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#### **ORIGINAL PAPER**



## The endogeneity of optimum currency areas in light of pan-European intra-industry trade patterns and business cycle synchronicity

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#### Abstract

The creation of a common European currency has been scrutinized in the context of optimum currency area theory since its origin in Mundell (1961). The debate gained particular prominence in light of the endogeneity hypothesis (Frankel and Rose 1998), which argues that once two countries establish a common currency, their economic structures and cycles increasingly align due to strengthening intraindustry trade. By contrast, the specialization hypothesis (Eichengreen 1992; Krugman and Venables 1996) argues that the creation of a currency union will predominantly increase inter-industry trade, ultimately lowering business cycle correlation. To test these views, we establish several indices of bilateral trade intensity across EU members using input-output data, measuring gross and so-called value-added trade, which also considers the contribution of intermediary goods in the production of final exports. The results of the fixed effect panel data framework indicate a strong and robust empirical relationship between growth correlations and intraindustry trade, much in line with both Mundell's and Frankel and Rose's theories. However, we cannot establish a similarly robust relationship between total trade intensity and growth correlations. We reconcile these results by identifying a statistically significant relationship between economic alignment and trade when only considering industrial production, highlighting the importance of pan-European industrial supply chains for European economic integration. Rerunning our regression framework on the subsample of the eurozone indicates that the common currency area displayed even stronger properties of an optimum currency area than the entire European Union.

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#### 1 Introduction

The question of under what conditions two or more countries should establish a common currency has been extensively discussed in the context of the optimum currency area (OCA) theory, first established by Mundell (1961) and McKinnon (1963). At its core, optimum currency area theory stipulates that two countries should enter a currency union if the "benefits", in the form of lower transaction expenses, outweigh the "costs" of forfeiting independent monetary policy. Commonly in associated literature, these factors are measured by the bilateral trade volumes (trade intensity) and GDP co-movement (business cycle synchronicity) respectively.

Whereas the original contributions to OCA theory are based on static comparisons of costs and benefits, later contributions are more concerned with the dynamic relationship between trade volumes and business cycle correlations. Two opposing views exist: According to the endogeneity hypothesis (e.g., Frankel and Rose (1998)), countries increase intra-industry trade, thus becoming more similar in terms of business cycle synchronicity, which reduces the costs of a monetary union. According to the specialization hypothesis (e.g. Eichengreen (1992), Krugman (2013)), countries increase inter-industry trade, which amplifies economic asymmetries and increases the costs of a monetary union.

This analysis aims at contributing to the discussion on the importance of trade relations, intra-industry trade within regional supply chains, and OCA theory; it also highlights the importance of industrial supply chains for European economic integration over the previous decades. Similarly to other authors (e.g., Johnson and Noguera (2012a), Johnson and Noguera (2012b), and Duval et al. (2016), we construct export indices measuring gross exports and exports calculated by share of value added in their production; establish a link of trade intensity to business cycle synchronicity under different measurements and specifications; and highlight the importance of the type of trade - inter-industry and intra-industry trade. Using data from the World-Input–Output Database (see Dietzenbacher et al. (2013)), we establish several export indices that consider trade intensity for gross trade, value-added trade as well as intra-industry trade within the European Union between 2000 and 2014. Ultimately, the regression results indicate several conclusions:

- Absolute levels of trade intensity differ between indices for gross trade and value-added trade; their correlation is extremely close. The same is not true for intra-industry trade. Average and median levels of all trade intensity indices increase strongly when comparing the periods before and after the Global Financial Crisis.
- After excluding the years of the Global Financial Crisis 2008 and 2009 and using lagged variables in order to preclude endogeneity, the export indices measuring intra-industry trade are often significantly correlated with GDP comovement. The variables retain their significance even when including standard control variables.

