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The Greek crisis: A story of self-reinforcing feedback mechanisms*

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Abstract

While there seems to be a well established consensus about the underlying causes to the Greek crisis, less is known about internal and external transmission mechanisms that ultimately caused unemployment to increase rapidly over this period. Motivated by the structural slumps theory in Phelps (1994), the paper attempts, therefore, to uncover the dynamic mechanisms behind prices, interest rates, and external imbalances that contributed to the severity and the length of the crisis. We find that the strongly increasing real bond rate and unemployment rate together with an persistently appreciating real exchange rate and a deterioration of competitiveness in the eurozone have contributed to persistently growing structural imbalances in the Greek economy. As the lack of confidence in the Greek economy grew steadily, the scene was set for a monumental structural slump. We find strong evidence of (i) a Phillips curve relation with a non-constant natural rate being a function of relative costs and the real exchange rate; (ii) a vicious circle of strongly increasing bond rate and unemployment rate; and (iii) a relation associating confidence with the development of relative costs and the real exchange rate. Over the crisis period, all variables exhibited self-reinforcing feedback adjustment somewhere in the system except for inflation rate. Unemployment took the burden of adjustment when the bond rate sky rocketed, competitiveness deteriorated, and confidence fell.

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1 Introduction

From 2008 to 2013, Greece experienced one of the most severe recessions in Europe with a fall in real output of 26% and unemployment reaching 26%. While 2017 marked the first time that real GDP growth exceeded 1% since 2007, the crisis measured by low economic activity was still unfolding on its tenth year. So why was the recovery so slow and which were the mechanisms triggering the Greek crisis?

A number of explanations have been proposed in the literature of which the most popular ones refer to initial macroeconomic imbalances (e.g. fiscal deficits, external deficits), deteriorating competitiveness, current account imbalances, and the strong external dependence combined with the sudden lending stop.[1] Apart from these, chronic structural problems in the economic and political system combined with badly designed policies to deal with them - often forced upon Greece by national, supranational and international institutions - have also been proposed.[2] Also, some sholars argue that the contraction was more severe than initially expected because some typical Greek characteristics of its economy were largely overlooked in the many reform programs. For example, the low quality of the Greek institutions also contributed to the he growing macroeconomic imbalances (see Economidis et al., 2017, Philippopoulos, 2014). In the same vein, Kollintzas et al. (2017) attribute the dismal growth in Greece to its 'insiders-outsiders' society by showing that the high public sector wage premium and self-employed taxation gap significantly contributed to the sovereign debt crisis.

But, while the above explantions are relevant for understanding the build-up of the Greek crisis, the severness of the Greek problems cannot be fully understood without accounting for the mechanisms triggered by Greece be-

[1]See, for example, Gibson et al. (2014), Honkapohja (2014), Christodoulakis (2015), Galenianos (2015), Bournakis et al. (2017), Ioannidis and Pissaridis (2015) and Meghir et al. (2017).

[2]For example, Meghir et al. (2017) provide a detailed analysis of the pathologies that made Greece vulnerable to the crisis with special focus on the product and labor market regulations and the financial system.

coming an eurozone member in 2001. As financial markets incorrectly considered risk to be evenly distributed in the euro area, the Greek bond rate dropped to unprecedented low levels as Greece entered the eurozone. This resulted in a strong increase in credit-financed demand, mostly for imports and contributed to a wage and price spiral both in the private and the public sector, creating huge current account imbalances.

Thus, Greece borrowed heavily to pay for unproductive consumption and excessive wages, so the resulting deficits hit the country hard when the crisis unfolded. While foreign lenders also were badly exposed, they were largely rescued. For example, Wyplosz (2017) argues that the Great Financial Crisis was rooted primarily in excessive risk-taking by financial intermediaries – a result of the poor regulation and supervision that emerged in connection with financial liberalization. A contributing cause of the external lending problem was, therefore, that financial markets mistakenly assumed that current-account imbalances of the member countries no longer mattered in the eurozone. This may explain why a high external debt country like Greece was able to finance its debt with low interest rate loans up to the crisis - even though the size of the fiscal imbalance must have made severe macroeconomic adjustment seem inevitable. When the financial markets learned their mistakes, Greece experienced the harsh consequences of strongly increasing interest rates and sudden lending stops.

The Greek misfortune was that most of its external borrowing had been used for unproductive spending, much of it closely tied to large and persistent public deficits that, given the rapidly increasing interest rates, became extremely harmful. Excessive public spending financed by external borrowing is generally considered the most serious obstacle for getting the Greek economy out of the crisis. See for example Gourimchas et al. 2016. But, rather than a pure sovereign debt crisis, Hyppolite (2016) argues that the Greek crisis is best viewed as an external debt crisis driven by a real estate bubble and unsustainable foreign capital flows.[3]

Thus, while there seems to be a well researched narrative about the underlying causes of the crisis, less is known about internal and external transmission mechanisms causing the rapidly increasing unemployment rate over this period. We believe, therefore, it is of considerable interest to uncover the dynamic mechanisms among unemployment, prices, interest rates, and

[3] He shows this using a new dataset that evaluates and breaks down national wealth accumulation in Greece since 1997.

external imbalances that contributed to the severity and the length of the crisis. A similar aim can be found in Juselius and Juselius (2012) that used the Cointegrated VAR (CVAR) model to uncover important relationships among unemployment, prices and interest rates in connection with the Finnish crisis in the beginning of 1990s. In many ways the economic mechanisms leading to the Finnish crisis were similar to the ones of the Greek crisis: the deregulation of the Finnish credit market in 1986 resulted in lower loan rates, a booming housing market and the build-up of a serious house price bubble that finally burst in 1991. House prices dropped by roughly 60 % and unemployment rose from a record low of 2 % to almost 20 %. These are huge fluctuations but of similar magnitudes as in the Greek crisis. Unlike the Greek economy, Finland managed to get out of the crisis in approximately three - very hard - years by devaluing the Finnish markka by 33 %. Also, unlike the Greek experience, the Finnish unemployment came down much faster, albeit stabilizing at a somewhat higher level compared to the pre-crisis period.

One important finding in the Finnish study was an empirically strong Phillips curve relation with a non-constant Phelpsian natural rate of unemployment measured by the real bond rate. The results generally provided support to the structural slumps theory by Edmund Phelps (1994) combined with the theory of balance sheet recession by Richard Koo (2010). The present paper takes a similar approach as Juselius and Juselius (2012), but recognizes that the Greek crisis, while similar in many respects, differs strongly in others. For example, the source of the debt (private/public, external/internal) and in particular the exchange rate regime are defining differences of crucial importance. The fact that Finland was able to devalue its currency while Greece was not, is likely to have made all the difference. It is one reason why the comparison with Finland is interesting.

The prolonged period of policy uncertainty following the outbreak of the Greek crisis clearly aggravated the deepening and the extension of the Greek crisis. Also, the failure of the 2012 sovereign debt restructuring (known as Private Sector Settlement, PSI) further weakened investors' confidence. Unlike the Finnish analysis we therefore include a variable measuring confidence in the Greek economy. Also, the development of the Greek competitiveness within and outside the eurozone is likely to be very important for the crisis mechanisms, so the former are also included in our model analysis.

Because of the severity of the crisis, we expect the macroeconomic dynamics both during, before and after the Greek crisis to be utterly complex. Our approach differs therefore from most papers that have empirically studied the Greek crisis by *not* taking the simple route of choosing *a priori* a few exogenous causes and then forcing this assumption on the model. We argue that it is seldom possible to know from the outset - and especially not in a complex crisis period - which variables are empirically endogenous (purely adjusting) and which are exogenous (purely pushing).

