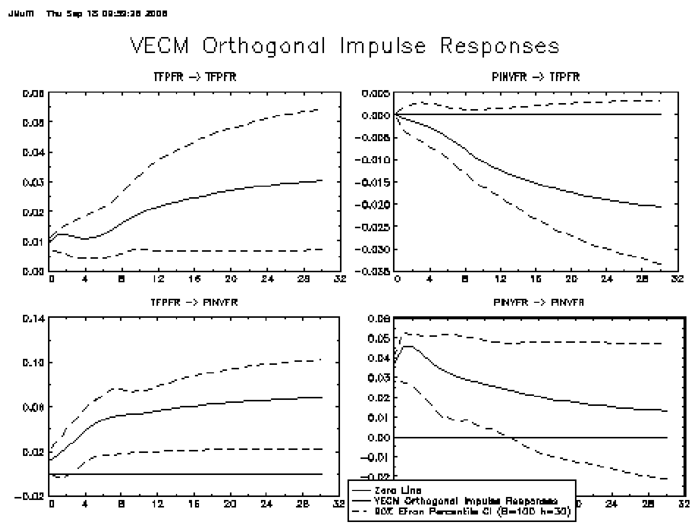


Figure A5.2: France (Generalised impulse responses)

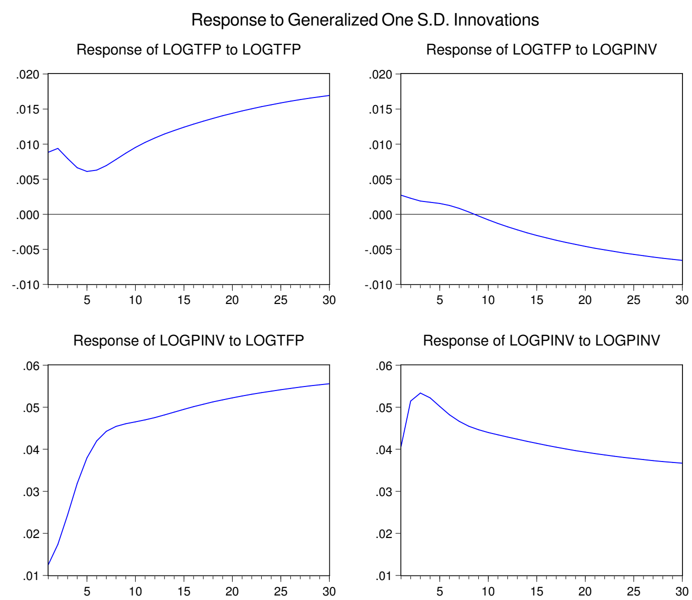


Figure A5.3: Italy (Choleski decomposition with ordering: TFP, public investment, ratio)

