ISTITUTO UNIVERSITARIO NAVALE
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# FLUCTUATIONS WITHIN THE EMU COUNTRIES: AN EMPIRICAL PERSPECTIVE

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# FLUCTUATIONS WITHIN THE EMU COUNTRIES: AN EMPIRICAL PERSPECTIVE

**Francesco Busato** *

**Abstract**

This paper wants to analyze some stylized facts concerning the real business cycle in the international framework. There are some questions which are usually investigated in this strand of studies: can a real business cycle model account for positive correlation between savings and investments? Can these models explain the cyclicality of the trade balance and current account? In this paper we check these stylezed facts for two groups of countries; the first one is made by the main EMU countries (Italy, Germany, France, Spain) while the second one by the largest non EMU countries (UK, US, Japan). We finally compare the properties of the probability distributions of the savings, the investiments, the trade balance and the GDP in all these countries.

**Keywords and phrases.** Real business cycle, EMU countries, Saving Investiment correlation, Trade Balance cyclicality.

* Columbia University

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This paper is in a preliminary form.

# Indice

## 1. Introduction

This paper wants to analyze some stylized facts concerning the real business cycle in the international framework. In this strand of studies there are some common questions-puzzles actually addressed: *can a real business cycle (here RBC) model account for positive correlation between savings and investments? Can these explain the cyclicality of the trade balance and current account?* In this paper we check these stylized facts for two groups of countries and we outline the structure of a real business cycle model capable in answering the above questions.

The paper is structured as follows. In this section we presents an extremely brief history of the real business cycle literature and its recent developments and in the third one describe the stylized facts for the two groups of countries; then we analyze and compare the probability distributions of these variables via the analysis and the comparison of the moments. In the last section we make a brief resume, we underline the contribution and the use of this work and then we conclude. At the end of the paper we attached a technical appendix which explains the implemented hypotesis tests.

In this section we present a very brief review of the RBC approach just to give the flavor of the topic we'll deal with[1] . The history of cycle analysis come from the 20's and the 30's. In that ancient period the scientists and also the economists concentrated their attention on the cyclical and dynamic properties of all natural phenomena; and among them, those concerning the economic world. Many different reasons reduced the interest in cycle dynamic and implication till the Seventies: in these years the contributions of Lucas [1980] gave new life to this strand of studies. The main goal of the literature in that period was directed to explain the secular growth of the United States and to "compete" with the standard growth theory in such field. In the Eighties we saw the RBC approach competing with the raising new-keynesian models [reference].

Finally, the actual literature is extending the implementation of the traditional RBC approach. The new class of model is sometimes described as the so called augmented RBC models, here ARBC models, [Henin, 1995]. In the actual literature on ARBC we can identify two different approaches: the one based on the Walrasian framework and the one based on the non-Walrasian one. The Walrasian framework is based on the canonical RBC model by King, Plosser and Rebelo [1988] and tries to improve the basic formulation introducing some developments. These concern the introduction of the labor market and its implications and puzzles [Hansen, 1995], the analysis of the international transmission of business cycles [Mendoza, Bruno-Portier] and the implementation of the so-called cash in advance constraints [Christiano-Eichenbaum,1992], [Cooley-Hansen, 1989]. From and empirical viewpoint actually these models have been extensively calibrated especially for France and US [2]. The Non-Walrasian framework switches from the competitive pricing to the monopolistic competition. The seminal models comes from Benassy [1987] and Blanchard-Kyotaky [1987]. Also in this strand of studies greater attention has been devoted to the labor market and its relation with the cycle. In this field of studies a very important approach concerns the so called creative destruction phenomenon. The seminal paper belongs to Mortensen [1990], but in the decade 1990-99 many contributions have been presented, e.g. Aghion-Howitt, [1991, 1998].

[1] We precise this section does not want to be a comprhensive review of RBC topics, but only a introduction to the framework will dealing with in the next sections.

## 2. The stylized facts for open economies

Especially in the last decade greater important has been devoted to the international fluctuations. There are two ways for formalizing an open economy real business cycle model: a two-country type model (e.g. Baxter and Crucini [1993]) and the small open economy framework (e.g. Mendoza [1991], Bruno Portier [1995]). More precisely, the still open questions concern the savings-investment correlation, the countercyclicality of the current account and trade balance, and the low cross country consumption correlation. From an empirical viewpoint we couldn't discriminate between evidences coming from the former or the latter approach, but we can identify which are the main problems and puzzle which the two kinds of analysis face. In this paper we address only the first two evidences; we made this choice because we are interested, as better explained in the conclusion, in building up an updated benchmark concerning those evidences which are treated in the small open framework.

As introduced, the first notable empirical evidence is the existence of high positive correlation between savings and investments. This issue has been subject to a long debate in the economic literature, beginning with the contribution of Feldstein and Horioka, [1980] that interpreted this phenomenon like an evidence against perfect capital mobility. But once we move to dynamical systems with stochastic shocks, that results are no more a necessary and sufficient conditions for claiming imperfect capital mobility. In fact it can be showed (Backus [1990], Baxter Crucini [1990]) that the savings-investments correlation depends on the persistence of productivity disturbances.

The second remarkable stylized fact concerns the cyclicality of current account and the trade balance with respect to the correspondent GDP. The traditional model of international economics (Busato [2000]) explain the countercyclicality of the trade balance (current account) as due to the income effect on the imports. This evidence has been observed in many countries (e.g. Backus and Kehoe [1989]). But, moving to a dynamical environment and using a real business approach we could explain this phenomenon as coming from the interaction of two effect: a pro-borrowing (because of the expected increase in future outcome) and a pro-saving one induced by a growth of the current output. Depending on which turns out to be stronger, we can obtain that countercyclicality. But it can be showed it is a not easy goal (Hercowitz [1989]).