- The correlations between GDP co-movement and indices measuring total trade intensity are insignificant when including fixed effects and simple control variables.
- We reconcile the results by using a subset of industrial production data, which yields positive and significant results for both intra-industry and total trade indices, highlighting the importance of pan-European manufacturing supply chains for European economic integration.
- These regression results for industrial production are even stronger for the subsample of the eurozone: coefficients have a higher level of significance, are larger in absolute value and the overall  $R^2$  is also higher.

The paper is laid out as follows: Sect. 2 provides an introduction to the significant amount of literature on optimum currency area theory, the debate between the endogeneity hypothesis and the specialization hypothesis, and an overview of relevant analyses utilizing input–output data. Sect. 3 describes the data set and the construction of the different variables used in the regression analyses with a focus on the different export indices. Sect. 4 presents the results of the panel data, time and country-pair fixed-effects regressions under different specifications; Sect. 5 provides regression results for industrial production data; and Sect. 6 expands on these results by running the regressions again on a different country sample, the eurozone. Sect. 7 discusses further robustness checks to all results; and Sect. 8 concludes.

#### 2 Literature overview

The European Union, and the eurozone specifically, have frequently found themselves at the center of economic debates on optimum currency area theory, oftentimes as the subject of scathing criticism regarding the feasibility of a pan-European currency. Although Mundell published his essay during a time of predominantly fixed exchange rate regimes over 60 years ago, the author already discussed the potential case of a common European currency in the context of his theory.

Since Frankel and Rose (1998), the discussion has shifted from simply looking at the *volume* of bilateral trade to the *type* of trade while also acknowledging that both trade and business cycle alignment evolve over time. There are two diverging views on the development of optimum currency areas in this regard. Authors like Eichengreen (1992) and Krugman (2013) are proponents of the socalled specialization hypothesis, which argues that countries within a currency union tend to increasingly specialize in sectors for which they have a comparative advantage, which increases inter-industry trade flows. These developments ultimately amplify economic asymmetries and aggravate the effects of external shocks. In contrast, authors like Frankel and Rose (1998) argue along the lines of the endogeneity hypothesis, which assumes that countries entering a currency union progressively increase intra-industry trade, resulting in continuous economic convergence across member states in terms of sectoral split-ups and business cycles. This will reduce the effects of asymmetric external shocks and increase the benefits of expanding supply chains across the currency union. Both sides of the debate provide empirical evidence for their respective theories.

Importantly, the arguments of Frankel and Rose (1998) are strongly aligned with the political reasoning of the European Commission in its assessment on the establishment of a European Monetary Union (Emerson et al. 1992). The main reasoning of the Commission focused on continued economic integration following the establishment of a currency union, which would lead to economic convergence and reduction in frequency and intensity of asymmetric shocks within the eurozone. This would mean that, even if the eurozone did not indicate properties of an OCA ex-ante, it could evolve into one over time. One of the earlier empirical analyses on the eurozone comes from De Grauwe and Mongelli (2005), who provide empirical evidence for the increasing alignment of European economies and financial markets in the years after the establishment of the Euro. Likewise, Schiavo (2008) finds further evidence for the endogeneity argument of currency areas. The importance of monetary unions on trade flows in general has also been discussed by Frankel and Rose (2002) as well as Baxter and Kouparitsas (2005), who also established an empirical link between bilateral trade flows and economic alignment (although the authors disagree on the assessment whether currency unions themselves have a similar effect). Fidrmuc (2004) also stresses the importance of intra-industry trade in the alignment of business cycles within the European Monetary Union. Other economists, such as Artis and Zhang (1997) and Hochreiter and Winckler (1995), similarly establish empirical analyses on common (pan-)European business cycles. Imbs (2004) and Inklaar et al. (2008) provide further evidence that intra-industry trade increases business cycle synchronicity.