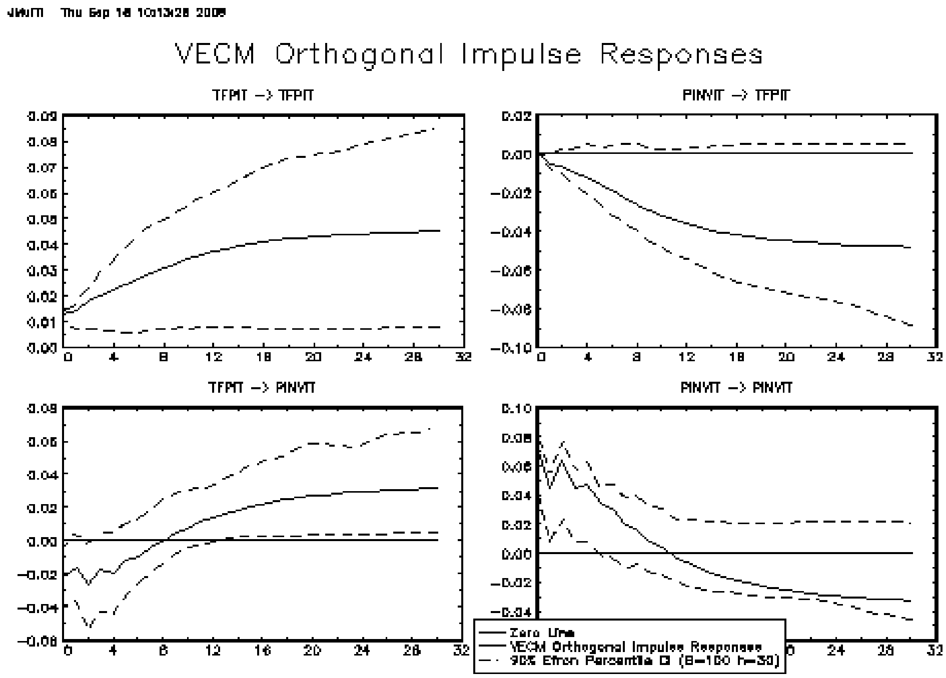


Figure A5.4: Italy (Generalised impulse responses)

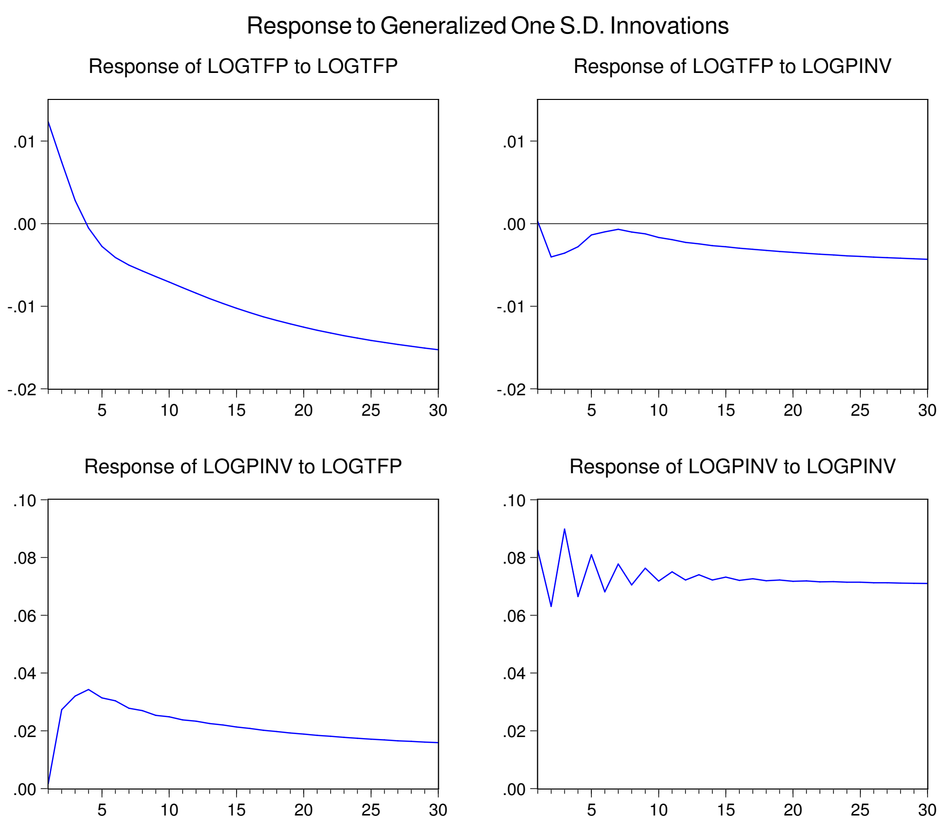


Figure A5.5: Spain (Choleski decomposition with ordering: TFP, public investment, ratio)