> "These two striking regularities that emerge from the international data constitute important evidences against which real business cycle model theory can be tested" Mendoza [1991].

**2.1. The econometric procedure.** The analysis we carry out in this paper looks at the foretold stylized facts from a RBC perspective. The countries I am interested in are those in the EMU; because it's not possible to study these issues for all the countries I chose the four most representative, Italy, Germany, France, Spain. They represent the main group (here Group 1). To carry out a serious econometric analysis, we chose some countries which don't belongb to the EMU and that could be used as a control group, here Group 2. The countries belonging to the latter group are the US, the UK and the Japan.

The first issue we study is the savings-investments correlation and the cyclicality of the trade balance for all the countries in the groups.

The second issue concerns the probability distributions of saving, investments, trade balance and GDP for the all countries in the two groups. We analyze the first two moments, the skewness and the kurtosis of the distributions and I compare the results between the series. To deal with this issue, we carry out the equality tests for the moments of the distributions to provide a more rigorous comparison among those variables and countries. To be precise, we used an F test based on the ANOVA procedure for the mean equality testing; the testing procedure for the null of equal variance is based on a F test, on the Siegel-Tukey test, and on the Barlett test. We want to precise that, for all the conclusions we deal with in the next pages, the confidence interval is 0.95. The tests' structure, and the testing procedure is explained in Appendix A. Moreover we report the plot of the time series of the variables we deal with to provide a better understanding of the stylized facts.

We used annual time series from the OECD compendium, 1999; the sample begins in the 1960 and ends up in the 1999. Before estimating the correlation coefficients, we detrendized all the time series using HP filter with smoothing parameter set to 100, as usual when dealing with annual data.

**2.2. The data for Italy.** Before the beginning of the analysis we underline that we'll explain very carefully the conclusions and the procedure implemented only for the Italian economy. This choice is based on a "time saving perspective". I will present, discuss and compare the stylized facts in the same order and following the same scheme for all the countries: hence, the time spent for the first becomes a positive externality when dealing with the others. Finally, we underline that for some countries the trade balance series is shorter than the one for GDP; we can reasonably sustain that this doesn't affect the results concerning correlation and cyclicality evaluated on the common sample.

The first issue we study is the investment-savings correlation and the properties of the probability distribution of these two variables. Then we move to analyzing the cyclicality of the trade balance and to the inspection of their probability distributions. The estimation of the former correlation for the Italian is positive [Table 1].

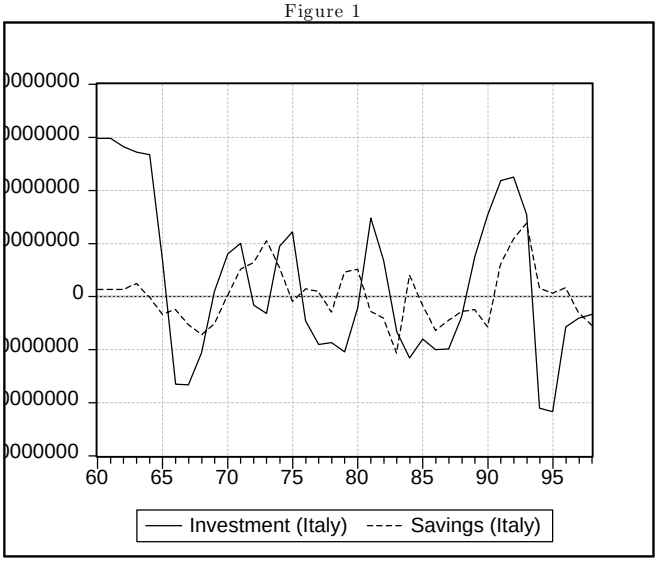
Table 1

| | *Investiment* | *Saving* |
|---|---|---|
| *Investiment* | 0.0000 | 0.2858 |
| *Saving* | 0.2858 | 0.0000 |

Saving and Investiment Correlation for Italy

This positive correlation is already evident from the graphical inspection of the series for investments and savings [Figure 1]. A more rigorous analysis leads to the rejection of the null of equal means and equal standard deviations between the distributions of investment and savings. The skewness of the two is not significantly different. But, when looking at the kurtosis we conclude that the investment distribution is flatter than the normal benchmark (Kurtosis 2.087699), while the savings' one is pretty close to the normal one (Kurtosis 3.077183).

Figure 1




The second issue we want to investigate concerns the cyclicality of the trade balance. The cyclicality of the Italian trade balance is "unusual", according to the OECD 1999 annual database. The trade balance results significantly procyclical. We'll see in the next pages how this results is unique and characterizes the Italian economic system.