Like Juselius and Juselius (2012), our approach relies on a full system CVAR model in which all systematic aspects of the data have to be satisfactorily described. Spanos (2009), for example, argues that a convincing test of the empirical relevance of an empirical model has to be carried out in the context of a fully specified statistical model that works as an adequate, though approximate, description of the Data Generating Process (DGP) given in its entireness. A CVAR model that has passed all basic specification tests, is essentially a summary of the most important empirical facts over the sample period and, thus, qualifies for such a statistical model. A model that has not passed such checks may - and often does - produce totally misleading conclusions. See Juselius and Franchi (2007) for an illustration of a real business cycle model. To achieve scientific objectivity, we argue therefore that data cannot be constrained from the outset in a theoretically pre-specified direction, as it then would be impossible to distinguish between results which are due to the assumptions made and results which are genuine empirical facts. The basic idea is to let the data speak as freely as possible about the mechanisms that caused the crisis and why it lasted so long. This is unlike approaches in which the data from the outset are silenced by prior restrictions asdetailed by Hoover et al. (2008).

The paper is organized as follows: Section 2 discusses broadly the Phillips curve with a Phelpsian natural rate based on Phelps (1994). Section 3 introduces the chosen data based on an ocular investigation. Section 4 introduces the empirical model, reports misspecification tests and determines the important reduced rank indices based on ML tests. The results show that data are approximately I(2) over this period. Section 5 reports the estimates of the long-run structure and Section 6 concludes.

2 The structural slumps theory and the non-constant natural rate

The aim of the structural slumps theory, developed by Edmund Phelps in the early nineties, was to explain how open economies connected by the world real interest rate - set in a global capital market - and the real exchange rate - determined in a global customers market for tradables - can be hit by long spells of unemployment. According to this theory, fluctuations in the real interest rates and real exchange rates play an important role in explaining the persistent long swings in the observed unemployment rates. The theoretical implication for a standard Phillips curve is that the natural rate of unemployment becomes a function of real interest rate and real exchange rates. While Phelps (1994) assumed that real interest rates and real exchange rates were stationary,[4] empirical evidence often finds that they are indistinguishable from a unit root process. Juselius (2013) argues that the structural slumps theory based on imperfect knowledge expectations would be more adequate to explain the long persistent movements in the data.[5]

In an imperfect knowledge world, the nominal exchange rate is primarily determined by financial speculation whereas prices of tradable goods, being determined in very competitive customer markets, are not likely to be affected by speculation - energy, precious metals and, recently, grain may be exceptions in this respect. Hence, relative prices would fluctuate much less than nominal exchange rates and real exchange rates would inherit the persistent swings of nominal exchange rates. Figure 1, panel (f), illustrates such persistent swings in the real effective exchange rate of the euro relative to the Greek trading countries outside the eurozone. Relative prices within the eurozone have also exhibited a pronounced upward persistence as shown in panel (e). The nominal bond rate was also strongly affected by financial behavior, in particular after it became aware of the unsustainability of the Greek debt. Figure 1, panel (c) shows the dramatic increases of the long-term Greek bond rate at the beginning of the risis. Since the nominal bond rate fluctuated much more than price inflation, the real interest rate inherited the persistent swings of the nominal interest rate. Hence, the strongly increasing

[4]This is because the theory was based on model consistent rational expectations

[5]Frydman and Goldberg (2007) show that financial behavior under imperfect knowledge can drive asset prices, such as nominal exchange rates and long-term bond rates, persistently away from long-run benchmark values.

real bond rate together with an appreciating real exchange rate and a deterioration of competitiveness in the eurozone is likely to have significantly aggravated the existing structural imbalances in the Greek economy. As the lack of confidence in the Greek economy grew steadily, the scene was set for a monumental structural slump a la Phelps (1994).

How would all this affect the Greek unemployment. As Greek enterprises had lost much of their previous competitiveness after a long period of permanent shocks to relative costs, a real depreciation would have been the obvious cure. But, as an eurozone member, Greece had given up the possibility to use the exchange rate as a policy tool. Unless Greece left the euro she could not count on exchange rates to restore lost competitiveness. But, unlike Finland in the nineties, the large proportion of external debt would have made such a choice extremely costly. Thus, Greek enterprises, facing domestic wage costs in excess of the foreign ones, may not have had other options than to improve labor productivity. This could, for example, be achieved by introducing new technology, by lowering domestic wage (extremely difficult) or by laying off the least productive part of the labor force and producing the same output with less labor. In all those cases unemployment rate would take the burden of adjustment.

In line with Phelps (1994), our empirical analysis is centered around a Phillips Curve with a non-constant natural rate:

$$\Delta p = -b_1(u - u^n), \tag{1}$$

where the natural rate of unemployment, u^n is potentially a function of the real effective exchange rate, $reer$, relative producer prices with respect to the eurozone, $relc$, market confidence, $conf$, and the real bond rate, r.

Figure 2 shows the data over the sample period 2004:5-2017:1. Panel (a) pictures the Greek inflation rate that, in spite of a strong seasonal pattern, looks reasonably stable. Panel (b) shows how unemployment declined in the period preceding the crisis as a result of the overheated Greek economy, only to increase to record levels a few years later. It illustrates the force with which the crisis struck the Greek economy. After topping in 2013, unemployment has slowly started to come down but at the end of the sample it is still at a very high level. Panel (c) pictures the bond rate and its extreme growth as the crisis unfolded. Panel (d) shows the confidence variable and its decline until approximately 2012 after which it was rising up to 2015 when the election of a new government - hostile to structural adjustment programs - caused it to drop dramatically. As it seemed almost impossible for Greece to honor its external debt, foreign lenders panicked and stopped lending. This almost pushed Greece over the edge and aggravated the very crisis the lenders feared. Panel (e) pictures the relative producer cost between Greece and Germany and shows its steady increase up to roughly 2012, when it started leveling off until 2014 after which it gradually started to decline. Panel (f) pictures the Greek effective real exchange rates and shows its steady real appreciation, mirroring the increase in the relative costs in panel (e).

3 The Empirical CVAR

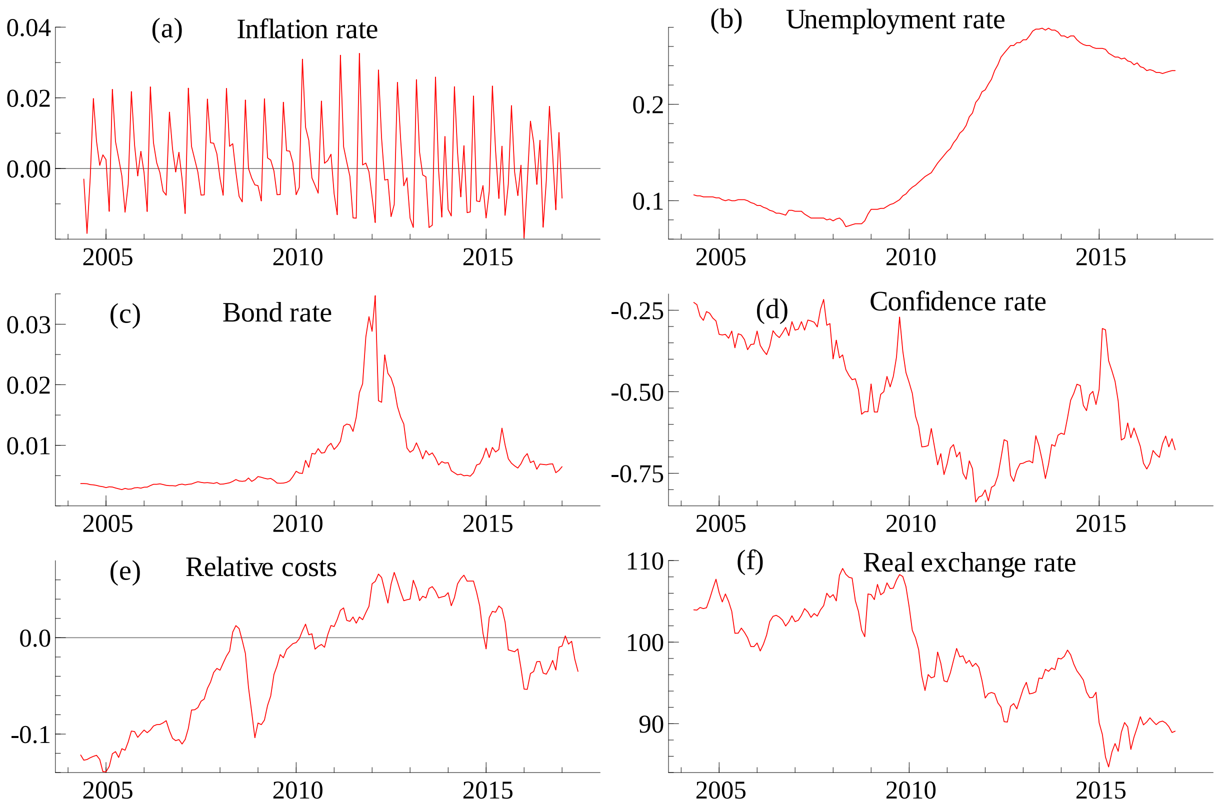
We consider the following VAR model (Johansen, 1995):