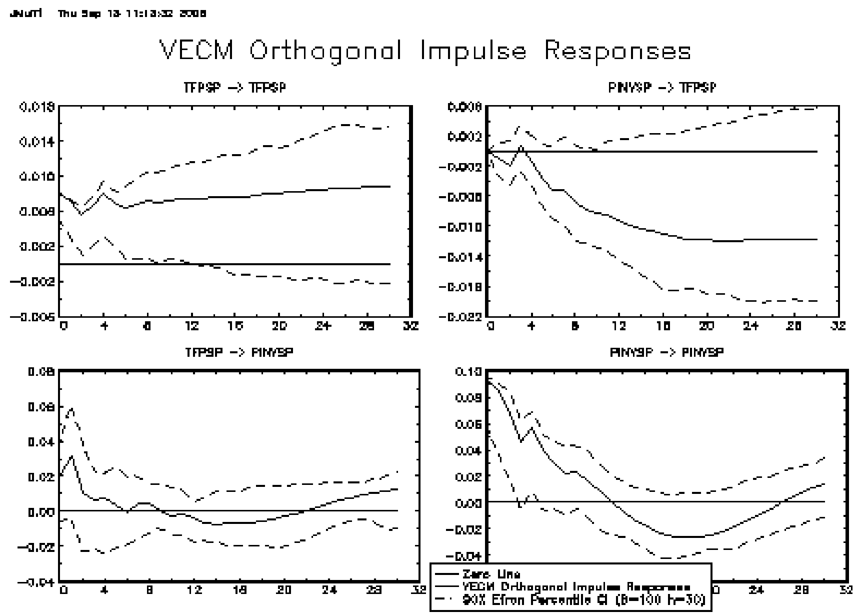


Figure A5.6: Spain (Generalised impulse responses)

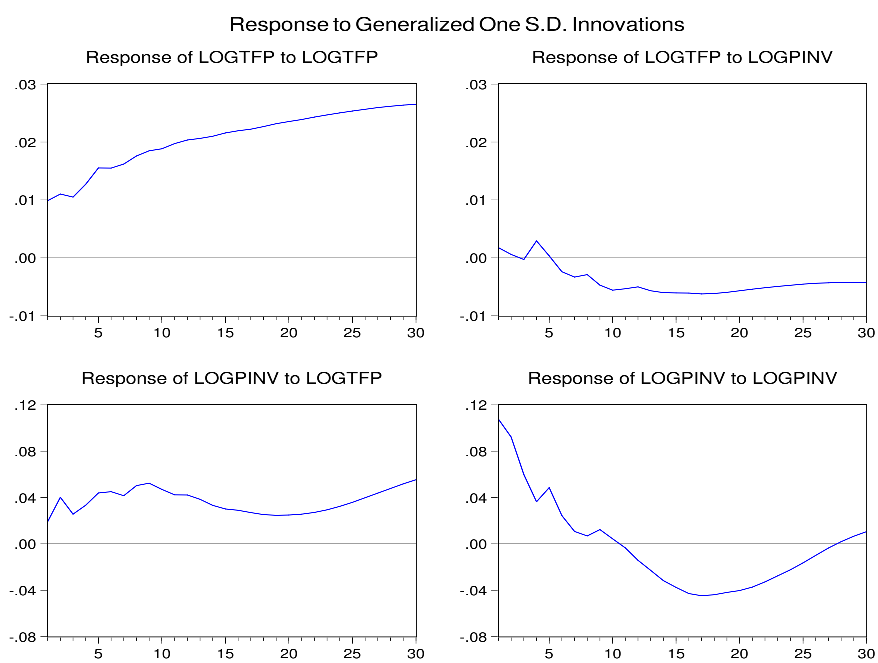


Figure A5.7: UK (Choleski decomposition with ordering: TFP, public investment, ratio)