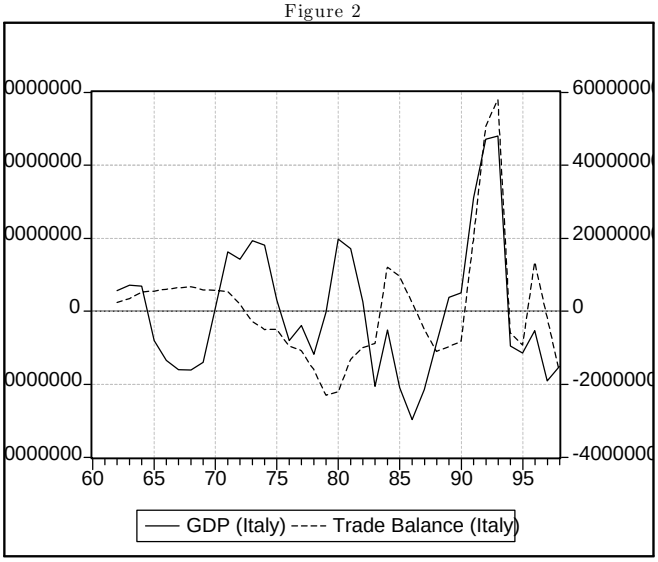
Table 2

| | *GDP* | *Trade Balance* |
|---|---|---|
| *GDP* | 0.0000 | 0.4898 |
| *Trade Balance* | 0.4898 | 0.0000 |

Trade Balance Cyclicality for Italy

Then, as we did for the investment and savings we analyze form a graphical viewpoint [Figure 2] the series and we investigate the moments of the probability distributions. Notice that we plot the two series using two crossing scales, one on the right end side -for the GDP- and one on the left end side -for the trade balance- of the graph; this procedure allows a more immediate comparison of the cyclicality of the two series. The same technique is implemented when dealing with the trade balance cyclicality for all the resting countries.

Figure 2




Looking at the implement tests of hypothesis, we accept the null of equal mean and variance. Inductively we can conclude that the two variables present an equal amplitude; the inspection of the plot of the series supports this claim. Looking at the symmetry of the series around the mean, both the series presents a larger right tail (the Skewness for the GDP equals 0.868991 and for the trade balance is 1.787315). A remark concerns the flatness of the distributions, because the trade balance one is extremely peaked (Kurtosis 7.239214) with respect to the one of the GDP (Kurtosis 3.458524) and the normal distribution benchmark (Kurtosis 3).

**2.3. The data for Spain.** The dynamic of the investment and saving series in Spain leads to a positive correlation between these two. The correlation matrix is the following:

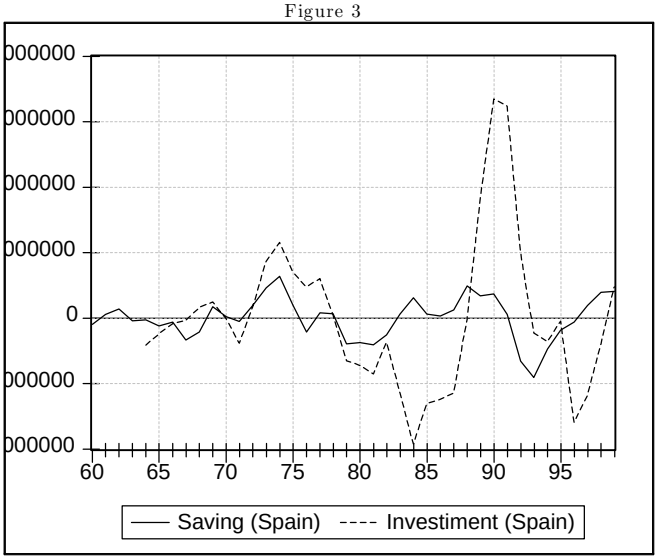
Table 3

| | *Investiment* | *Saving* |
|---|---|---|
| *Investiment* | 0.0000 | 0.2240 |
| *Saving* | 0.2240 | 0.0000 |

Saving and Investiment Correlation for Spain

We now describe the series looking at their moments. Looking at the first moment, we reject the null of equal means (7.73E-08 for the investment and -1474.211for the savings), while we accept the null of equal standard deviation. We can therefore inductively claim that savings and investment fluctuations presents the same amplitude. Moreover the two series differ with respect to the symmetry and the flatness. The investment present a large right tail (Skewness 1.168164) and a really peaked distribution (Kurtosis 4.878037); the savings probability distribution is, instead, quite symmetric and present a normal kurtosis.

Figure 3




When we estimate the cyclicality of the trade balance, we obtain a negative correlation with the GDP. This results is reported in the next table and the plot of the two series is Figure 4.

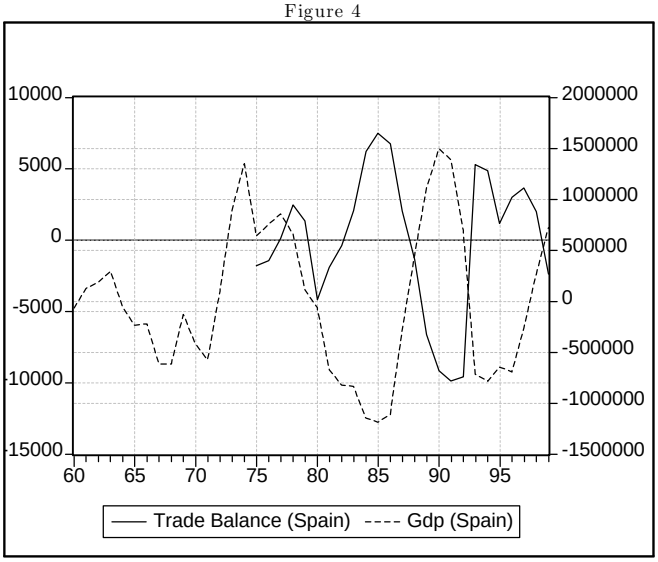
Table 4

| | *GDP* | *Trade Balance* |
|---|---|---|
| *GDP* | 0.0000 | −0.7952 |
| *Trade Balance* | −0.7952 | 0.0000 |

Trade Balance Cyclicality for Spain

Moving to the analysis of the distribution, and testing for the equality of the first two moments, we rejects the null of equality for the mean while we accept it for the standard deviation. Then checking for the skewness and the kurtosis, we conclude that the trade balance distribution is asymmetric toward the left end side and flatter than the normal and the GDP ones. More precisely the Skewness is -0.575513 for the trade balance and 0.179136 for the GDP and the Kurtosis is 2.583549 for the trade balance and 1.724198 for the GDP.