With respect to its methodology, this analysis also relates to economic research focusing on the broader topics of global trade patterns, global and regional supply chains, and the impact of trade on business cycle synchronicity and GDP comovement. Related research has increasingly shifted toward the use of so-called input-output databases, which enable the calculation of trade indices beyond simple gross export data. Gross trade data might not be capturing the adequate trade and economic relations between two countries as it omits the value-added of domestic and foreign intermediary goods in the production of a gross exports as well as third-country or indirect exports. The contributions of Johnson and Noguera (2012a) and Johnson and Noguera (2012b)) are particularly noteworthy in this regard, since they undertook the effort of establishing a comprehensive input-output data set on international trade themselves. Even more closely related to this paper are several articles that similarly establish a link between trade intensity and business cycle synchronicity, such as Calderon et al. (2007) within a gravity equation framework; and de De Soyres and Gaillard (2019) who utilize a series of fixed-effects regressions. The most closely related research for this analysis is the work of Duval et al. (2016), who also study the relationship between trade intensity and business cycle synchronicity using input-output data. The authors show that value-added trade flows and business cycles seem to be correlated across a global country sample - the same relationship is not present when using gross trade indices.

#### 3 The WIOD data set and computation of main variables

Input–output data sets provide a more distinct view on international trade relations compared to simple gross export statistics. Similar to other authors and organizations before them - e.g., the OECD-WTO TiVA or EORA (OECD 2012) and Lenzen et al. (2013) - Dietzenbach and Timmer construct their World Input–Output Database by merging statistics on international trade flows with data of domestic and foreign input–output relationships between the individual sectors. Their comprehensive data set comprises of 56 business sectors and 43 countries, plus a collective unit capturing all other trade flows labeled 'rest of the world'. This data base is particularly suitable for the analysis at hand compared to similar IODs: it covers all EU-28 members for the full period of 2000-2014 without gaps and the split-up of business sectors is granular enough for the calculation of subindices such as industrial production.

The importance of the concept of value-added trade for this analysis justifies a closer look at the formal derivation of the so-called 'Leontief inverse'. Generally speaking, the use of input–output data and the mathematical computation of value-added trade flows became a prime focus of trade analyses about ten to fifteen years ago. Several economists and international organizations have published different versions of the derivation of the Leontief-inverse since. We will focus on the most important points from Johnson and Noguera (2012a), the UNCTAD (2013), Koopman et al. (2014) and the IMF Working Paper from Aslam (2017).

At its core, input–output data sets represent a combination of national supply and use tables (SUTs) and international trade statistics. Several data sets exist - such as the EORA, the OECD TiVA, or the WIOD used in this analysis - but all of them share the same basic structure (Fig. 1). The below diagram is a simplified overview of an input–output data set (see Koopman et al. 2014):

The figure shows the simplified case of two countries (country A and country B) with one business sector each. The components of input–output data are: intermediary



Fig. 1 Overview of the Structure of an Input-Output Data Set

goods, for which the matrix is usually specified as T; the value-added by the individual sectors themselves, labeled  $V_a$  and  $V_b$ ; and final demand of every country,  $Y_i$  for country i. Every column represents the production process of each sector, which uses intermediary goods and value-added by the sector itself to produce gross input of sector i,  $X_i$ . Each row indicates the utilization of gross input  $X_i$  - either as an intermediary good in production processes of other business sectors or as final consumption domestically and abroad. The sum of all uses of  $X_i$  is defined as the gross output. Under the explicit assumptions on input–output data, gross input  $X_i$  will equal the sum of all gross output  $X_i$ . This yields the following equation in matrix form:

$$X = T + Y$$

Defining T = AX, with A representing the technological coefficients, i.e., the units of intermediary goods used to produce one unit of gross output, solves the equation:

$$X = AX + Y$$
$$(I - A)X = Y$$
$$X = (I - A)^{-1}Y$$

with *I* as the identity matrix. The term  $(I - A)^{-1}$  is the so-called Leontief inverse, since the underlying assumption is that production of output takes the form of a Leontief production function.