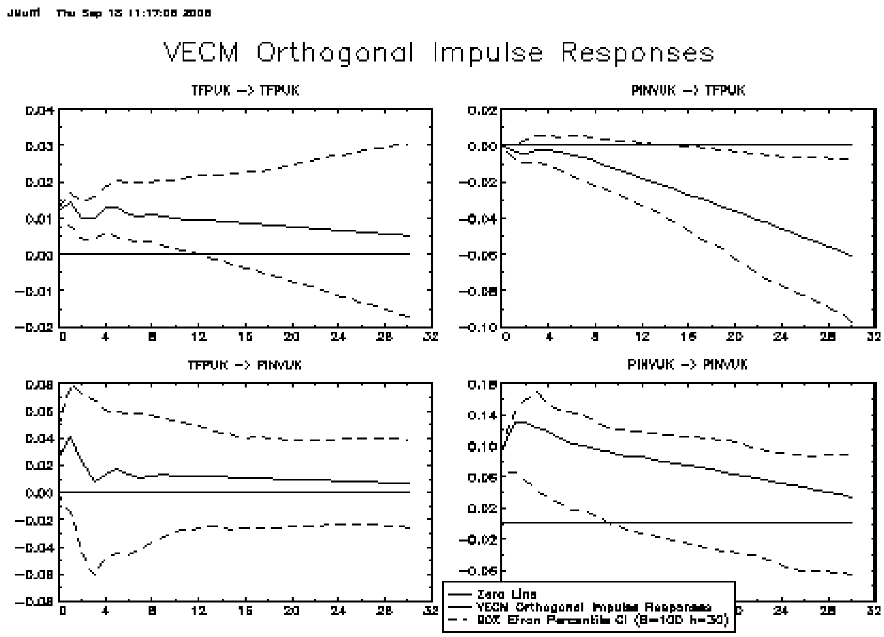
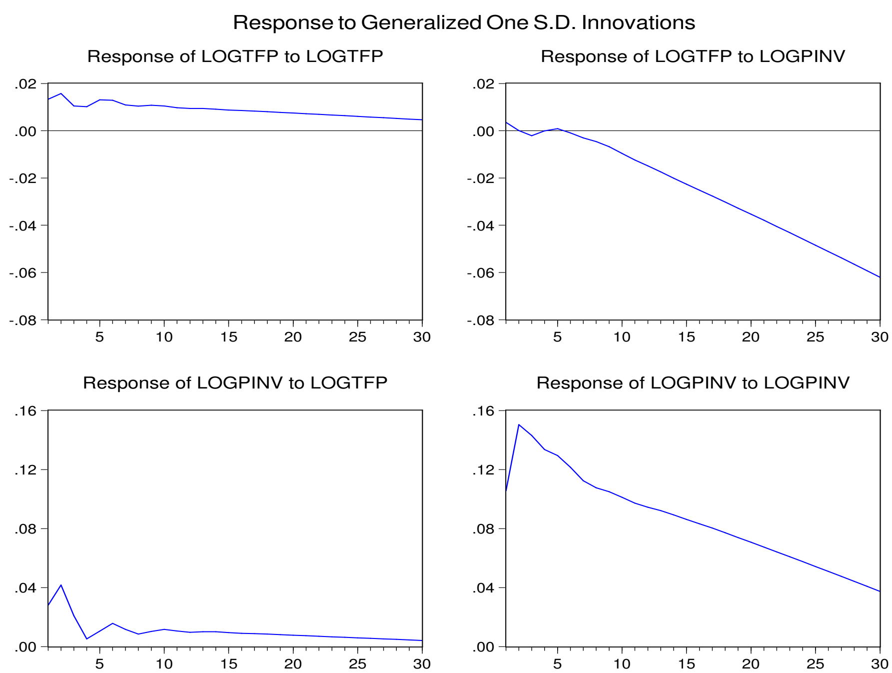


Figure A5.8: UK (Generalised impulse responses)