Figure 4




**2.4. The data for France.** The correlation between the saving and investment turns out to be significantly positive.

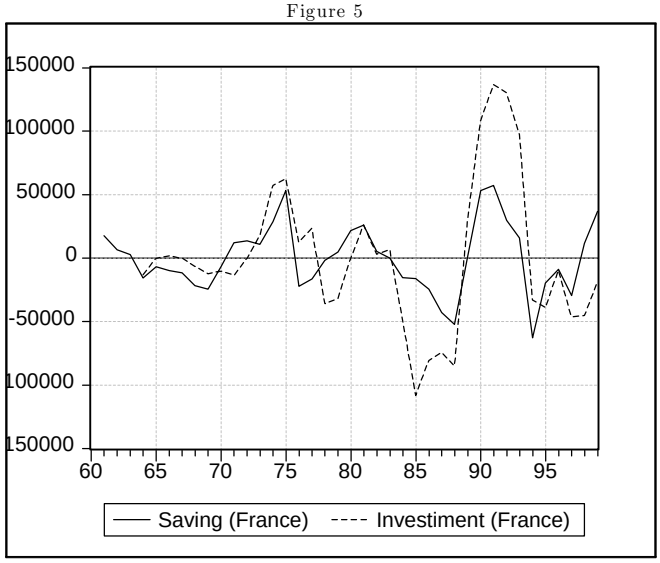
Table 5

| | *Investiment* | *Saving* |
|---|---|---|
| *Investiment* | 0.0000 | 0.7250 |
| *Saving* | 0.7250 | 0.0000 |

Saving and Investiment Correlation for France

The inspection of the series makes more clear what outlined by the table. A deeper, statistical analysis, leads us to conclude that the two means are significantly different one from the other (-747.9795 for the savings and 7.39E-09 for the investment) while the second moments (and inductively the amplitudes) are statistically equal (27955.72 for the savings and 56142.80 for the investments). Finally we can reasonably claim that the two series have a statistically equal symmetry and flatness.

Figure 5




When looking at the trade balance, we conclude that it fluctuates in a countercyclical fashion with respect to the GDP.

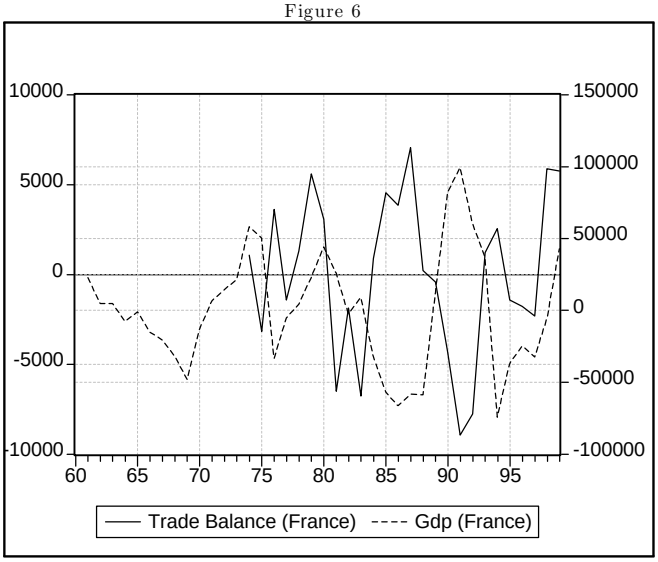
Table 6

| | *GDP* | *Trade Balance* |
|---|---|---|
| *GDP* | 0.0000 | −0.4888 |
| *Trade Balance* | −0.4888 | 0.0000 |

Trade Balance Cyclicality for France

Testing for moment equality within these two variables, we conclude that the trade balance presents a significantly different mean from the GDP (-8.79E-11 for the trade balance and 2363.416 for the GDP); the standard deviation of the former is instead not statistically different from the latter's one (4436.180 for the trade balance and 48162.47 for the GDP). Finally the Skewness and the Kurtosis of the distribution of these two variables are close each other. Notice that the trade balance series is shorter than the GDP one; France is one the countries affected by this cheat. But, as anticipated at the beginning this does not affect significantly our conclusions.

Figure 6




**2.5. The data for Germany.** The correlation between the saving and the investment in Germany is still positive.

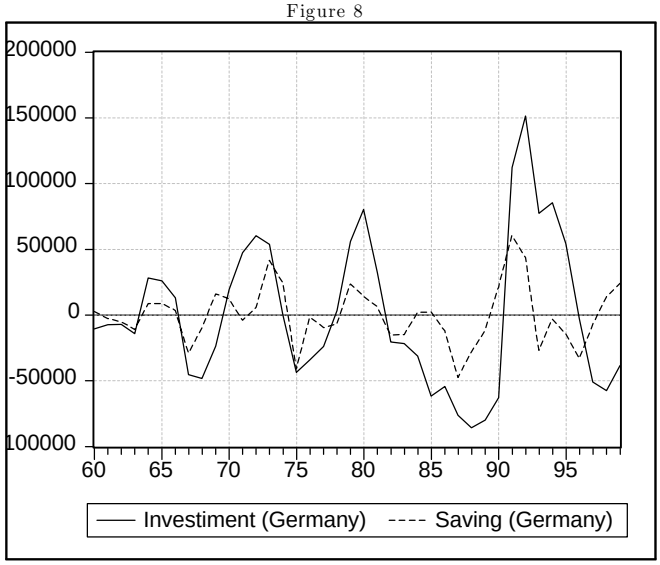
Table 8

| | *Investiment* | *Saving* |
|---|---|---|
| *Investiment* | 0.0000 | 0.2240 |
| *Saving* | 0.2240 | 0.0000 |

