Backus, Kehoe and Kydland (1993) - International Business Cycles: Theory and Evidence - Have the conclusions changed?

Bachelor's Thesis submitted

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Abstract

Backus, Kehoe and Kydland (1993) identified many empirical regularities related to international business cycles. The recurrence of cross-country correlation of output that is higher than that of consumption is particularly interesting because models predict the exact opposite. This difference between theory and data is known as the quantity anomaly. Given the relevance for subsequent research, we reassess Backus, Kehoe and Kydland's (1993) results using 23 years of more recent data and conclude that, although cross-country correlations have generally decreased, the quantity anomaly still persists.

Contents

List of Abbreviations

AUS	Australia
AUT	Austria
CAN	Canada
EU15	European aggregate
FRA	France
DEU	Germany
ITA	Italy
JPN	Japan
CHE	Switzerland
GBR	United Kingdom
USA	United States
ACZ	Ambler et al. (2004)
BKK or BKK (1993)	Backus et al. (1993)
BKK (1992)	Backus et al. (1992)
OECD	Organisation for Economic Co-operation and Development
RBC	Real Business Cycle

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1 Introduction

The 1982 ground-breaking paper "Time to Build and Aggregate Fluctuations" from Finn Kydland and Edward Prescott was responsible, according to Rebelo (2005), for introducing three great ideas in macroeconomics: (i) dynamic general equilibrium models constitute a useful tool to study business cycles, (ii) business cycle models can be consistent with the empirical regularities of long-run growth and (iii) the comparison of model properties and stylized facts can be done in a much more quantitative fashion by calibrating these models with microeconomic data and long-run properties of the economy and then generating artificial data to be compared with actual data.

David Backus, Patrick Kehoe and Finn Kydland have applied these ideas in "International Business Cycles: theory and evidence" (1993)[1], henceforth BKK or BKK (1993), to analyze international comovements among countries. They have expanded Kydland and Prescott's (1982) RBC model to include a second country, calibrated and simulated the model and then compared the result of the simulations with the regularities actual economies experienced in the second half of last century. Among several differences between theory and data, one stood out for its robustness: the data displayed a much too high cross-country correlation of output and a much too low cross-country correlation of consumption when compared to the model's predictions. Due to its insensitivity to calibration and even to radical changes in the model structure, this difference grew to be know as the quantity anomaly. Further research on international business cycle have taken these empirical findings for granted and many of the following DSGE models were built to accommodate them.

Given the relevance of BKK findings to the subsequent research in the field of interna-

[1]This paper was later published in the book "Frontiers of Business Cycle Research" edited by Thomas F. Cooley (Cooley (1995)).

tional business cycles, we reassess BKK's empirical results in the present paper using 23 years of extra data. In section 2 we shortly introduce the baseline model BKK have used to generate the simulations of international business cycles and compare it with its closed-economy version. We also point out the modifications BKK made to the baseline model, which, despite their success in correcting other discrepancies between model and data, were not able to solve the quantity anomaly. We then analyze in section 3 the specificities of our data and how it compares to BKK's. We also comment on the implications of the Hodrick-Prescott filter, which was the method used by BKK to filter the data. In section 4, we redo exactly the same calculations BKK have done using our wider time frame and compare the results. We then use an alternative approach to measure international comovements and compare our results not only to BKK's but also to Ambler et al.'s (2004), who have completed a similar analysis. We conclude that the quantity anomaly persists and end the paper by indicating how more recent models have dealt with international business cycles and sought to accommodated the quantity anomaly.

Before starting the next section, we would like to emphasize that this paper aims to be reproducible.[2] The data and the R code used to analyze it are all available online.[3]

[2]The *ultimate* standard for judging scientific research is replication. Yet, it's not always possible to fully replicate an experiment. In our case, for example, one would have to independently gather data on all analyzed economic variables for each country once again. Such a task is virtually impossible. The concept of reproducible research tries to bridge the gap between mere publication of results and full replication of research. This is accomplished by making available, along with the results, the data set and the computer code used to analyze it. In this sense, reproducibility is a *minimum* standard to judge scientific claims. See Peng (2011).

[3]The code with instructions and all the data used in this paper can be downloaded at http://denismaciel.github.io/BKK-International-Business-Cycle/.

2 The Model

Dynamic general equilibrium models have been successful in explaining many features of business cycles (Prescott (1986)). Kydland and Prescott's (1982) famous closed-economy model, in which a single aggregate productivity shock generates the business cycles, has been able to account for the magnitude of variations in output, consumption and investment and for the correlations of consumption and investment with output that actual economies experience. Their model generates most of the regularities that can be seen in the data: consumption and investment that are positively correlated with output (i.e. procyclical) and volatilities of investment and consumption that are respectively higher and lower than output volatility.

2.1 BKK's Expanded Model

Backus et al. (1992) take the model a step further and expand it to include two countries with imperfectly correlated technology shocks. By doing so, they attempt to apply the Real Business Cycle (RBC) framework to explain international business cycles. The expanded model need not only to maintain the good results of its closed-economy predecessor by explaining variations and comovements within a country, but it should also be able to reproduce the cross-country comovements of variables that characterizes the international business cycle.

To generate the simulations, BKK (1993) use a more simple version of BKK's (1992) expanded model. It consists of two countries that produce one unique good and have the same preferences and production technology. The single source of uncertainty in the model are country-specific technology shocks to total factor productivity, which are also the drivers of the business cycles. Households maximize over time a utility function that depends on

consumption and leisure and provide the labour, which, together with capital, constitutes the input for the production function.

Table 1 shows the results obtained by simulating four different models. The first row refers to Kydland and Prescott (1982)'s closed economy. The second row refers to the simplest expanded model of BKK (1993) with complete markets and no costs of transportation. The last two rows refer to modifications to the expanded model. In the third row, the model is simulated with transportation costs and, in the fourth, the possibility of trade between the two countries is excluded.

The ability to borrow in international markets have a significant influence on the fluctuations of consumption and investment, since both variables are no longer constrained by the country's production. In comparison to the closed-economy model, consumption and investment become less correlated to output. Investment volatility also increases because the ability to freely move resources across borders leads the country with the more favorable technology shock to receive a greater amount of capital than it would have received in a closed setup.