$$\Delta x_t = \Pi x_{t-1} + \Gamma_1 \Delta x_{t-1} + \Gamma_2 \Delta x_{t-2} + \mu_0 + \Phi_1 D_t + \Phi_2 S_t + \varepsilon_t, \qquad (2)$$

where

- $x_t' = [\Delta p_t, u_t, b_t, conf_t, relC_t, reer_t]$
  - Δp_t is inflation measured as $\Delta \log(CPI)_t)$, source OECD, economic outlook,
  - u_t is unemployment rate measured as the number of unemployed relative to the workforce, source OECD, economic outlook,
  - b_t is the long-term government bond rate divided by 1200 to make it comparable with monthly inflation rate measured as $\Delta \log CPI$,
  - $conf_t$ is an index between -1.0 and +1.0 measuring the level of confidence in the Greek society, source Reuters' Eikon,
  - $RelC_t = PPI^{Gr} - PPI^{Ge}$ is a measure of the log of Greek producer cost relative to Germany, source Eurostat,
  - $reer_t$ = the log of the effective real exchange rate for Greece, source OECD, economic outlook.
- D_t is a vector of dummy variables
- S_t is a vector of eleven seasonal dummies.
- $\varepsilon_t \sim Niid(0, \Omega)$

The sample period covers 2004:5-2017:1.


(a) Inflation rate
0.04
0.02
0.00
2005
2010
2015
(b) Unemployment rate
0.2
0.1
2005
2010
2015
(c) Bond rate
0.03
0.02
0.01
2005
2010
2015
(d) Confidence rate
-0.25
-0.50
-0.75
2005
2010
2015
(e) Relative costs
0.0
-0.1
2005
2010
2015
(f) Real exchange rate
110
100
90
2005
2010
2015

3.1 Misspecification tests and extraordinary shocks

Figure 2 visualizes the extreme changes in the unemployment rate and the bond rate, but also in the variables measuring confidence and producer costs relative to Germany. Such extreme events can be challenging for the CVAR analysis as it is based on the assumption of multivariate normality. There are basically three potential remedies: to leave out the crisis years altogether under the assumption that they are not representative for the purpose of the study; to condition on weakly or strongly exogenous variables under the assumption that they have caused the extreme fluctuations in the data; to control for the extreme events using appropriately designed dummy variables. Since a better understanding of the crisis is the main purpose of this study, the first option has not been considered. Checking the second option we found, not surprisingly, that the real exchange rate was both weakly and strongly exogenous. This was independently of the choice of rank so the subsequent results will be based on a partial VAR conditional on the exogenous real effective exchange rate.[6] While conditioning on the real effective exchange improved the specification, several large outliers remained nonetheless in the model. Hence, the dummy option was also needed. The vector D_t in (2) contain dummy variables that control for the following extraordinary events in this period:

- $Dp11.09_t = 1$ in 2011:9, 0 otherwise, controls for the first large increase in the bond rate,
- $D_p11.11_t = 1$ in 2011.11 and 2011.12, 0 otherwise, controls for two subsequent large increases in the bond rate,
- $D_p12.02_t = 1$ in 2012.2, -2 in 2012.3 and 1 in 2012.5, controls for a large double change in the bond rate,
- $Dp15.02_t = 1$ in 2015.2, controls for the effect of the election of a new government on the confidence variable.

The left hand side of Table 1 reports the estimates of the four dummy variables where significant coefficients are in bold face. It appears that the first three dummies are needed to control for extreme unanticipated changes in the bond rate as the crisis evolved. $D_p12.02$ controls for the effect on

[6] For the chosen value, $r = 4$, the weak exogeneity test was $\chi^2(4) = 2.00[0.74]$.

Table 1: Dummy variables and misspecification tests

	$D_p11.09$	$D_p11.11$	$D_p12.02$	$D_p15.02$	$Jarque-Bera$	$ARCH(3)$
$\Delta\Delta p_t$	0.01 [2.6]	0.00 [0.03]	−0.003 [−1.5]	0.01 [2.4]	0.61[0.74]	1.9[0.60]
Δu_t	−0.002 [−0.9]	−0.002 [−1.1]	0.001 [0.7]	0.001 [0.7]	0.71[0.70]	4.9[0.18]
ΔB_t	**0.005** [5.3]	**0.007** [10.5]	**0.008** [20.7]	−0.001 [−1.4]	15.63[0.00]	7.8[0.05]
$\Delta Conf_t$	−0.067 [−1.7]	0.005 [0.2]	−0.009 [−0.5]	**0.23** [5.7]	2.29[0.32]	2.0[0.57]
$\Delta RelC$	0.005 [0.6]	0.001 [0.1]	−0.002 [−0.6]	**0.05** [5.3]	5.13[0.08]	0.9[0.83]

the bond rate when Greece agreed to a debt restructuring scheme with its private creditors. As a result the first adjustment program was rolled over into a second one and the previously dramatic increases in the bond rate finally reversed. $Dp15.02_t$ is needed to control for the effect on the confidence variable and relative prices as a new government was elected. The latter was politically opposed to the adjustment programs, so the risk of Grexit was elevated at this time.

The right hand side of Table 1 reports univariate Jarque-Bera normality tests and ARCH tests. The multivariate normality test was $\chi^2(10) = 18.3[0.05]$, the multivariate ARCH was $\chi^2(225) = 204.4[0.83]$ and the multivariate autocorrelation test of second order was $\chi^2(25) = 23.4[0.55]$. Figures A1-A5 in the Appendix show actual and estimated changes of the variables, the residuals, autocorrelogram and the residual histograms compared to the normal distribution for all the variables. With the exception of the bond rate pictured in Figure A.3, the VAR model seems reasonably well specified. But even the bond rate - considering its huge changes over the crisis period - has a surprisingly nice and symmetrical residual distribution. Because the CVAR estimates are fairly robust to moderately excessive kurtosis, we consider the model sufficiently well specified after the big outliers have been controlled for.

3.2 Rank determination

Figure A.2 in the appendix illustrates the pronounced persistence of the change in the unemployment rate, suggesting that also the differenced process may contain a unit root. A unit root in the differenced process implies that

$\Gamma = I - \Gamma_1 - \Gamma_2$ also has a reduced rank. Because such a root cannot be removed by changing the rank of Π, the statistical analysis has to be performed in the I(2) model.