Saving and Investiment Correlation for Germany

In this picture we plot the series for saving and investment, both detrendized using the same procedure I used for the all variables in the sample. Testing for equality, we obtain that the mean of the investment is not significantly different from the one of the savings (respectively 3.28E-09 and 3.40E-09). The investment flow presents a higher amplitude (Std. Dev. 55886.12) than the savings (Std. Dev. 22278.99). Finally the skewness and kurtosis of the two distribution is not significantly different. The plot of the two series confirms what we outlined above.

Figure 8




As usual, the next step is to analyze the cyclicality of the current account and/or the trade balance. The correlation is negative and thus we can claim that the German trade balance is countercyclical.

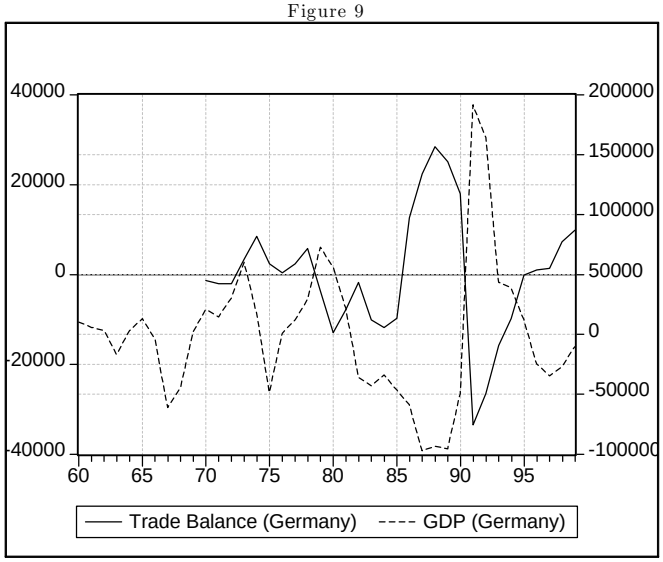
Table 9

| | *GDP* | *Trade Balance* |
|---|---|---|
| *GDP* | 0.0000 | -0.7852 |
| *Trade Balance* | -0.7852 | 0.0000 |

Trade Balance Cyclicality for Germany

Analyzing the probability distribution of the two variables, we reject the null of equal means (-6.57E-11 for the trade balance and 2932.695 for the GDP) while we accept the null of equal amplitude. Looking at the kurtosis we see that the trade balance has a more peaked distribution than the GDP (3.361469 for the trade balance and 4.316550 for the GDP). The trade balance doesn't present a significant skewness while the GDP shows up with a larger right tail (Skewness 0.965702).

Figure 9




The Germany is the last country of the first Group we analyze. Now we deal with the empirical evidences concerning the non EMU countries.

**2.6. The data for U.K..** The U.K. is the first country within the non EMU group; let me precise again that the structure of the presentation and the hypothesis used for the first group still hold. The first issue we deal with is the correlation between saving and investments: as reported in the usual correlation matrix estimated for the UK we get a positive correlation. This results is consistent with the evidences found in the EMU countries.

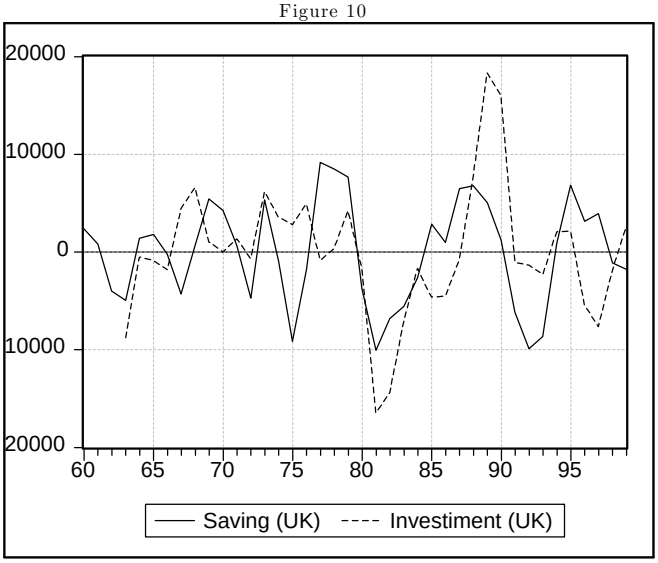
Table 10

| | *Investiment* | *Saving* |
|---|---|---|
| *Investiment* | 0.0000 | 0.4016 |
| *Saving* | 0.4016 | 0.0000 |

Saving and Investiment Correlation for UK

When dealing with the analysis of the stochastic properties of the variables, we reject the null of equal means: in fact the mean of the investment equals 5.44E-10, while the savings fluctuate over a mean of 22.43766. The standard deviations of the two series are not significantly different each others: for the investment we have 6656.733 and for the savings we have 5429.467. Finally, the two present a different kurtosis (4.613545 for the investments and 2.088503 for the saving) and a quite similar skewness. The graph of the two series is reported in Figure 10.

Figure 10




The second issue we want to discuss is the cyclicality of the trade balance. It results significantly negative and equal to -0.7721. This results is consistent, as well as the savings-investment correlation, with the evidences found in the other countries.