2.2 The Quantity Anomaly

The two-country RBC model in its simplest form (Table 1: Benchmark), i.e. with free movements of goods and financial assets and absence of transportation costs, differs in various aspects from the data. In this model, investment and net exports are too volatile, consumption is too smooth and outputs of the two countries are negatively correlated. In this sense, the closed-economy model fares much better than its international, two-country version in mimicking the data. Most of these discrepancies between theory and data disappear, however, when either the parameter values or the structure of the model are changed. For

			Ratio of σ to σ_y				Correlation with Output				
	σ_y	σ_{nx}	c	x	n	z	c	x	nx	n	z
Closed Economy	1.80		0.35	3.58	0.58	0.50	0.94	0.80		0.93	0.90
Benchmark	1.50	3.77	0.42	10.99	0.50	0.67	0.77	0.27	0.01	0.93	0.89
Transport Cost	1.35	0.37	0.47	2.91	0.47	0.75	0.81	0.92	0.23	0.92	0.98
Autarky	1.26		0.54	2.65	0.91	0.99	0.90	0.96		0.91	0.99

(a) Standard Deviation and Comovements within a Country

	Cross-country Correlations				
	y	c	x	n	z
Benchmark	-.21	.88	-.94	-.78	.25
Transport Cost	-.05	.89	-.48	-.70	.25
Autarky	.08	.56	-.31	-.51	.25

(b) Comovements between the two Countries

Table 1: Standard Deviations, Within- and Cross-country Comovements from Models

example, the volatility of net exports and of investment, which are respectively seven and three times higher in the model, decrease to the levels observed in the data as quadratic transport costs are incorporated into the model (Table 1: Transport Cost).

One specific discrepancy, however, proved to be highly robust. The ranking of cross-country correlations that results from the model ($\rho_{c,c^*} > \rho_{y,y^*}$) is the exact opposite to the one found in the data ($\rho_{y,y^*} > \rho_{c,c^*}$). The theoretical economy originates correlations of consumption across countries that are larger than the cross-country output correlations. Yet, in the data, output has a higher correlation than consumption across countries. BKK named this discrepancy the quantity anomaly[4] because of its insensitivity to changes not only in the parameters of the model but also in the model's structure.

[4]BKK (1993) identified also a second anomaly: the standard deviation of terms of trade is larger in the data than it is in the model. Nevertheless, we will focus only on the quantity anomaly in this paper.

2.3 Robustness of the Quantity Anomaly

Correlation between outputs in the model is negative (-0.21). Conversely, output correlation between the USA and other ten countries are all positive in BKK data set; the highest correlation being with Canada (0.76) and the lowest with Austria (0.38). The model presents a negative correlation of output of the two countries because a positive technology shock in one country increases the marginal productivity of both labor and capital in it. The higher returns create the incentive to move the factors of production from the other country to the country experiencing the most favorable technology shock. Accordingly, output increases in one country at the expenses of the other.

On the other hand, consumption between the two countries will be perfectly correlated in the model economy, if markets are complete – i.e. if agents can share risks across countries – and preferences are additively separable between consumption and leisure (Scheinkman (1984)). In BKK's benchmark model, although markets are complete, preferences are non-separable. For that reason, the correlation of consumption of the two countries in the model is 0.88 instead of one. Although not perfectly correlated, consumption displays a much too high cross-country correlation when compared to BKK's data (0.51 between US and Europe).

To address these two issues (high correlation of consumption and low correlation of output), BKK completely ban risk sharing between countries from the model (Table 1: Autarky). There is no trade of goods or securities and the only link between the two countries in the resulting autarky is the positive correlation between technology shocks. In this extreme experiment, cross-country correlation drops to 0.56 but output correlation stays much less positively correlated (0.08) than it is in the data (0.70 between US and Europe). The high correlation between consumption levels even under complete ban of risk sharing,

BKK speculate, might be attributed to the permanent income hypothesis: with a positive technology shock affecting one country, the agents of the other are aware that the shock will spill over and so increase consumption in the present and delay investment into the future.

Cross-country correlations of consumption and output are deeply related in the model. One can increase the correlation of output between the two countries by making productivity shocks more highly correlated. This, however, comes at the cost of decreasing the consumption correlation. By choosing different values for the shock correlation, the model can mimic either the correlation of consumption or the correlation of output in the data, but not both at the same time. In this sense, the quantity anomaly refers not to the size of output and consumption correlation individually. Instead, the relative size of output and consumption correlations constitutes the anomalous behavior of the model.

3 The Data

3.1 BKK's Two Papers

Before delving into the peculiarities of the data we have used, it is important to call the reader's attention to the fact that Backus, Kehoe and Kydland have dealt with the topic of international business cycles in two different papers. Both "International Real Business Cycles" (1992) and "International Business Cycles: Theory and Evidence" (1993) show cross-country correlations between the US and various countries for output and consumption. Nevertheless, the source of the data, the countries analyzed and the time frame of the observations are not the same. For that reason, there are some significant differences between the results of the two papers.

BKK's (1993) time frame is the same for all countries and all variables, 1970:1 to 1990:2. The data came from OECD's both *Quarterly National Accounts* and *Main Economic Indicators*.[5] BKK (1993) analyzes 11 countries, two less than BKK (1992). Both papers include an European aggregate. The length of the time series used by BKK (1992) to calculate the international comovements varies from country to country, the longest being for the United States (1960:1 - 1990:2) and the shortest for the European aggregate (1970:1 - 1986:4). The source of the data is IMF's *International Financial Statistics*.

The distinct sources and time frames of the data give rise to non-negligible differences between the two papers. For example, the cross-country correlation of output between Australia and the US differs by 0.26, while the difference of cross-country correlation of consumption between France and the US is 0.40 (-0.18 in BKK (1992) and 0.22 in BKK (1993)). It is important to stress the differences in the results of the two papers to justify

[5]Data from IMF's *International Financial Statistics* are also used in this paper but only to measure the exchange rate, which is not relevant for the scope of this paper.

our approach in collecting and transforming the data. The example of BKK (1992) and BKK (1993) shows that differences in the source of data can have serious influence on the end results. Since our goal is to reassess BKK's (1993) results, our aim will be the collection of data from sources as similar as possible to those used by BKK (1993) lest such a comparison ceases to make sense.

That being said, it should be noted that despite the differences, some important features of the data are the same for both BKK (1992) and BKK (1993). Output is positively correlated among all countries in the two papers, except for South Africa in BKK (1992). And consumption is far from being as highly correlated as in the model. There are even negative cross-country correlations of consumption between the US and four other countries: Australia in BKK (1993) and Finland, France and South Africa in BKK (1992).

On the following, BKK will be used to refer only to the paper "International Business Cycles: Theory and Evidence" (1993).

3.2 Our Data

The countries of our data set are the same as in BKK's: Australia (AUS), Austria (AUT), Canada (CAN), France (FRA), Germany (DEU), Italy (ITA), Japan (JPN), Switzerland (CHE), United Kingdom (GBR), United States (USA) and an European aggregate[6] (EU15).

The data we are going to work with come also from OECD's *Quarterly National Accounts* and *Main Economic Indicators*. Unfortunately, BKK give relatively little information about how the data they have used are measured. It is only said that output, consumption, fixed investment and government purchases are measured in real terms while the ratio of net ex-

[6]In our paper, the European aggregate includes fifteen countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom. BKK did not specify which countries are part of their European aggregate.

ports to output is measured in current prices. From the 20 measures OECD makes available, we have decided to use VPVOBARSA[7] to measure output, consumption, investment and government spending. To calculate the ratio of net exports to output, we have used CPCARSA[8], which is the current-prices equivalent to VPVOBARSA. For more details on how the decision to use these measures was made, see Appendix A.1.