An easy representation of the mathematical concept is the simple case of two countries (labeled 1 and 2) with one sector each (also defined as sector 1 and 2). The corresponding calculation is simply:

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

solving for the gross output matrix yields:

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} I - a_{11} & -a_{12} \\ -a_{21} & I - a_{22} \end{bmatrix}^{-1} \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

Accordingly, the general case with n countries and m sectors is (see Koopman et al. (2014)):

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} I - a_{11} & -a_{12} & \cdots & -a_{1m} \\ -a_{21} & I - a_{22} & \cdots & -a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ -a_{n1} & -a_{n2} & \cdots & I - a_{nm} \end{bmatrix}^{-1} \begin{bmatrix} \sum_i^m y_{1i} \\ \sum_i^m y_{2i} \\ \vdots \\ \sum_i^m y_{mi} \end{bmatrix}$$

#### 3.1 Gross and value added trade indices

Using the standard assumption of Leontief production vectors of goods produced in the EU, we construct two distinct calculations for export indices from WIOD data measuring trade within the common European market. Similar to Frankel and Rose (1998) and Duval et al. (2016), we define the standard measurement for bilateral trade intensity:

$$T_t^{ab} = ln \left( \frac{X_t^{ab} + X_t^{ba}}{GDP_t^a + GDP_t^b} \right)$$

Where T represents (the logarithm of) bilateral trade intensity between country-pair a and b in year t;  $X^{ab}$  represents exports from country a to b and (vice versa); and  $GDP^a$  represents total GDP of country a. We construct two indices that measure bilateral trade intensity between the 28 EU members in 2014 for the entire period of 2000-2014: a gross trade index and a value-added trade index using the Leontief inverse.

#### 3.2 Intra-industry trade indices

The calculation for intra-industry trade intensity is similar to the ones in the previous section, with the exception that the index only considers intra-industry trade flows.

$$T_{t}^{ab} = ln \left( \left( 1 - \frac{\sum_{r=1}^{n} |X_{t}^{ab,r} - X_{t}^{ba,r}|}{\sum_{r=1}^{n} (X_{t}^{ab,r} + X_{t}^{ba,r})} \right) \left( \frac{X_{t}^{ab} + X_{t}^{ba}}{GDP_{t}^{a} + GDP_{t}^{b}} \right) \right)$$

With  $X^{ab,r}$  denoting exports from country a to country b in sector r in year t. The first half of the right hand side of the equation is essentially a Grubel-Lloyd index (of intra-industry trade) and the second half is the calculation of total bilateral trade intensity.

As stated before, standard OCA theory according to Mundell (1961) only considers the volume of total trade between two countries as a determinant for whether they could form an OCA. However, the specialization versus endogeneity debate highlights the importance of the type of trade between two countries in the context of OCA theory. Strong intra-industry trade relations, coupled with high correlation of business cycle synchronicity could empirically support Frankel and Rose's endogeneity argument. We therefore construct the indices for intra-industry trade from the WIOD, parallel to the definitions of the trade indices in the previous step. The descriptive statistics below indicate that the cross-correlation between the value-added and gross intra-industry trade indices is much lower compared to total trade indices.

#### 3.3 Additional variables

Similar to other related analyses, the main dependent variable for business cycle synchronicity is a measurement of GDP co-movement:

$$GC_t^{ab} = \frac{(g_a^t - g_a^*)(g_b^t - g_b^*)}{\sigma_a^g \sigma_b^g}$$

Where  $g_a$  denotes GDP growth in country a and  $g_a^*$  and  $\sigma_a$  the average growth rate and standard deviation thereof during the observation period. We construct this instantaneous correlation of economic growth for two measures: annual real GDP growth and the log difference in annual real GDP levels. The subsequent data tables only show the results for business cycle synchronicity calculated with real GDP growth; growth correlations using the log difference of GDP serve as a robustness check. The data comes from Eurostat, substituting individual data gaps for some countries with estimations of the respective central banks.

Furthermore, we establish additional control variables in order to verify the initial findings. Similar to Kalemli-Ozcan et al. (2013) and Duval et al. (2016), we include the log product of the GDP, the log product of the population, and the absolute difference in log GDP per capita of any country pair to account for different growth dynamics across different groups of countries. The respective data comes from IMF IFS, Eurostat, and IMF WEO data respectively.