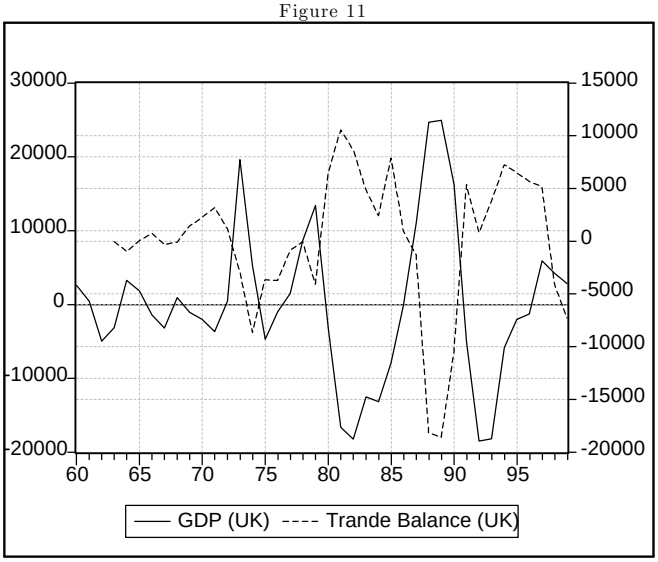
Table 11

| | *GDP* | *Trade Balance* |
|---|---|---|
| *GDP* | 0.0000 | -0.7721 |
| *Trade Balance* | -0.7721 | 0.0000 |

Trade Balance Cyclicality for UK

When we test for the equality of the moments of the probability distributions, we reject the null of equal mean (for the trade balance: -2.52E-11 and for the GDP: 51.35803) while we accept the null of equal variance (for the trade balance: 6508.228 and for the GDP: 10775.78). The trade balance distribution presents a significant asymmetry towards the left side while the GDP is quite symmetric. Finally, both the distributions are more peaked than the normal benchmark; more precisely, the trade balance distribution is more peaked than the GDP's one (Kurtosis for the trade balance 4.496798 and for the GDP 3.18240)

Figure 11




**2.7. The data for the US.** The investment and the savings flows are positively correlated along the whole sample; the correlation matrix is reported in the next table, while the two series are plotted in Figure 12.

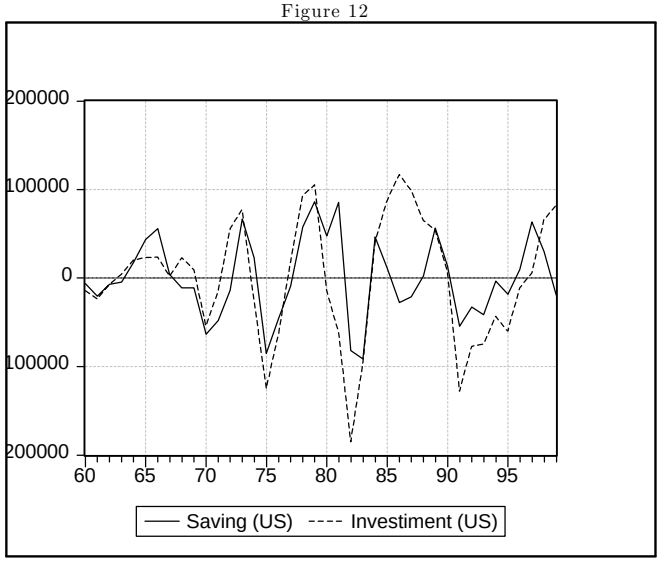
Table 12

| | *Investiment* | *Saving* |
|---|---|---|
| *Investiment* | 0.0000 | 0.6077 |
| *Saving* | 0.6077 | 0.0000 |

Saving and Investiment Correlation for US

The statistical analysis of the two time shows that the two means are not significantly different each other; moreover we observe how the standard deviation and thus the amplitude is not significantly different between the two; the savings flow is quite symmetrical around the zero line (its skewness is not significantly different from zero) while the probability distribution of the investment presents a longer left probability tail (skewness -0.455887). Moreover both the series presents a kurtosis similar to the normal distribution,as we notice from the kurtosis which estimate is 2.434388 for the savings and 2.921996 for the investments.

Figure 12




We then consider the cyclicality of the trade balance. The correlation between the latter and the GDP, both detrendized, is negative as reported in the next correlation matrix.

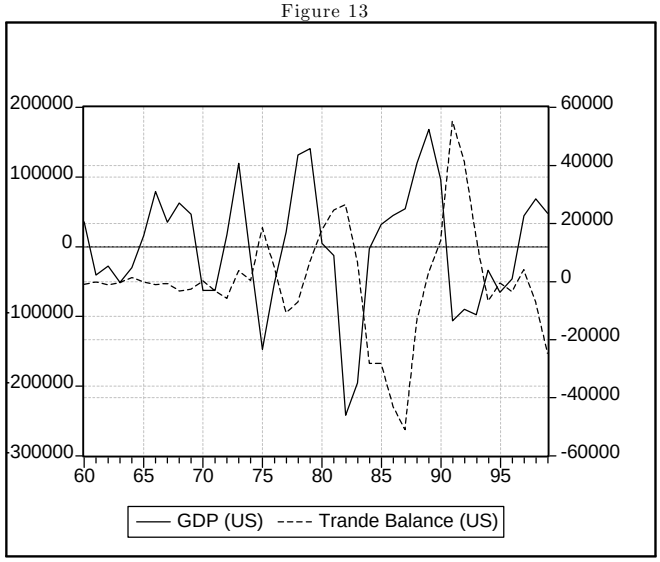
Table 13

| | *GDP* | *Trade Balance* |
|---|---|---|
| *GDP* | 0.0000 | -0.4258 |
| *Trade Balance* | -0.4258 | 0.0000 |

Trade Balance Cyclicality for US

The mean is significantly different, as well as the median. The estimated standard deviation for the trade balance equals 19269.46 while the one of the GDP is 88626.64 and hence we reject the null of equal second moments between the two series. Inductively we conclude that the series present a significantly different amplitude. Also the skewness of the two series is different, positive the one of the trade balance (this means that we conclude for a right long tail) and negative the one the GDP (this means that we conclude for a left long tail). The distribution of the trade balance is peaked with respect to a normal one (kurtosis for the normal distribution equals 3) and with respect to the GDP which kurtosis is 3.339169.