We follow the exact same approach used by BKK to calculate the implicitly defined Solow residuals and ignore capital k in the equation: $\log z = \log y - [\theta \log k + (1-\theta)\log n]$.

The statistics of civilian employment were obtained by combining OECD's *Short-Term Labour Market Statistics* with *Main Economic Indicators* (see Appendix A.2). We summarize the data we have used in Table 2 and provide the exact specification used by OECD.

	Name	Code	Measure
y	Gross domestic product - expenditure approach	B1_GE	VPVOBARSA
c	Private final consumption expenditure	P31S14_S15	VPVOBARSA
x	Gross fixed capital formation	P51	VPVOBARSA
g	General government final consumption expenditure	P3S13	VPVOBARSA
n	Employed population, Aged 15 and over, All persons	LFEMTTTT	STSA
	Exports of goods and services	P6	CPCARSA
nx	Imports of goods and services	P7	CPCARSA
	Gross domestic product - expenditure approach	B1_GE	CPCARSA

Table 2: Variable Specification of OECD

We have expanded BKK's time frame both into the future (to include 23 years of more recent data) and into the past (to include all observations that are available in the OECD's data base). A detailed description of the length of the time series for each variable and sample country can be found in Table 3. Most of the variables have observations ranging

[7]VPVOBARSA refers to volume estimates (constant 2010 prices), converted with 2010 purchasing power parities, expressed in US dollars, at annual levels and seasonally adjusted

[8]CPCARSA refers to current prices and current purchasing power parities, expressed in US dollars, at annual levels and seasonally adjusted

from 1960:1 until 2015:1. The US and the UK are exceptions with the first observation of some variables dating back to 1947:1 and 1955:1, respectively. Estimates for even longer time frames, including the prewar period, are available in Backus and Kehoe (1992), but are not as reliable as the data gathered after 1945 and thus are not considered in this paper.

	GDP		Consumption		Investment		Government		Net Exports		Employment	
Country	Last	First	Last	First	Last	First	Last	First	Last	First	Last	First
AUS	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:2	1967:1
AUT	2015:2	1960:1	2015:2	1960:1	2015:2	1960:1	2015:2	1960:1	2015:1	1960:1	2015:1	1969:1
CAN	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:2	1955:1
CHE	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1		
DEU	2015:2	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1962:1
EU15	2015:1	1961:1	2014:4	1961:1	2014:4	1961:1	2014:4	1961:1	2015:1	1960:1		
FRA	2015:2	1960:1	2015:2	1960:1	2015:2	1960:1	2015:2	1960:1	2015:1	1960:1	2013:4	1978:1
GBR	2015:2	1955:1	2015:1	1955:1	2015:1	1955:1	2015:1	1955:1	2015:1	1960:1	2015:1	1969:2
ITA	2015:2	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1960:1	2015:1	1959:1
JPN	2015:2	1960:1	2015:2	1960:1	2015:2	1960:1	2015:2	1960:1	2015:1	1960:1	2015:2	1955:1
USA	2015:2	1947:1	2015:2	1947:1	2015:2	1955:1	2015:2	1955:1	2015:2	1947:1	2015:2	1955:1

Table 3: Length of the Time Series for each Country

3.3 Hodrick-Prescott Filter

The analysis of international comovements among countries requires a precise definition of business cycles. Time series of economic variables can be seen as the result of the interaction between two components: one with slow variations (growth trend) and one that changes rapidly (the business cycle). The problem is that these two components, trend and cycle, are unobservable. What can be observed are only the results of their interaction, i.e. the measured values of output, investment etc. Before starting the analysis, the researcher needs to decide how to estimate the trend component and consequently determine the cycles.

The method used by BKK, also applied in this paper for comparability, is the Hodrick-Prescott filter described in Hodrick and Prescott (1981). This filter emphasizes the medium- and high-frequency movements in the data and "can be thought of as removing a smooth

trend line (like one might draw freehand) from the data" (Backus and Kehoe (1992)). According to Baxter (1995), the resulting series will be stationary, if the filtered series is integrated of order four or less. Figure 1 depicts the filtered GDP series of the US. The red line represents the trend; the blue line the cycles.

The parameter λ, which penalizes variability in the trend component – the larger the value of λ, the smoother is the trend –, is set to be $\lambda = 1,600$ following the suggestion of Hodrick and Prescott (1981) for quarterly data.

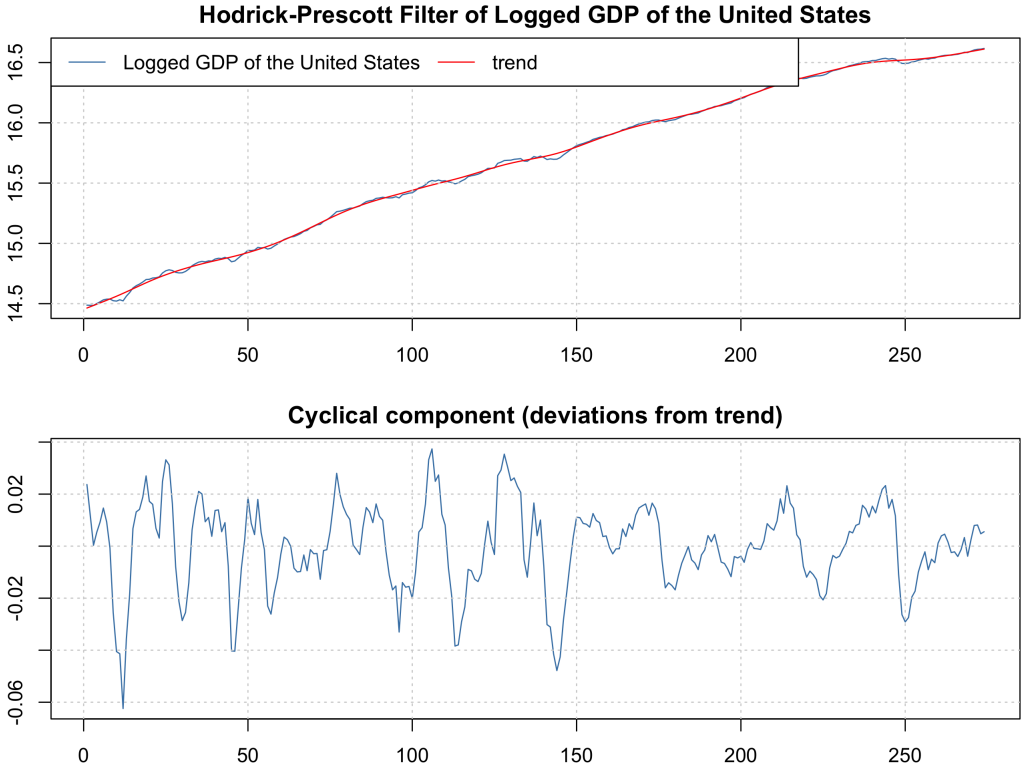


Figure 1: GDP of the United States detrended with Hodrick-Prescott Filter

Despite its wide application in the research of business cycles, the HP Filter have received some critics for its implications in determining the business cycle characteristics. King and Rebelo (1993) find that the HP Filter not only lowers the standard deviations of the filtered variables (which is expected from a filter) but it also alters the correlation between the filtered variables substantially. Moreover, the conditions, under which the HP filter is optimal in