The hypothesis that x_t is $I(2)$ is formulated as a reduced rank hypothesis on $\Pi = \alpha\beta'$ and an additional reduced rank hypothesis on $\alpha'_\perp \Gamma \beta_\perp = \xi\eta'$ where ξ, η are $(p-r) \times s_1$ and $\alpha_\perp, \beta_\perp$ are orthogonal complements of α, β. The total number of stochastic trends, $(p-r)$, are divided into s_1 trends of order $I(1)$ and s_2 trends of order $I(2)$. Note that the $I(1)$ reduced rank condition is associated with the levels of the variables, whereas the $I(2)$ condition with the differenced variables.

The determination of the reduced rank indices is based on the maximum likelihood trace tests derived in Nielsen and Rahbek (2007) and reported in Table 2. The procedure starts with the most restricted model ($r = 0, s_1 = 0, s_2 = 5$) with s_1 denoting the number of $I(1)$ trends and s_2 the number of $I(2)$ trends, and continues row-wise until the first non-rejection at ($r = 4, s_1 = 0, s_2 = 1$) with a p-value of 0.47.[7] The column of $s_2 = 0$ contains the trace tests for the I(1) model.

A correct choice of rank indices is crucial for obtaining statistically reliable results. Unfortunately it is also a difficult choice since economic data are often informationally weak about the division into pulling and pushing forces. It is, therefore, important to use all relevant information. The characteristic roots are particularly useful in this respect and Table 2, lower part, reports the moduli of the five largest roots for the unrestricted VAR as well as for the restricted models ($r = 4, s_1 = 0, s_2 = 1$) and ($r = 4, s_1 = 1, s_2 = 0$). The unrestricted VAR (conditional on the real exchange rate) contains two large roots almost on the unit circle (0.98, 0.98) plus another large root (0.86) which may or may not correspond to a unit root. The choice of ($r = 4, s_1 = 1, s_2 = 0$), i.e. the I(1) model with $r = 4$, shows that this choice would leave a large near unit root of 0.97 in the model rendering all inference on stationarity totally unreliable. The choice of ($r = 4, s_1 = 0, s_2 = 1$) would eliminate the two very large roots but leave a fairly large unrestricted root of 0.88 in the model. While being quite large, it is far from unlikely that it corresponds to a stationary but slowly adjusting economic relation.

We conclude that the I(2) model is an appropriate reduction of the data-generating process and continue with this choice. It corresponds to four

[7] The tests for $r = 0$ and 1 were all strongly rejected and the table reports the results only for $r = 2, 3, 4$.

Table 2: The trace tests

$p-r$	r	$s_2=5$	$s_2=4$	$s_2=3$	$s_2=2$	$s_2=1$	$s_2=0$
3	2			139.5 [0.00]	86.5 [0.00]	65.5 [0.00]	58.4 [0.01]
2	3				49.7 [0.04]	38.6 [0.02]	31.5 [0.04]
1	4					**11.9** [0.47]	9.4 [0.33]
The five largest characteristic roots							
$r=5, p-r=0$		0.98	0.98	0.86	0.77	0.77	
$r=4, s_1=1, s_2=0$		1.0	0.97	0.88	0.76	0.76	
$r=4, s_1=0, s_2=1$		1.0	1.0	0.88	0.75	0.75	

polynomially cointegrating relations $\beta' x_t + \delta' \Delta x_t$ where $\beta' x_t$ and $\delta' \Delta x_t$ are both $I(1)$.

4 The Long-run Structure

As shown above, the $I(2)$ condition is formulated as a reduced rank on a transformed Γ matrix implying that the latter is no longer unrestricted as in the $I(1)$ model. Because of this, Johansen (1997, 2006) suggested a different parameterization more suitable for likelihood based inference (see also Doornik and Juselius, 2017):

$$\Delta^2 x_t = \alpha \left[\begin{pmatrix} \beta \\ \beta_1 \end{pmatrix}' \begin{pmatrix} x_{t-1} \\ t-1 \end{pmatrix} + \begin{pmatrix} d \\ d_0 \end{pmatrix}' \begin{pmatrix} \Delta x_{t-1} \\ 1 \end{pmatrix} \right]$$

$$+\zeta \begin{pmatrix} \beta \\ \beta_0 \end{pmatrix}' \begin{pmatrix} \Delta x_{t-1} \\ 1 \end{pmatrix} + \Gamma_1 \Delta^2 x_{t-1} + \Phi D_t + \varepsilon_t, \tag{3}$$

$$t = 1, ..., T$$

The relations in the hard brackets correspond to the polynomially cointegrated relations, $\tilde{\beta}' \tilde{x}_{t-1} + d' \Delta \tilde{x}_{t-1}$, with $\tilde{x}_t' = [x_t, t]$. They capture a situation where the deviations from a long-run static equilibrium, $\tilde{\beta}' \tilde{x}_t$, are a (near) $I(1)$ process and, therefore, have to be combined with the differenced process, $d' \Delta \tilde{x}_t$ also $I(1)$, to become stationary. Such relations can often be given an interpretation as dynamic rather than static equilibrium relations. The relations in soft brackets, $\zeta\beta'\Delta\tilde{x}_{t-1}$, correspond to medium-run relations among the differenced variables.

The long and persistent swings visible in Figure 1 suggest that the system might be subject to self-reinforcing feedback mechanisms somewhere in the system. Such behavior is likely to show up as a combination of equilibrium error increasing (positive feedback) and error correcting behavior (negative feedback) either in the adjustment to the five polynomially cointegrating relations, $\alpha(\beta^{'}x_t + d'\Delta x_t)$, or in the adjustment to the changes in the β-relations, $\zeta\beta'\Delta x_t$.

A polynomially cointegrated relation can be interpreted as a dynamic equilibrium relation in the following sense: When data are $I(2)$, $\beta^{'}x_t$ is generally $I(1)$ and can be given an interpretation as a static equilibrium error that exhibits pronounced persistence. In this case, one can interpret the coefficients α and d as two levels of equilibrium correction: The α adjustment describes how the acceleration rates, $\Delta^2 x_t$, adjust to the dynamic equilibrium relations, $\beta^{'}x_t + d'\Delta x_t$ and the d adjustment describes how the growth rates, Δx_t, adjust to the long-run equilibrium errors, $\beta^{'}x_t$.

The signs of β, d, and α determine whether the variable $x_{i,t}$ is error increasing or error correcting in the medium and the long run. If $\alpha_{ij}\beta_{ij} < 0$ or/and $\alpha_{ij}d_{ij} < 0$, then the acceleration rate, $\Delta^2 x_{i,t}$, is equilibrium correcting to $(\beta_i^{'}x_t + d_i'\Delta x_t)$; if $d_{ij}\beta_{ij} > 0$ (given $\alpha_{ij} \neq 0$), then $\Delta x_{i,t}$, is equilibrium error correcting to $\beta^{'}x_t$; if $\zeta_{ij}\beta_{ij} < 0$ then $\Delta^2 x_{i,t}$ is equilibrium correcting to $\beta_i'\Delta x_{t-1}$. In all other cases the system is equilibrium error increasing.

Table 3 reports estimates of α, β and d subject to six over-identifying restrictions on β, which can be accepted based on $\chi^2(6) = 4.67[0.59]$.[8] For a given identified β, the d parameters are uniquely determined without further restrictions.[9] The standard errors of β are derived in Johansen (1997) and those of d by the delta method in Doornik and Juselius (2017). Table 4 reports the estimated adjustment coefficients ζ of $\hat{\beta}^{'}\Delta x_t$, where $\hat{\beta}$ is given by the identified structure of Table 3.

The α, d and ζ coefficients allow us to investigate how the system responds to imbalances either by equilibrium error correcting or error increasing behavior. To facilitate readability, statistically insignificant adjustment coefficients

[8] See Johansen (1997) for the derivation of the LR test.

[9] Mosconi and Paruolo (2014) propose an identification scheme where the d coefficients are identified in their own right.

(with a t-ratio $< |1.6|$) are replaced by an asterisk (*).[10] Error-increasing coefficients are shown in bold face.