Lastly, we establish an index measuring similarity in industry structure (Imbs 2004) from the same WIOD data set as for the main explanatory variables:

$$SIS_t^{ab} = -\sum_{r=1}^n |S_t^{a,r} - S_t^{b,r}|$$

where  $S_t^{a,r}$  denotes output in sector r of country a at time t.

#### **4** Regression results

#### 4.1 Descriptive statistics

We make two crucial adjustments to the data sample in order to achieve the regression results. First, we lag the data (similar to Duval et al. (2016)) in order to address endogeneity concerns. Second, a simple scatter plot shows that two years in the data sample - namely the years with the highest impact of the Global Financial Crisis 2008 and 2009 - are clear outliers with respect to business cycle synchronicity (see appendix). This has a significant impact on the regression results. The impact of the GFC on the different European Union members was quite divergent, and these cannot be accounted for through common time-fixed effects. In the context of the regression analysis, it reduces the significance of the coefficient of the main explanatory variable in almost all specifications. We therefore exclude these years from the regression analysis and from the computation of the dependent variable.

The initial country sample is the EU-28, which could be controversial in two respects. On the one hand, the focus on the entire European Union, rather than the eurozone specifically, might appear inconsistent given the explicit focus on OCA theory. Still, economic integration has been a primary policy goal for all EU members, not just for the eurozone members. Our results could therefore serve as

Table 1 Descriptive statistics	escriptive statistics	Dependent variable: growth correlations					
	Variable	Obs	Mean	Std. dev.	Min	Max	
	GCreal	4536	0.506	1.046	-4.904	7.110	
	GCln	4536	0.506	1.049	-4.901	6.925	

Table 2 Descriptive statistics

Independent variable	e: total trade in	ntensity (IIT),			
Variable	Obs.	Mean	Std. dev.	Min	Max
IIT (gross trade)	4536	-8.539	4.108	-23.679	-2.985
IIT (value added Leontief)	4536	-6.540	1.500	-10.144	-2.983
Within correlation o	f intra-industr	y trade intensity (I	IT)		
Variable			Gross		VA L
IIT (gross trade)			1.000		
IIT (value added Le	ontief)		0.766		1.000

a suitable benchmark to compare economic integration dynamics across the two country groups. On the other hand, the sample also includes many countries for the entire observation period, although they were only EU members for a part of it. For example, we include Croatia in the sample, although it joined the EU only in 2013. This broad definition of EU members, however, has the advantage that it represents a stable sample of countries and much of the economic and trade alignment already occurs in the context of a lengthy accession process ahead of the actual membership. Even though the first group of the Central and Eastern European EU member states joined in 2004, they had already enjoyed largely unrestricted access to the common EU market at predominantly zero tariffs since 1994 while also operating under the same comprehensive legislative and regulatory framework. This had significant impact on their economic development and economic integration with Western Europe. Therefore, this definition should not distort the regression results.

The descriptive statistics of the main variables are given in Tables 1, 2, and 3. The correlation between the different export indices appears high, despite significant differences in the absolute value of specific observations across the indices: The cross-correlation is 0.972 for total trade. However, the correlation between intra-industry trade indices in gross and value-added terms is much lower, at 0.766. This is also the reason why this aspect of the analysis could yield particularly relevant results.

Another interesting aspect, not visible in the simple descriptive statistics, is a significant shift towards international trade flows when calculating trade flows using the approach of the Leontief-inverse. First, we note that international exports have risen substantially during the 15 years of our observation period. In 2014, they were 2.64 times higher in gross terms and 2.66 times higher in value added terms compared

Independent variable: total tra	de intensity (	ГТ),			
Variable	Obs.	Mean	Std. dev.	Min	Max
TT (gross trade)	4536	-6.520	1.709	-12.166	-2.614
TT (value added Leontief)	4536	-5.778	1.298	-9.102	-2.743
Within correlation of trade into	ensity (TT)				
Variable			Gross		VA L
TT (gross trade)			1.000		
TT (value added Leontief)			0.972		1.000