the sense of minimizing the mean squared error, are unlikely to be met in practice. They conclude that mechanically applying the HP filter removes important variations of the time series that are normally associated with the business cycles. Conversely, Cogley and Nason (1995) shows also that HP filter might create business cycle characteristics that do not exist in the actual data, if it is applied to integrated time-series. More recently, Phillips and Jin (2015) have found that, contrary to the dominant belief in applied macroeconomics, detrending with HP filter normally fail to filter stochastic trends from the series.

The HP filter assumes that deviations from growth trend are short and output returns to its potential growth quickly. For that reason, it may deliver particular bad results in long recessions.[9] In case of a deep slump, the HP filter will make the growth trend flatter, which in turn leads to the cycle component being not as large as it would otherwise be. In sum, HP filtering tend to underestimate the duration of economic downturns. For us, this might be a problem when dealing with the period of the Great Recession. If we analyze US output values filtered with HP filter, however, we see that output stayed below its trend from 2008:4 to 2011:4. According to the National Bureau of Economic Research, the Great Recession ended in June 2009. Thus, in this specific case at least, HP filter have not excessively shortened the duration of the recession.

[9] A summary of an interesting controversy about the HP filter that took place in the economic blogosphere can be found at http://bruegel.org/2012/07/blogs-review-hp-filters-and-business-cycles/.

4 The Results

We will now compare our results with BKK's in order to address the question of whether the empirical regularities identified in 1993, specifically those regarding international comovements, are still valid. To make comparison easier, our results are presented beside BKK's, which appear in parenthesis.

4.1 Within-country Comovements and Volatility

We report the values for standard deviations and within-country correlations in Table 4 and Table 5, respectively. Table 4 gives information about volatility by displaying the ratio of the standard deviation of each variable to the standard deviation of output (except for net exports, whose standard deviation is presented in absolute terms, following BKK). Table 5 shows comovements of economic variables inside each country. Its second column shows the autocorrelation of GDP with its one-period-lagged value and the following columns report the contemporaneous correlation between GDP and the respective variable.

	Std. Dev. (%)		Ratio of Std. Dev. to that of y				
Country	y	nx	c	x	g	n	z
AUS	1.32 (1.45)	1.14 (1.23)	.83 (.66)	2.98 (2.78)	1.28 (1.28)	.79 (.34)	.77 (1.00)
AUT	1.24 (1.28)	.80 (1.15)	.94 (1.14)	2.65 (2.92)	.68 (.36)	.67 (1.23)	.97 (.84)
CAN	1.36 (1.50)	.88 (.78)	.81 (.85)	2.94 (2.80)	1.04 (.77)	.77 (.86)	.70 (.74)
CHE	1.66 (1.92)	1.89 (1.32)	.64 (.74)	2.35(2.30)	.92 (.53)	(.71)	(.67)
DEU	1.58 (1.51)	.70 (.79)	.77 (.90)	2.57 (2.93)	.86 (.81)	.67 (.61)	.84 (.83)
EU15	1.07 (1.01)	.43 (.50)	.72 (.83)	2.43 (2.09)	.53 (.47)	(.85)	(.98)
FRA	1.12 (.90)	.62 (.82)	.79 (.99)	2.30 (2.96)	.58 (.71)	.49 (.55)	.73 (.76)
GBR	1.48 (1.61)	.88 (1.69)	1.08 (1.15)	2.58 (2.29)	.84 (.69)	.65 (.68)	.84 (.88)
ITA	1.46 (1.69)	1.00 (1.33)	.87 (.78)	2.56 (1.95)	.58 (.42)	.48 (.44)	.94 (.92)
JPN	1.56 (1.35)	.79 (.93)	.79 (1.09)	2.22 (2.41)	.74 (.79)	.33 (.36)	.92 (.88)
USA	1.63 (1.92)	.43 (.52)	.77 (.75)	2.48 (3.27)	.84 (.75)	.64 (.61)	.65 (.68)

Table 4: Standard Deviations

Country	Autorcor.	c	x	g	nx	n	z
AUS	.70 (.60)	.44 (.46)	.66 (.68)	.00 (.15)	-.26 (-.01)	.56 (.12)	.84 (.98)
AUT	.72 (.57)	.54 (.65)	.68 (.75)	-.05 (-.24)	-.12 (-.46)	.29 (.58)	.91 (.65)
CAN	.83 (.79)	.78 (.83)	.69 (.52)	-.21 (-.23)	.05 (-.26)	.76 (.69)	.89 (.84)
CHE	.83 (.90)	.70 (.81)	.78 (.82)	.34 (.27)	-.23 (-.68)	(.84)	(.93)
DEU	.78 (.65)	.63 (.66)	.84 (.84)	-.06 (.26)	-.06 (-.11)	.58 (.59)	.91 (.93)
EU15	.86 (.75)	.80 (.81)	.91 (.89)	-.20 (.10)	-.34 (-.25)	(.32)	(.85)
FRA	.55 (.78)	.68 (.61)	.83 (.79)	-.03 (.25)	-.11 (-.30)	.58 (.77)	.93 (.96)
GBR	.80 (.63)	.77 (.74)	.74 (.59)	-.08 (.05)	-.35 (-.19)	.62 (.47)	.92 (.90)
ITA	.82 (.85)	.69 (.82)	.79 (.86)	-.04 (.01)	-.48 (-.68)	.33 (.42)	.95 (.96)
JPN	.78 (.80)	.75 (.80)	.86 (.90)	.07 (-.02)	-.20 (-.22)	.46 (.60)	.98 (.98)
USA	.85 (.86)	.77 (.82)	.92 (.94)	-.13 (.12)	-.35 (.-37)	.77 (.88)	.92 (.96)

Table 5: Within-country Correlation between Output and other Variables

Our results are in line with what have come to be known as the stylized facts of the business cycle. Consumption is procyclical and, except for UK, less volatile than output. Differently from BKK's result, in which three countries had consumption more volatile than output, consumption volatility relative to output seems to have decreased. From the eleven countries, eight have experienced reductions in this measure. From the three that have seen its consumption volatility rise, only Australia experienced an increase greater than 0.1.