The estimated long-run structure, $\beta' x_t$, consists of four identified relations describing highly persistent deviations from long-run static equilibrium relations. To improve interpretability, they are formulated as long-run relations + a nonstationary residual, $z_{i.t}$. The first relation is normalized on inflation rate, the next two on unemployment rate and the last one on the confidence rate.

1. a Phillips Curve type of relation: $\Delta p_t = -0.02 u_t \ + z_{1,t}$;[11]

2. a self-reinforcing relation between unemployment rate and the bond rate: $bond_t = 0.02 u_t + z_{2,t}$;

3. a natural rate relation associating unemployment rate with the relative producer price between Greece and Germany and with the real effective exchange rate: $u_t = 0.87 relC_t - 0.62 reer_t + z_{3,t}$.

4. a relation associating a measure of confidence with the relative producer cost between Greece and Germany and with the real effective exchange rate: $conf_t = -0.97 relC_t + 1.83 reer_t + z_{4,t}$.

Cointegration is a measure of co-movements and as such is silent about causality, but combined with the α coefficients it is possible to infer where in the system long-run adjustment has taken place. Whether the variable i is error-correcting or error-increasing in response to an equilibrium error measured by cointegration relation j, can be inferred by checking whether $\alpha_{ij}\beta_{ij} < 0$ (error-correcting behavior) or $\alpha_{ij}\beta_{ij} < 0$ (error-increasing behavior) for significant values of α_{ij}. If only one $\alpha_{ij}\beta_{ij}$ is significant in cointegration relation j, then it provides some evidence of a causal link, if several are significant, then this provides evidence of joint feed-back effects. Such a check shows that

[10] Note that all β coefficients have t ratios that are sufficiently large to be statistically significant also after a near unit root correction.

[11] The small coefficient of unemployment rate in the first and second relation can be explained by data transformations. Inflation is measured as the monthly difference of logCPI (a very small number) and bond rate is measured as the annual rate divided by 1200 to give a corresponding monthly measure. Unemployment rate is measured as percentage unemployment rate divided by 100 which is approximately 30 times as large as the measurements of inflation rate and the bond rate. If standardized data had been used the coefficient of 0.02 would instead have been 0.6.

1. inflation rate, but not unemployment rate, is significantly adjusting to the first relation, the Phillips curve, consistent with the theoretical prior;

2. both unemployment and the bond rate are adjusting to the second relation signifying strong dynamic feed-back effects between the two. It shows that the bond rate has increased as the level of unemployment has increased and that the unemployment rate has increased as the bond rate has increased;

3. only unemployment is very significantly adjusting to the third relation, suggesting that it is our best candidate for a non-constant natural rate relation; and

4. only confidence rate is very significantly adjusting to the fourth relation, suggesting a causal link from fluctuations in relative producer prices and the real exchange rate to confidence in the Greek economy.

In all cases, the α adjustment represents equilibrium-error-correction. The remaining significant α coefficients show that unemployment rate has adjusted very strongly to all relations except for the first Phillips curve relation. Thus, the results show very clearly that unemployment rate is the variables that has taken the burden of adjustment over this period.

In the I(2) model, the static equilibrium error, $\beta' x_t$, is a very persistent process implying there are forces preventing the variables to equilibrium-correct in the short run. In this case, the econometric logic tell us that changes in system variables, $d'\Delta x_t$, will commove with the persistent equilibrium error, $\beta' x_t$, to produce a dynamic long-run relation, $\beta' x_t + d'\Delta x_t$, that is stationary. As mentioned above, the d coefficients can be interpreted as a measure of the dynamic adjustment (either error-correcting or error-increasing) of the changes of the variables. Error-increasing behavior is of particular interest in crisis periods as it suggests self-reinforcing adjustment behavior in the system. We shall pay special attention to such evidence in the detailed discussions of the dynamic relation.

The first dynamic relation (the Phillips curve relation) is given by:

$$\begin{aligned}\Delta p_t + 0.02u_t &= 0.002\Delta(\Delta bond_t - \Delta p_t) + 0.12\Delta u_t - 0.09\Delta conf_t \\ &\quad +0.17\Delta relC + 0.04\Delta reer - 0.004 + u_{1t}\end{aligned}$$

Table 3: The estimated long-run structure

Test of restricted β structure $\chi^2(6) = 4.67[0.59]$

	Δp	u	$bond$	$conf$	$relC$	$reer$	t
β_1	1.00	0.02 [12.3]	–	–	–	–	–
d_1	0.002 [3.4]	**−0.12** [−3.4]	−0.002 [−3.4]	0.09 [2.8]	−0.17 [−3.3]	−0.04 [−2.1]	0.004 [5.9]
α_1	−1.10 [−7.15]	*	**−0.08** [−2.53]	*	0.71 [2.05]	–	–
β_2	–	−0.02 [−4.61]	1.00	–	–	–	–
d_2	0.01 [3.7]	−0.29 [−3.7]	**−0.01** [−3.7]	0.36 [5.1]	−0.31 [−2.4]	*	−0.00 [−1.8]
α_2	*	0.13 [3.24]	−0.14 [−7.59]	*	*	–	–
β_3	–	1.00	–	–	−0.87 [−8.31]	0.62 [162.45]	–
d_3	−0.08 [−4.0]	4.32 [4.0]	0.09 [4.0]	−4.71 [−5.3]	**5.07** [3.0]	*	−3.04 [−7.4]
α_3	*	−0.01 [−3.57]	−0.01 [−3.85]	0.26 [3.14]	0.04 [1.99]	–	–
β_4	–	–	–	1.00	0.97 [3.29]	−1.83 [−150.0]	–
d_4	−0.23 [−4.4]	12.65 [−4.4]	0.26 [−4.4]	**−6.33** [−2.8]	19.53 [4.2]	6.90 [3.9]	8.93 [7.1]
α_4	0.01 [2.57]	−0.01 [−5.58]	*	−0.13 [−5.02]	−0.01 [−1.92]	–	–

* stands for an α coefficient with a t-ratio of less than 1.3

where u_{1t} is a stationary process pictured in Figure 8, panel (a). The results show that an equilibrium error in the Phillips curve relation, $\Delta p_t + 0.02u_t$, is associated with a positive change in the real bond rate, with a positive change in unemployment rate (an error-increasing effect), with a drop in confidence, with an increase in relative producer prices and with a real appreciation of the euro with respect to Greek prices.

In the long-run, the α coefficients show that inflation has been significantly error-correcting consistent with the Phillips curve hypothesis whereas the bond rate has been error-increasing to the *change* in the bond rate, signifying its almost explosive behavior in the crisis period. Thus, the Phillips curve has moved away from long-run equilibrium values because of the self-reinforcing adjustment behavior of the unemployment rate partly caused by a strongly increasing bond rate. Finally, the relative producer price has been error-correcting to the *changes* in relative price, but not very significantly so.

The second relation is given by:

$$bond_t - 0.02u_t = 0.01\Delta(\Delta bond_t - \Delta p_t) - 0.36\Delta conf_t + 0.31\Delta relC + u_{2,t}$$

where $u_{2,t}$ is a stationary process pictured in Figure 8 panel(b). The results show that the disequilibrium between the bond rate and the unemployment rate can be explained by an increase in the real bond rate (an error-increasing effect), a drop in confidence and an increase in relative producer prices. Both unemployment and the bond rate are error-correcting in the long run. This relation can predominantly be seen as a crisis relation signifying the almost explosive behavior of both the bond rate and the unemployment rate, but with the bond rate leading the race as evidenced by its error-increasing behavior.