Figure 13




**2.8. The data for Japan.** We find the celebrated positive correlation between the savings and investment also for the Japanese economy.

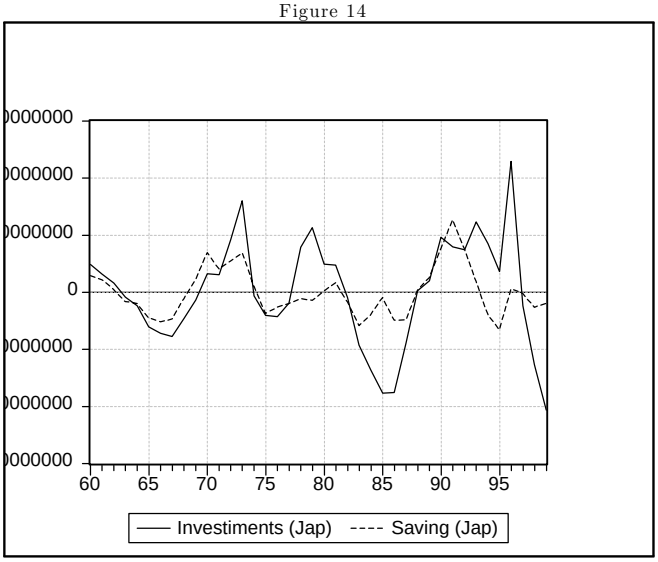
Table 14

| | *Investiment* | *Saving* |
|---|---|---|
| *Investiment* | 0.0000 | 0.5633 |
| *Saving* | 0.5633 | 0.0000 |

Saving and Investiment Correlation for Japan

Analyzing the properties of the two series, we estimate that the investment and savings means are not significantly different one from the other (2.17E-07 for the investment and 2.10E-07 for the savings), as well as the kurtosis (3.027555 for the investment 3.422942 for the savings); the probability distribution of the investment shows up a larger left tail (skewness-0.112048) while the one of the savings a larger left tail (skewness 0.838452). Finally, the amplitude of the two series is not significantly different. The next graph plot the two series.

Figure 14




The next step concerns the cyclicality of the trade balance for the Japanese economy: consistently with all the countries we examined up to now, we estimate the trade balance to be countercyclical.

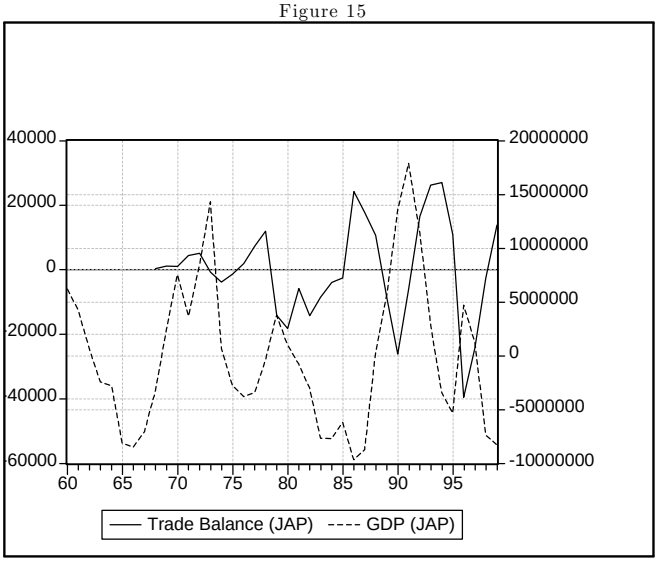
Table 15

| | *GDP* | *Trade Balance* |
|---|---|---|
| *GDP* | 0.0000 | -0.2926 |
| *Trade Balance* | -0.2926 | 0.0000 |

Trade Balance Cyclicality for Japan

After performing the tests for equalities of the two distributions, we notice that the two means are significantly different each other (559725.9 for the GDP and 1.17E-10 for the trade balance), while the same claim is not proved for the amplitude. We thus see that the standard deviations are 7190379 for the GDP and 15145.17 for the trade balance. When dealing with symmetry and flatness, the GDP presents a larger right tail (Skewness 0.651560) and quite normal flatness (Kurtosis 2.726993); the trade balance shows up a larger left tail (Skewness -0.359042) and a quite normal flatness (Kurtosis 3.223404). The plot of the two detrendized series is reported in the next figure.

Figure 15




## 3. Conclusions

In this paragraph I want to resume all the work done, to propose some conclusions and explain why this analysis is useful and with interesting perspective.

Looking at all the countries, in both groups, we can conclude that the positive correlation between the savings and the investment is a robust empirical evidence. As we saw in the literature, it is possible to explain it by a traditional viewpoint, as done in Feldstein and Horioka, or by a real business cycle perspective. But let me underline again that this paper has a empirical goal and does not want to investigate the reasons behind this stylized facts or discuss the better framework for dealing with it. In the next correlation matrix we collect the correlation coefficient that we estimated and we discussed in the previous section.