Investment is also procyclical but more volatile than output. In Japan, the country with the lowest volatility, investment has been 2.22 times more volatile than output, while in Australia, where it is most volatile, investment has been almost three times more volatile than output. Different from consumption, there has not been a clear tendency in the behavior of investment volatility from BKK years to nowadays. The sharp decrease US has experienced in investment volatility is worth noting, however. Standard deviation of investment relative to that of output in the US has decreased from 3.27 to 2.48. This combined with the Italian increase has led to a reduction of the range of the investment volatility distribution from

1.32 in BKK to 0.72.

Autocorrelation of output has not changed in any noticeable way. Six countries have witnessed an increase and five a decrease in this measurement, most of which of modest magnitude. Output volatility has decreased for six countries and increased for five. Remarkable, however, is that the distribution has become more uniform. Countries that had higher volatilities of output have in general experienced a decrease (United States, Switzerland and Italy), while those with lower volatilities have seen their volatilities increase (France, European aggregate and Japan). The tails of the distribution are now closer to the mean.

Government spending does not display a clear tendency regarding its correlation with output. In our sample most of the countries have a negative correlation between output and government spending but with small magnitude. Moreover, the largest correlation in magnitude is positive (Switzerland, 0.34). Together, these two facts – majority of small-magnitude negative correlations and the highest correlation in magnitude being positive – makes a strong case for the acyclicality of government spending. In BKK's data set, correlations between output and government spending are most positive but never greater than 0.27 in magnitude, which also indicates that government spending has being acyclical since then.

The volatility of employment and its correlation with output have changed considerably for some countries but the overall picture have stayed constant. The same happened to Solow residuals: some countries experienced increases in its volatility, while others have seen it decline. The overall distribution of the cross-country correlations of both employment and Solow residuals, however, does not seem to have changed.

4.2 International Comovements of the USA

Having seen that stylized facts within economies have barely changed, we now turn to the comovements among countries. We use – as BKK did – the US economy as a benchmark and measure how its economic variables correlate with the respective variables of the other ten countries in the sample. Table 6 presents the contemporaneous cross-country correlations between USA and the other ten countries.

In accord with BKK findings, outputs are positively correlated. The magnitude of the correlations, however, seems to have decreased. Of ten output correlations, nine have become smaller. Only UK's output experienced a slight increase in its correlation with American output. Smaller cross-country correlations of output point in the direction of an approximation between theory and data.

Consumption behaves similarly as in BKK. In the longer time frame of our data, there is a positive correlation between the US and all countries but Italy. In BKK's data set, US consumption correlation was positive with all countries except for Australia. Although not as clear as in the case of output, there seems to be tendency for the magnitude of consumption correlation to decrease. Different from the decrease in cross-country correlation of output, the decrease in consumption correlation across countries accentuates the contrast between theory and data, since the model predicts very high correlation of consumptions (0.88).

Comovements of investment and government spending between US economy and the other countries have not changed their behavior in any remarkable way. Nonetheless, we note that, although US investment still correlates positively with the other sample countries', the range of the distribution have decreased from 0.57 to 0.39. Cross-country correlations of government spending are still very low meaning that government spending is virtually

uncorrelated between countries.

From our calculations, net exports appear to be uncorrelated between US and the other countries. If anything, a light tendency to a negative correlation may be identified. BKK have not reported cross-country correlations of net exports.

US employment correlates positively with other countries' in our data as well as in BKK's. The cross-country correlation of Solow residuals is still positive between the US and all other countries but its magnitude seems to have decreased.

Updating BKK's calculations with 23 years of recent data does not change the conclusions they have arrived at in 1993. Cross-correlations of output and consumption might have decreased on average. Yet, this fact does not do much to disprove the central discrepancy BKK had found between theory and data. What characterizes the quantity anomaly is not the output or consumption correlation itself but precisely the relative magnitude of both. Since consumption and output correlations have decreased together, the relation between them has stayed virtually the same and so too the quantity anomaly.

	Correlation with Same U.S. Variable						
Country	y	c	x	g	nx	n	z
AUS	.27 (.51)	.02 (.-19)	.36 (.16)	.07 (.23)	.05	.37 (-.18)	.28 (.52)
AUT	.28 (.38)	.17 (.23)	.33 (.46)	.09 (.29)	.09	.27 (.47)	.24 (.17)
CAN	.75 (.76)	.56 (.49)	.35 (-.01)	.33 (-.01)	-.31	.60 (.53)	.63 (.75)
CHE	.30 (.42)	.21 (.40)	.38 (.38)	-.03 (.01)	-.11	(.36)	(.43)
DEU	.37 (.69)	.30 (.49)	.42 (.55)	.05 (.28)	-.04	.37 (.52)	.31 (.65)
EU15	.53 (.66)	.44 (.51)	.51 (.53)	.23 (.18)	-.11	(.33)	(.56)
FRA	.36 (.41)	.29 (.39)	.35 (.22)	-.03 (-.20)	.04	.16 (.26)	.37 (.39)
GBR	.59 (.55)	.45 (.42)	.44 (.40)	.21 (-.04)	.01	.67 (.69)	.50 (.35)
ITA	.32 (.41)	-.03 (.02)	.12 (.31)	.14 (.09)	-.16	-.01 (-.01)	.24 (.35)
JPN	.32 (.60)	.22 (.44)	.35 (.56)	.03 (.11)	-.22	.41 (.32)	.20 (.58)

Table 6: Cross-country Correlations

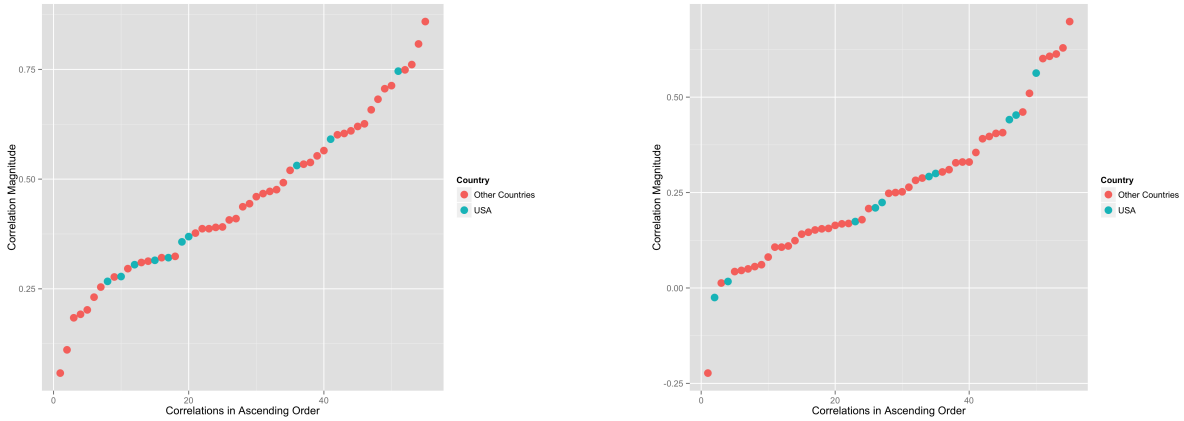
4.3 International Comovements of all Countries

While analyzing international comovements, BKK have only used correlations involving the US economy. By doing so, they have ignored other 45 cross-country correlations for each variable resulting from the sample with eleven countries. As Ambler et al. (2004) put, the US economy is not representative among industrialized economies in terms neither of size nor of openness. For that reason, cross-country correlations of US economy might not provide a good picture of what happens among the other countries.