The third relation is given by:

$$\begin{aligned} u_t - 0.87relC_t + 0.62reer_t &= -0.09\Delta(\Delta bond_t - \Delta p_t) - 4.3\Delta u_t + 4.7\Delta conf_t \\ &\quad -5.1\Delta relC_t + 3.04 + u_{3,t} \end{aligned}$$

where $u_{3,t}$ is a stationary process pictured in Figure 8 panel(c). The results show that the deviation from the natural rate of unemployment relation (Phelps, 1994) can be explained by (i) a negative effect from a change in the real interest rate (a change in the latter is likely to go together with an appreciated value of the real exchange rate), (ii) a negative effect of a change in unemployment rate (an error-correcting effect), (iii) a positive effect of a change in confidence (a positive change in the latter is likely to go together with a declining level relative prices), and (iv) a negative effect of a change in relative producer prices (an error-increasing effect). The latter shows that in the medium run, the persistent deviations of unemployment from its non-constant natural rate was strongly affected by the error-increasing behavior of relative producer costs. However, in the long run, the α coefficients show that relative producer prices are error-correcting ($\alpha_{53} = 0.04$), whereas the remaining variables - unemployment, the bond rate and confidence - are all error-correcting.

The forth relation is given by:

$$\begin{aligned} conf_t + 0.97relC_t - 1.83reer_t &= -0.23\Delta(\Delta bond_t - \Delta p_t) - 12.7\Delta u_t \\ &\quad +6.3\Delta conf_t - 19.5\Delta relC_t - 6.9\Delta reer_t \\ &\quad +8.9 + u_{4,t} \end{aligned}$$

Table 4: The estimated coefficients to the medium-run relations

Loadings to	$\beta_1'\Delta x_t$	$\beta_2'\Delta x_t$	$\beta_3'\Delta x_t$	$\beta_4'\Delta x_t$
	ζ_1	ζ_2	ζ_{31}	ζ_3
$\Delta^2\Delta p_t$	-1.12 [-5.97]	$*$	0.36 [2.50]	0.13 [2.50]
$\Delta^2 u_t$	**0.13** [1.49]	$*$	-0.43 [-6.56]	-0.16 [-6.31]
$\Delta^2 bond_t$	0.10 [2.54]	-0.98 [-17.51]	0.05 [1.77]	0.02 [1.96]
$\Delta^2 conf_t$	$*$	-3.78 [-1.50]	**$-$2.08** [-1.54]	-0.67 [-1.32]
$\Delta^2 relC_t$	-1.19 [-2.80]	$*$	**0.70** [2.16]	$*$

where $u_{4,t}$ is a stationary process. The results show that a deviation from a long-run confidence relation can be explained by a negative effect from an increase in the real bond rate, a negative effect from an increase in the unemployment rate, a negative effect from an increase in the relative price (an error-correction effect), a negative effect from a depreciation of the real exchange rate, and finally a positive effect of a change in confidence implying equilibrium increasing behavior in the medium run. However, in the long run, the α coefficients show that confidence is error-correcting ($\alpha_{44} = -0.13$) and so are the remaining variables - inflation, unemployment and relative producer prices.

Table 4 reports the medium run responses to changes in the static equilibrium errors, $\beta' x_t$. As before, error-increasing coefficients are in bold face. We find error increasing behavior in the unemployment equation as a response to the change of the first equilibrium error, $\Delta(\Delta p + 0.02u)$ and in the confidence and relative producer price equations to the change of the natural rate equilibrium error, $\Delta(u - 0.87relC + 0.62reer)$. These effects may capture the gradual deterioration of confidence and relative costs as a result of the strongly increasing bond rate and unemployment rate.

Altogether, the results provide strong evidence of many self-reinforcing feed-back mechanisms during the Greek crisis period. Unemployment was found to be error-increasing to the Phillips curve relation in the medium run (both in levels and changes), but error-correcting to the second and third relation; the bond rate was error-increasing in the medium run to the natural rate relation between inflation and the bond rate; confidence was error-increasing to the fourth relation but error-correcting to the third relation;

relative prices were error-increasing to the third relation but error-correcting to the fourth relation. The only variable that has not shown any evidence of error-increasing behavior is the Greek inflation rate. This gives empirical support to the structural slumps theory combined with imperfect knowledge expectations as discussed in Section 2.

Considering the wild fluctuations over this period, the results are remarkably good. The signs of the coefficients are as expected, the estimated relations are plausible as a description of dynamic transmission mechanisms in a period of severe crisis. While one should be careful not to over-interpret the medium-run effects, $\alpha d'\Delta x_t + \zeta\beta'\Delta x_t = \Gamma = I - \Gamma_1 - \Gamma_2$, as they are often more unstable over time than $\Pi = \alpha\beta'$, the plausibility of the coefficient estimates gives credibility of the results.

Whether the results will hold also when the crisis is finally over is a more difficult question. We believe that the pronounced persistence of the equilibrium errors is likely to disappear and the corresponding error-increasing adjustment dynamics to become more insignificant, but that many of the estimated long-run relations may remain relevant. If the equilibrium errors become less persistent, the data will probably become approximately $I(1)$.

5 Concluding remarks

Motivated by the structural slumps theory in Phelps (1994) we present empirical results relevant for a more elaborate understanding of the deep and prolonged Greek crisis starting roughly in 2008. Based on a cointegrated VAR analysis, the data were found to be approximately $I(2)$ over this period consistent with prolonged imbalances from equilibrium states due to self-reinforcing feed-back mechanisms. The latter can be a sign of an approaching economic crisis.

At the core of the Greek crisis we identified a critical relationship between the bond rate and the unemployment rate. When the crisis erupted, the bond rate increased strongly and unemployment started to increase, the increase in unemployment rate caused the bond rate to increase further and unemployment to follow suite, and so on. This vicious cycle was orchestrated by a continuous fall in the confidence rate that kept deteriorating until relative producer costs stopped increasing around 2012. The empirical results showed that all variables, except CPI inflation, exhibited error-increasing behavior somewhere in the system. This feature is likely to have aggravated the crisis and effectively prevented good policy solutions. Thus, the Greek recession seems to have grown out of many imbalances that were allowed to develop over a too long time. But, while accruing imbalances may counterbalance each other to some extent, a balance that is maintained by several imbalances is a very fragile balance. A large shock somewhere in the system, is sufficient for the whole thing to collapse as demonstrated in 2008 when the financial crisis hit Greece - and the world economy - with unprecedented force.

The results of the paper support the following narrative of the Greek drama: As Greece joined the euro, the level of interest rate dropped to previously unprecedented levels; low interest rates and easy access to foreign capital caused credit financed consumption - public as well as private - to soar. As a result, wages and prices were rising and the Greek competitiveness was consequently deteriorating. As external and internal imbalances grew, the financial market realized that risk was not equally distributed among the eurozone countries and that the Greek external debt was largely unsustainable. The dramatic rise of the Greek bond rate increased the cost of investment and production and made it very costly just to maintain previously accumulated imbalances. As a result unemployment took the burden of adjustment. As the euro rate was determined by factors mainly outside the control of Greece, she was stuck in a situation with no feasible options: a dramatic lowering of wage costs is politically almost impossible; leaving the euro would have been extremely costly due to the large proportion of external debt. The prolonged period of policy uncertainty following the outbreak of the crisis contributed to the drop in confidence of the Greek economy and to the increase of the already high unemployment rates and the depressed state of the economy.

An important lesson to be learnt from the results of this paper is that imbalances in the economy - whether internal or external - can be intolerable costly if they allowed to accrue over longer periods. But a reliable monitoring system, that signals the build-up of crucial macroeconomic imbalances well ahead of the outbreak of a crisis, is likely to lower the probability of a similar disastrous drama in the future.