Annex 6. Estimation results (Π only)

```
France

sample range:               [1962, 2001], T = 40

estimation procedure:       One stage.  Johansen approach

Loading coefficients:
=====================
          d(TFPFR)  d(PINVFR)  d(RATIOFR)
------------------------------------------
ec1(t-1)|   -0.021    -0.027    -0.009
        |   (0.005)   (0.021)   (0.001)
        |   {0.000}   {0.211}   {0.000}
        |  [-4.176]  [-1.251]  [-6.711]
------------------------------------------

Estimated cointegration relation(s):
====================================
             ec1(t-1)
----------------------
TFPFR  (t-1)|    1.000
            |   (0.000)
            |   {0.000}
            |   [0.000]
PINVFR (t-1)|    0.646
            |   (0.197)
            |   {0.001}
            |   [3.279]
RATIOFR(t-1)|    9.448
            |   (0.936)
            |   {0.000}
            |  [10.092]
----------------------
```

```
Italy

sample range:              [1963, 2001], T = 39

estimation procedure:      One stage.  Johansen approach


Loading coefficients:

====================

          d(TFPIT)  d(PINVIT)  d(RATIOIT)

------------------------------------------

ec1(t-1)|    0.063     0.162     0.000

        |   (0.018)   (0.102)   (0.007)

        |   {0.000}   {0.112}   {0.982}

        |   [3.549]   [1.589]   [0.023]

------------------------------------------


Estimated cointegration relation(s):

====================================

             ec1(t-1)

----------------------

TFPIT  (t-1)|    1.000

            |   (0.000)

            |   {0.000}

            |   [0.000]

PINVIT (t-1)|   -1.385

            |   (0.097)

            |   {0.000}

            | [-14.329]

RATIOIT(t-1)|    0.132

            |   (0.309)

            |   {0.669}

            |   [0.427]

----------------------
```

Spain

sample range: [1964, 2001], T = 38

estimation procedure: One stage. Johansen approach

Loading coefficients:

====================

	d(TFPSP)	d(PINVSP)	d(RATIOSP)
ec1(t-1)	0.044	0.090	-0.003
	(0.009)	(0.111)	(0.007)
	{0.000}	{0.415}	{0.722}
	[4.723]	[0.814]	[-0.355]
ec2(t-1)	-0.040	-0.247	-0.002
	(0.009)	(0.109)	(0.007)
	{0.000}	{0.024}	{0.794}
	[-4.320]	[-2.263]	[-0.261]

Estimated cointegration relation(s):

===================================

	ec1(t-1)	ec2(t-1)
TFPSP (t-1)	1.000	0.000
	(0.000)	(0.000)
	{0.000}	{0.000}
	[0.000]	[0.000]
PINVSP (t-1)	0.000	1.000
	(0.000)	(0.000)
	{0.000}	{0.000}
	[0.000]	[0.000]
RATIOSP(t-1)	4.601	2.650
	(0.101)	(0.115)
	{0.000}	{0.000}
	[45.341]	[22.976]

UK

sample range: [1963, 2001], T = 39

estimation procedure: One stage. Johansen approach

Loading coefficients:

	d(TFPUK)	d(PINVUK)	d(RATIOUK)
ec1(t-1)	0.030	0.031	-0.001
	(0.006)	(0.044)	(0.002)
	{0.000}	{0.481}	{0.475}
	[5.396]	[0.705]	[-0.714]

Estimated cointegration relation(s):

	ec1(t-1)
TFPUK (t-1)	1.000
	(0.000)
	{0.000}
	[0.000]
PINVUK (t-1)	-1.522
	(0.096)
	{0.000}
	[-15.825]
RATIOUK(t-1)	-1.156
	(0.531)
	{0.030}
	[-2.175]

Annex 7. Calibration

Table A7.1: Calibration of the parameters for the theoretical model.

β	γ	ψ	σ	θ_1	θ_2	δ	δ_g	$\bar{x}$	η	$\bar{\tau}^i$	$\bar{\tau}^l$	μ_z	ρ_x	ρ_l	σ_z	σ_x	σ_l
0.96	0.01	1.36	1.50	0.30	0.10	0.10	0.04	0.06	0.41	0.20	0.40	0.02	0.95	0.95	0.07	0.02	0.02