We inquire next how well the correlations involving the US represent the distribution of all correlations. We are interested here not only in how United States' output correlates with, say, Germany's and Japan's but also in how these two correlate with each other. To address this issue, we plotted in Figure 2 all the 55 correlations of output and consumption in ascending order. Output and consumption were chosen for being the two most relevant variables for the quantity anomaly. Correlations involving the US are highlighted, so that the reader can have an idea of the implications of choosing the US as the benchmark for determining the properties of international comovements.

Output correlations are all positive. Those involving US are on average smaller than the others. Consumptions correlations are also mainly positive with two exceptions (ITA-USA and AUS-DEU). For consumption, however, US correlations are more evenly spread along the distribution.

We now approach the problem of determining the characteristics of the international comovements from a perspective other than BKK's. Instead of reporting only the cross-country correlations of the US, we calculate the mean of the correlations between all countries of our sample. We also calculate the mean of the correlations involving the US to assess in



(a) Output Correlations **(b)** Consumption Correlations

Figure 2: Output and Consumption Correlations among all Countries

how far BKK's approach deviates from ours. Ambler et al. (2004), hereafter ACZ, adopt a similar approach[10] and we report their results in square brackets. Table 7 shows in its first column the average of all correlations, in the second column the average correlations involving US and in the remaining columns various quantiles summarizing the distribution of all correlations.

	Mean	USA Mean	0%	10%	25%	40%	**50%**	60%	75%	90%	100%
y	**.45 [.22]**	.41 (.54)	.06	.23	.31	.39	**.44**	.48	.60	.71	.86
c	**.26 [.14]**	.26 (.32)	-.22	.05	.12	.17	**.25**	.29	.39	.56	.70
x	**.38 [.18]**	.36 (.36)	.01	.15	.24	.32	**.37**	.42	.51	.61	.83
g	**.10**	.11 (.35)	-.28	-.07	-.03	.05	**.07**	.11	.15	.33	.78
nx	**.08**	-.08	-.31	-.22	-.08	.02	**.05**	.09	.20	.41	.75
n	**.28 [.20]**	.36 (.32)	-.04	.02	.10	.20	**.26**	.32	.41	.61	.69
z	**.35 [.16]**	.34 (.48)	-.02	.14	.22	.32	**.35**	.38	.47	.51	.72

Table 7: Average Cross-country Correlation among all Countries

We first note that the mean and the median of all correlations are very similar, so they can

[10] ACZ also reassess BKK's results using a greater sample of countries and slightly different data. They use a sample of twenty industrialized countries with data from 1960:1 to 2000:4. Different from BKK, they include capital when calculating the Solow residuals. They also report the standard errors and test for the statistical significance of their results.

be used interchangeably to characterize the distribution. The quantiles of the distribution also indicate that the quantity anomaly is unlikely to have disappeared. 50% of the output correlations are greater than 0.44, while none of the consumption correlations is as high as 0.88, the expected value in theoretical economies. The largest consumption correlation is 0.70 and 90% of them lie below 0.56.

It turns out that averaging only USA correlations delivers surprisingly similar figures to the ones resulting from averaging all correlations. If net exports are not considered,[11] the largest difference between overall and USA mean is in civilian employment, which amounts to 0.07. Except for investment and employment, the correlations of variables have decreased when compared to BKK's results. USA mean of output correlations have dropped by 0.13 and consumption by 0.06. However, these decreases are not as striking as those reported by ACZ. Output correlation drops from 0.54 in BKK to 0.22 in ACZ. In this respect, ACZ's results brings the data closer to the model, which predicts low and, depending on the version of the model, even negative cross-correlation of output. Consumption, on the other hand, decreases by 0.18, a result which accentuates the difference between model and data, since cross-country correlation of consumption should be very high according to the theory.

Our results represent a middle ground between BKK and ACZ. The greater sample used by ACZ seems to be key for the large decrease in all the cross-country correlations. However not as striking as in ACZ, the larger time frame we have adopted also had an impact in diminishing the correlations among countries.

[11] US trade balance has a *sui generis* behavior due to the status of the dollar as the international reserve currency. The rate of return on US foreign investments is two to three times higher than the interest rate the US has to pay for liabilities of other countries. This allows the US to constantly run trade deficits without becoming more indebted. For that reason, US comovements of net exports might not be a good proxy for the whole distribution of cross-country correlation of net exports. For more on what have become to be known as the exorbitant privilege, see Eichengreen (2011)

This overall decrease in cross-country correlations have little impact on the quantity anomaly.On the one hand, the overall decrease in cross-country correlations attenuates the discrepancy between theory and data, because it means that output correlations will become closer to the levels predicted by the model. On the other hand, the decrease in cross-country correlation of consumption accentuates this discrepancy, since consumption correlation is very high in the theoretical economy.

In fact, the quantity anomaly becomes even more salient when each pair of cross-country correlation is considered individually. In Figure 3 we plot the cross-country correlation of output and consumption for each of the 55 possible pairs of countries. The line has a slope of 45 degrees and represent all combinations of values for which output correlation equal consumption correlation. Of all pairs, only two lay below the line and thus violate the empirical regularity that outputs correlate more strongly than consumptions (AUS-FRA and CHE-GBR in red). For all the others, correlation of outputs is greater than correlation of consumption.

In sum, the quantity anomaly persists: the difference between output and consumption correlation is roughly 0.20 both in BKK's calculations and ours. Although ACZ arrives at a milder difference of only 0.08, they reject the null hypothesis that the cross-correlation of output is less than or equal to the average cross-correlation of consumption ($H_0 : \rho_{y,y^*} \leq \rho_{c,c^*}$) at 5% significance level. What's more, when the pairs of countries are taken into consideration individually, the quantity anomaly becomes even more evident: out of 55 pairs, 53 have correlation of output that are greater than that of consumption.