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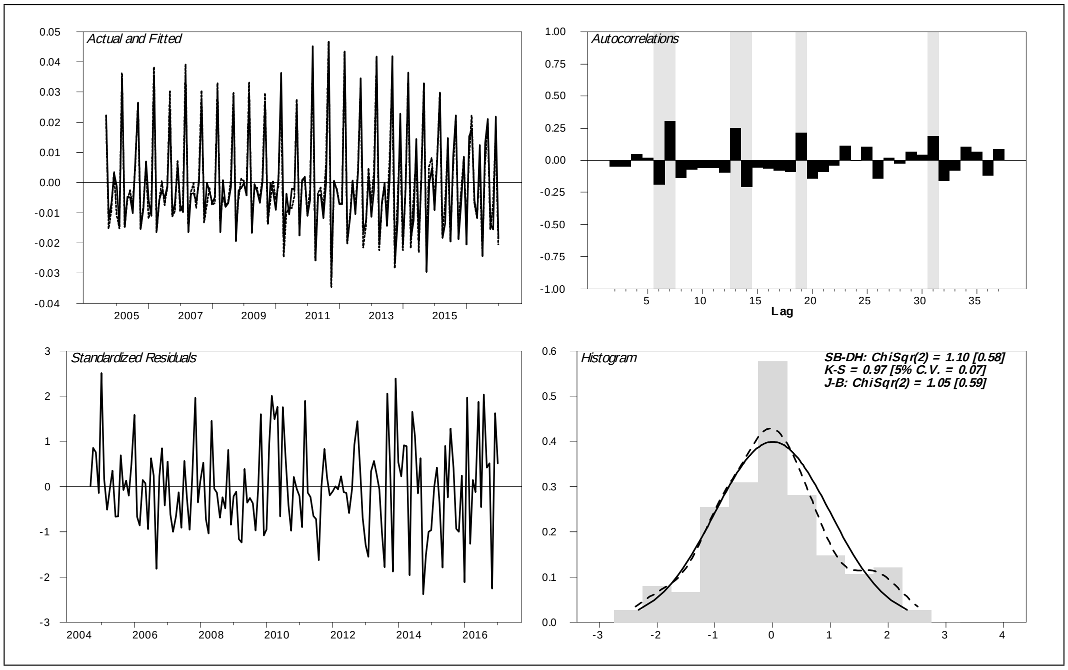
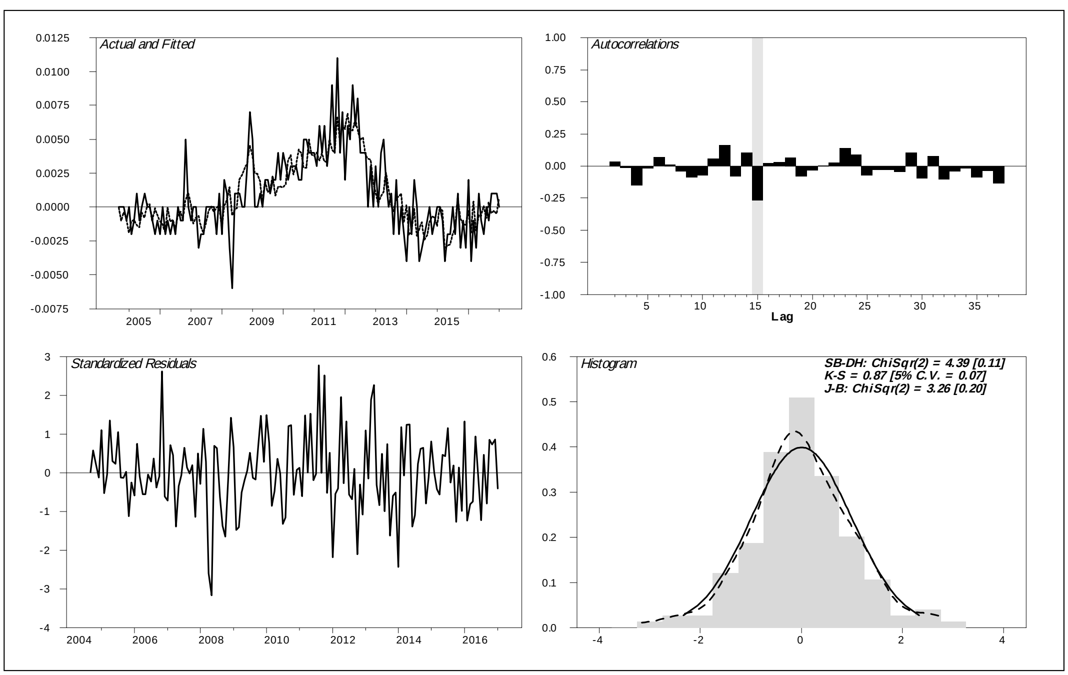
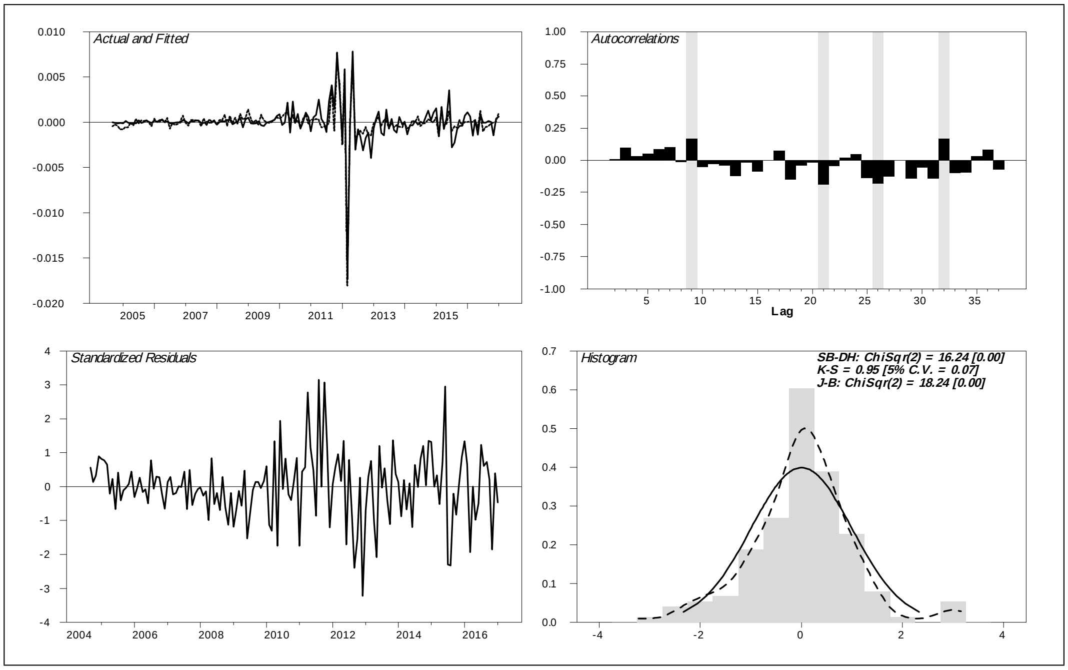
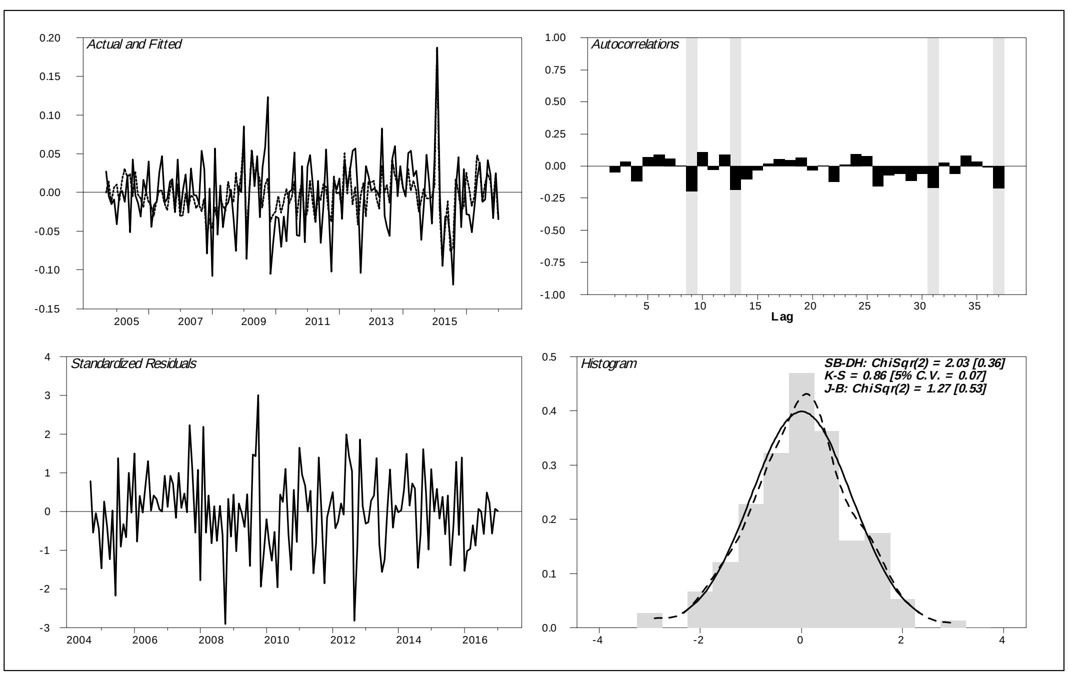
7 Appendix: Residual analyses