Table 16 (Correlation between Savings and Investiments)

| **COUNTRY** | **sample period** |
|---|---|
| | 19*60-1999* |
| | |
| Italy | 0.283 |
| Spain | 0.224 |
| France | 0.725 |
| U.K. | 0.402 |
| Germany | 0.520 |
| | |
| Japan | 0.563 |
| U.S. | 0.608 |

Source: OECD data set and author calculations

The second striking regularities I discussed in this paper is the cyclicality of the trade balance in a small open economy environment. As well as for the former

correlation, this evidence seems significantly robust. The only outlier is represented by the Italian estimated correlation coefficient which is significantly positive. To conclude I aggregate the estimated correlation coefficients in Table 17.

Table 17 (Cyclicality of the Current Account)

| **COUNTRY** | **sample period** |
|---|---|
| | 19*60-1999* |
| | |
| Italy | 0.500 |
| Spain | -0.795 |
| France | -0.489 |
| U.K. | -0.772 |
| Germany | -0.781 |
| | |
| Japan | -0.293 |
| U.S. | -0.426 |

Source: OECD data set and author calculations

Now, to conclude this small paper, I want to outline the message and the contribution of these paper.

This paper can be seen as an updating of the many papers (e.g. Feldstein and Horioka or Baxter and Crucini) which have been written about the savings investment correlation, also called the Feldstein and Horioka puzzle, and the cyclicality of the trade balance.

The second important reason for starting this work and then writing a paper concerns the necessity of an updated benchmark for the properties of the distributions of the savings and the investment flows, the trade balance and the GDP for the more important European countries. This paper could be an important and useful starting point for the construction of a RBC model, in small open economy framework, interested in dealing with the issues here discussed.

## 4. Appendix A

In this appendix I describe the testing procedure I implemented for comparing the probability distributions of the variables investigated in this paper.

**4.1. Mean Equality Test.** This test is based on a single-factor, between-subjects, analysis of variance (ANOVA). The basic idea is that if the subgroups have the same mean, then the variability between the sample means (between group) should be the same as the variability within any subgroup (within group). Now I briefly describe the structure of the implemented test. Denote the i-th observation in group $g$ as $x_{s,i}$, where for groups $g = 1, 2, ..., G$. The between and within sums of squares are defined as

$$SS_B = \sum_{g=1}^{G} n_g \left(\bar{x}_g - \bar{x}\right)^2$$

$$SS_W = \sum_{g=1}^{G} \sum_{i=1}^{n_g} (x_{i,g} - \bar{x})^2$$

where $\bar{x}_g$ is the sample mean within group g and $\bar{x}$ is the overall sample mean. The F-statistic for the equality of means is computed as

$$F = \frac{SS_B / (G-1)}{SS_W / (N-G)}$$

where N is the total number of observations. The F-statistic has an F-distribution with $G-1$ numerator degrees of freedom and $N-G$ denominator degrees of freedom under the null hypothesis of independent and identical normal distribution, with equal means and variances in each subgroup.

**4.2. Variance Equality Tests.** This procedure tests the null hypothesis that the variances in all G subgroups are equal against the alternative that at least one subgroup has a different variance. See Conover, et al. (1981) for a general discussion of variance testing. To be precise I implemented the following tests:

- **F-test**. This test statistic is reported only for tests with two subgroups (G = 2). Compute the variance for each subgroup and denote the subgroup with the larger variance as L and the subgroup with the smaller variance as S. Then the F-statistic is given by

$$F = \frac{s_L^2}{s_S^2}$$

  where $s_g^2$ is the variance in subgroup $g = L, S$. This F-statistic has an F-distribution with $n_L - 1$ numerator degrees of freedom and $n_S - 1$ denominator degrees of freedom under the null hypothesis of equal variance and independent normal samples.
- **Siegel-Tukey test**. This test statistic is reported only for tests with two subgroups (G = 2). The test assumes the two subgroups are independent and have equal median. The test statistic is computed using the same steps as the Mann-Whitney U test for median equality, with a different assignment of ranks. For the Siegel-Tukey test, first rank all observations from lowest to highest. Assign rank 1 to the lowest value. Then assign rank 2 to the highest value and rank 3 to the second highest value. Assign rank 4 to the second lowest value and rank 5 to the third lowest value, and so on. In other words, the ranking for the Siegel-Tukey test alternates from the lowest to the highest value for every other rank.
- **Bartlett test**. This test compares the logarithm of the weighted average variance with the weighted sum of the logarithms of the variances. Under the joint null hypothesis that the subgroup variances are equal and that the sample is normally distributed, the test statistic is approximately distributed as a $\chi^2$ with $G-1$ degrees of freedom. Note, however, that the joint hypothesis implies that this test is sensitive to departures from normality. For details, see Sokal and Rohlf (1995) and Judge, et al. (1985).

- **Levene test.** This test is based on an analysis of variance (ANOVA) of the absolute difference from the mean. The F-statistic for the Levene test has an approximate F-distribution with $G-1$ numerator degrees of freedom and $N-G$ denominator degrees of freedom under the null hypothesis of equal variances in each subgroup (Levene, 1960).
- **Brown-Forsythe (modified Levene) test**. This is a modification of the Levene test in which we replace the absolute mean difference with the absolute median difference and appears to be a superior test in terms of robustness and power (Conover, et al. (1981), Brown and Forsythe (1974), Neter, et al. (1996)).

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