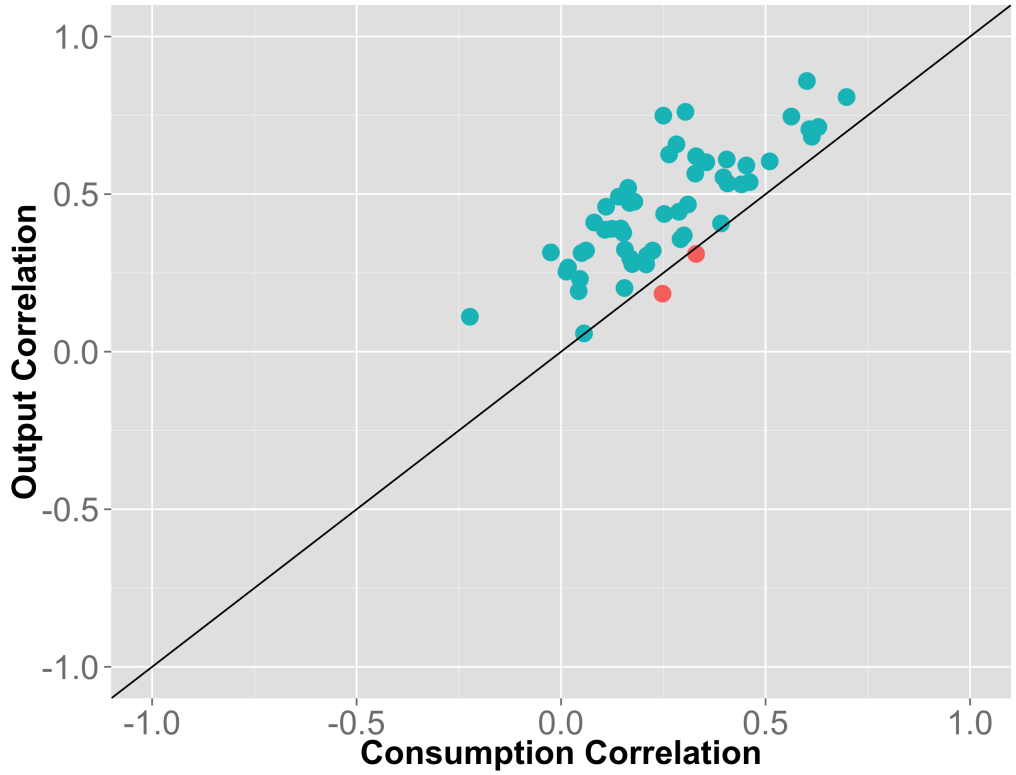


Figure 3: Cross-country Correlation of Output and Consumption for each Pair of Countries

4.4 Further Research on International Business Cycles

We indicate next two papers that claim to have corrected the quantity anomaly, at least partially, and point out different directions that research in international business cycle have taken in the last years.

Kehoe and Perri (2002) corrects the problem of negative cross-country correlation of output. They build a model in which countries can default on their loans: the single mechanism to enforce loans is the threat of excluding the defaulting country from future trade. This friction in the credit market generates a positive cross-country correlation of output (0.25), which is still smaller than that of consumption (0.29), however.

Faia (2007) disputes the idea that the central driver of international comovements is trade and makes the case for financial institutions as a good predictor of the size of the

comovements between countries. She shows that there is a negative relation between pairwise output correlation and a measure of financial distance and constructs a model with financial frictions that mimics the positive comovements of output, investment and employment.

Other works have taken different approaches in analyzing the international business cycles. Kose et al. (2003) have used a Bayesian method on yearly data to divide the international business cycle into three factors (world, region and country-specific factors) and have come to the conclusion that the common world factor plays and important role in explaining the business cycles for a 60-country sample. Stock and Watson (2003) apply a structural vector autoregression (VAR) model[12] to explain the reduction of volatility among G7 countries in the last two decades and conclude that the less volatile economies result from the decrease of the common international shocks. Fund (2010) apply also a structural VAR to highlight the relevance of US financial shocks to a main driver of international business cycles.

There is a variety of approaches that can be adopted while studying international business cycles. In the recent years, it seems that more advanced econometric techniques, such as structural VAR models, have been more often used than the simple analysis of comovements among countries, which we have adopted in this paper.

[12]Webb (1999) provides a simple and enlightening introduction to VAR models.

5 Conclusion

We reassessed some of the results of BKK on international business cycles in the light of 23 extra years of data. We conclude that standard deviations and the within-country comovements have not changed much. Conversely, cross-country correlations experienced a decrease for almost all variables.

We have also come to the conclusion that using the US as a benchmark for measuring international comovements among countries does not generate the distortions that one might have expected because of the unique size and degree of openness of the American economy.

Moreover, our results represent a middle ground between BKK and ACZ. It seems that smaller cross-country correlations obtained by ACZ can be attributed more to the greater number of sample countries they have analyzed than to the length of their time series.

We conclude that the quantity anomaly, the most intriguing finding of BKK, persists in our results and in ACZ's. In our data, the cross-country correlation of output is higher than that of consumption for 53 pairs of countries out of 55, correlations of output, which are expected to be negative from simulations of the model, are all positive and not a single consumption correlation is as high as 0.88, the expected value in theoretical economies.

Finally, the overall decrease in cross-country correlations did not eliminate the anomaly precisely because what constitutes such an anomaly is the relative size between correlations of output and consumption. Since both correlations have decreased, their relative size has not changed in any significant way.

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A Appendix - Aspects of the Data

A.1 Selection of Unit of Measurement

One of the crucial tasks while writing this paper was to choose in which unit of measurement the data would be expressed. The OECD's *National Accounts* offers 27 different measures, 20 of which might be relevant to measure stock values of the variables we are interested in. The other seven refer either to growth or population measurements.

Unfortunately, BKK does not mention expressly which unit they have opted for noting only that they have used real values for all variables except for net exports, which was measured in current prices.

Confronted with the dilemma of which unit of measurement to use, we have followed three steps to make a decision:

1. Data on output was downloaded from OECD's website in all measures available.

2. A loop in R was applied to calculate the cross-country correlations of output between the United States with the ten other BKK countries in *all* measures.

3. We compared the results and chose the one most similar to BKK's.

If the data between 1947:1 and 2015:2 are considered, there are enough observations, such that the cross-correlation of output between the US and other the other sample can be computed in *nine* units of measurement. But if only the BKK's interval (1970:1 - 1990:2) is considered, correlations between the US and all other countries can be computed in only *four* different measures. Table 8 displays the cross-correlations of the United States resulting from these 4 measures along with the same correlations calculated by BKK and ACZ.