8 Appendix: Graphs of the equilibrium errors


Actual and Fitted
Autocorrelations
Lag
Standardized Residuals
Histogram
SB-DH: ChiSqr(2) = 1.10 [0.58]
K-S = 0.97 [5% C.V. = 0.07]
J-B: ChiSqr(2) = 1.05 [0.59]


Actual and Fitted
Autocorrelations
Lag
Standardized Residuals
Histogram
SB-DH: ChiSqr(2) = 4.39 [0.11]
K-S = 0.87 [5% C.V. = 0.07]
J-B: ChiSqr(2) = 3.26 [0.20]


Actual and Fitted
Autocorrelations
Lag
Standardized Residuals
Histogram
SB-DH: ChiSqr(2) = 16.24 [0.00]
K-S = 0.95 [5% C.V. = 0.07]
J-B: ChiSqr(2) = 18.24 [0.00]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Autocorrelations
Lag
Standardized Residuals
Histogram
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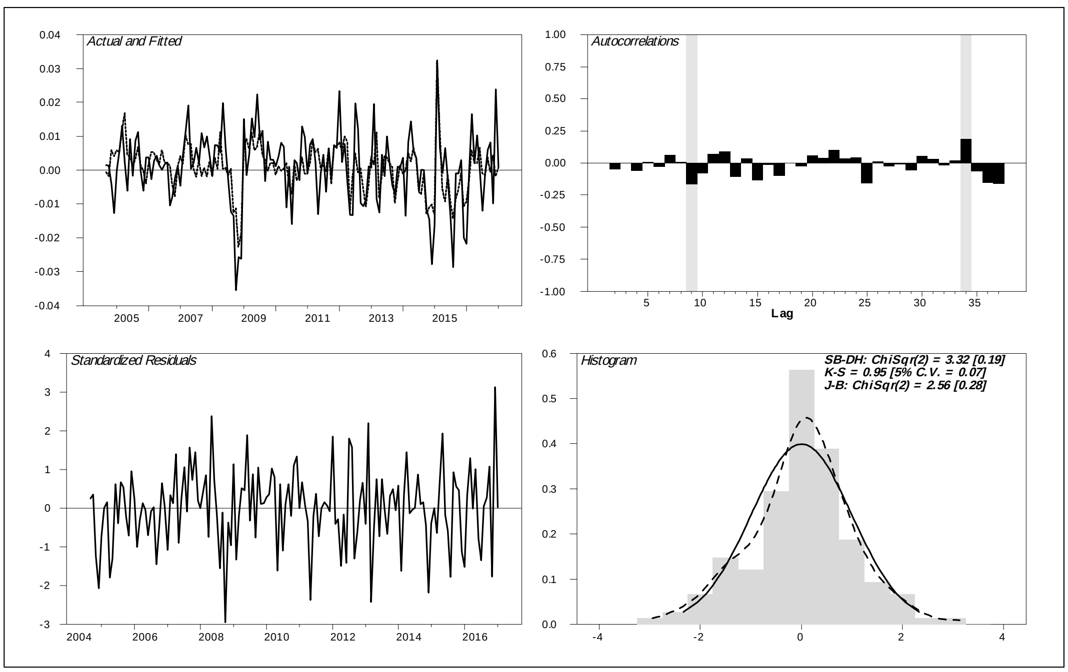
J-B: ChiSqr(2) = 1.27 [0.53]



Actual and Fitted
Autocorrelations
Lag
Standardized Residuals
Histogram
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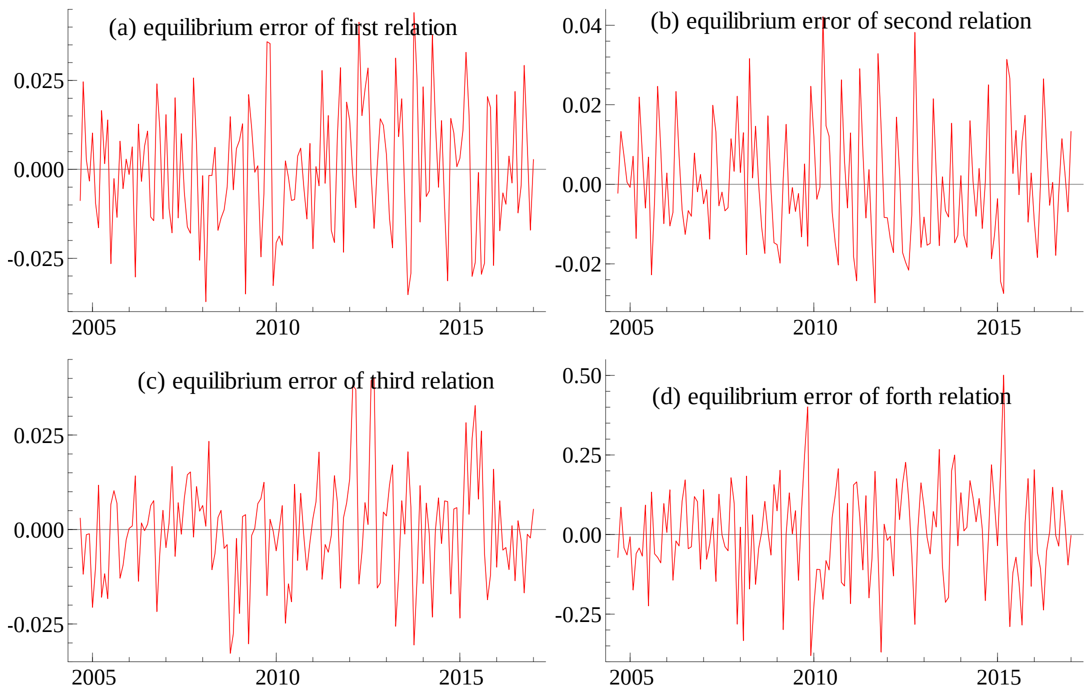
K-S = 0.95 [5% C.V. = 0.07]
J-B: ChiSqr(2) = 2.56 [0.28]


(a) equilibrium error of first relation
0.025
0.000
-0.025
2005
2010
2015
(b) equilibrium error of second relation
0.04
0.02
0.00
-0.02
2005
2010
2015
(c) equilibrium error of third relation
0.025
0.000
-0.025
2005
2010
2015
(d) equilibrium error of forth relation
0.50
0.25
0.00
-0.25
2005
2010
2015