	AUS	AUT	CAN	CHE	DEU	FRA	GBR	ITA	JPN
Backus et al. (1993)	.51	.38	.76	.42	.69	.41	.55	.41	.60
Ambler et al. (2004)	.40	.32	.77	.35	.50	.27	.68	.33	.39
CARSA	.00	.08	.29	.11	.29	-.14	-.01	-.04	.22
CPCARSA	.27	-.00	.56	.26	.41	.11	.30	.24	.38
VOBARSA	.35	.29	.71	.41	.66	.39	.62	.37	.60
VPVOBARSA	.35	.29	.71	.41	.66	.39	.62	.37	.60

Table 8: Cross-country Correlation of US Output in four different Mesaures , 1970:1 - 1990:2

We first dismiss CARSA and CPCARSA measures. They not only yield correlations that strongly differ from BKK's figures but also both refer to current prices. This contrasts sharply with BKK's data, which are expressed in real terms.

VOBARSA and VPVOBARSA measures are clearly the closest not only to BKK's but also to ACZ's results. Both yield the same figures, because they represent the same measurement, only scaled by different factors: VOBARSA is expressed in national currency, while VPVOBARSA in US dollars. Multiplying a time series by a constant does not affect the standard deviation between its periods nor its correlation with other series. We then opt for VPVOBARSA. It allows for comparisons not only of variation (standard deviation) and comovements (correlation) but also of magnitude, since the outputs of all countries will be expressed in the same unit (US dollars).

A.2 Civilian Employment Series

BKK's quarterly data on civilian employment come from OECD's *Main Economic Indicators*. Yet, the *Main Economic Indicators*'s data on quarterly civilian employment are not available on OECD's website as of this writing. Instead, OECD provides quarterly data on employed population in its *Short-Term Labour Market Statistics*. As can be seen from Table 9, the

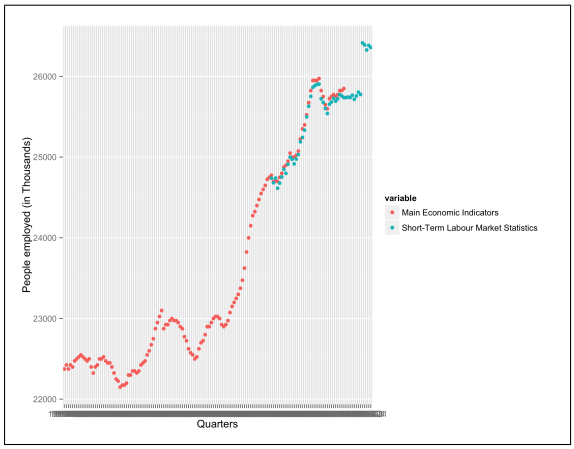
length of the series of some countries available in *Short-Term Labour Market Statistics* are too short for the comparison with BKK's results to be reasonable. Fortunately, data on civilian employment from OECD's *Main Economic Indicators* were available for France, United Kingdom and Italy in the Federal Reserve Bank of St. Louis website[13], which allowed us to expand these series. Similar data for Switzerland and the European aggregate were not found and given the short length of *Short-Term Labour Market Statistics*'s series for these two, we opted to exclude from our calculations of comovements of civilian employment.

Country	AUS	AUT	CAN	FRA	DEU	ITA	JPN	CHE	GBR	USA	EA19
Last	2015:2	2015:1	2015:2	2015:1	2015:1	2015:1	2015:2	2015:1	2015:1	2015:2	2015:1
First	1967:1	1969:1	1955:1	2003:1	1962:1	1998:1	1955:1	1998:2	1999:2	1955:1	2005:1

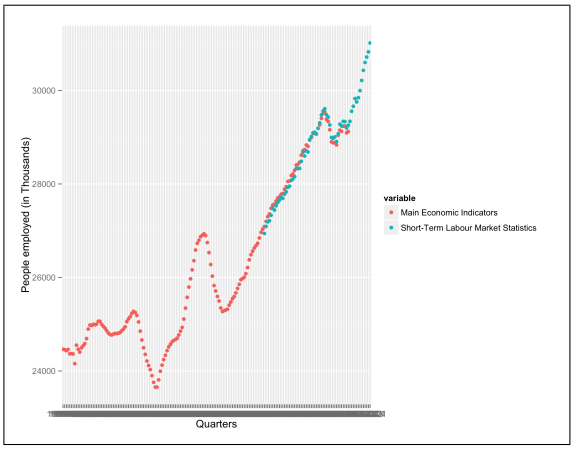
Table 9: Length of *Employed Population* series from *Short-Term Labour Market Statistics*

Before deciding whether to combine the *Short-Term Labour Market Statistics* and *Main Economic Indicators* series on employment, we have plotted in Figure 4 the series together to see how similar they are. It turns out they are similar enough. For this reason and in order to obtain longer series, we have decided to chain the two series for France, United Kingdom and Italy. We multiply the *Short-Term Labour Market* series by a factor such that both series have the same value at the period for which the *Main Economic Indicators* series has its last observation. The two series were then merged with *Short-Term Labour Market* complementing the missing values of *Main Economic Indicators*. The length of the resulting time series can be seen in Table 3.

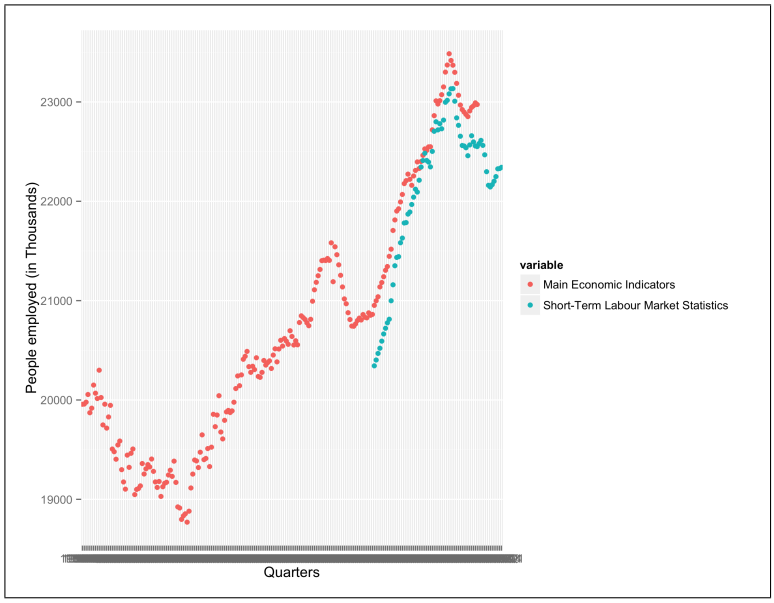
[13] https://research.stlouisfed.org/



(a) France



(b) United Kingdom



(c) Italy

Figure 4: Civilian Employment Series

Declaration of Authorship

I hereby confirm that I have authored this Bachelor's thesis independently and without use of others than the indicated sources. All passages which are literally or in general matter taken out of publications or other sources are marked as such.

Berlin, September 5, 2015

Denis Augusto Pinto Maciel