#### Table 3 Descriptive statistics

to 2000. Second, value-added international exports are generally higher than gross exports in absolute value - by a factor of 1.84 in 2000 and 1.86 in 2014. Third, when including intra-national trade flows, the overall difference between value-added exports and gross exports reduces substantially. In fact, total gross exports are 2-3% higher for the entire data sample (mainly due to the exclusion of the residual trade flows to and from the 'rest of the world'). This means that gross intra-national trade flows potentially overestimate the share of their domestic production, which could be the case if the last production step of a global value chain predominantly occurs domestically. In this case, the contribution of all previous production steps, domestic and foreign, in order to produce a 'final consumption' good are entirely disregarded in terms of value-added.

The above descriptive statistics are essentially static, as are the below regression results. They report the relationship between growth correlations and trade intensity for the entire period 2000-2014 (with the exception of the years of the Global Financial Crisis, GFC), but not how this relationship evolved over time. However, both the endogeneity and the specialization hypothesis use dynamic elements in predicting how two countries within an economic or monetary union will develop. It is therefore necessary to determine how our main variables developed over the course of the observation period. For our sample, all explanatory and dependent variables increased significantly for the majority of EU-28 countries. The average growth correlation more than doubles for both indices when comparing the periods before and after the financial crisis. This is despite the fact that the years with some of the highest growth correlations - during the GFC - are excluded from the calculations. The results are similar when looking at the different measurements for trade intensity. It appears mean and median values for intra-industry trade and total trade between two countries, as a share of their added GDP figures, also increased by between 12% and 50%. Although rising business cycle synchronicity and trade intensity are rather aligned with the predictions of optimum currency area theory and the endogeneity hypothesis, we should note that other factors could influence these metrics as well. During and after crisis periods, growth correlations often increase. Relevant shocks during our observation sample were the Great Financial Crisis, and the European debt crisis, which both can contribute to higher growth correlations. We also note that the below regression results are covering the entire observation period (Table 4).

#### 4.2 Time- and country-pair fixed effects OLS estimates for intra-industry trade

While both the specialization and endogeneity hypothesis predict the possibility of rising trade volumes between members of a currency union, they differ in their assessment on the type of trade and its effect on economic convergence. It is not simply the *volume* of trade that determines whether two or more countries could constitute a viable currency union, but also the *type* of trade. If intra-industry trade flows dominate and are significantly correlated with GDP co-movement, this could provide indication that the European Union had developed according to Frankel and Rose's endogeneity hypothesis. Table 5 gives the results of the regression analyses using intra-industry trade intensity according to the different specifications of the independent variable.

The standard regression models is defined as follows:

$$GC_{t}^{ab} = \alpha_{ab} + \alpha_{t} + \beta(IIT_{t-1}^{ab}) + \gamma(CONTROLS_{t-1}^{ab}) + \epsilon_{t}^{ab}$$

GC represents the variable for business cycle synchronicity; IIT is the measurement for bilateral intra-industry trade intensity in the aforementioned specifications, the main explanatory variable; CONTROLS stands for the set of additional control variables; and  $\alpha_{ij}$  and  $\alpha_t$  constitute the country-pair and time fixed effects parameters. A series of Breusch-Pagan Tests confirms that the pooled data set could suffer from heteroscedasticity. All OLS regressions use robust standard errors, clustered around country-pairs.

Both indices for intra-industry trade are significant and positive when including the standard control variables and using real growth rates as the measurement for business cycle synchronicity. Both coefficients, for value-added and for gross intra-industry trade, lie marginally beyond the 5% confidence interval (but still well within the 10% confidence interval). More importantly, the absolute value of the index for intra-industry trade - by a factor of 8 times. In fact, the value of the coefficient measuring value-added

	Mean		Median	
	Before GFC	After GFC	Before GFC	After GFC
GCreal	0.3566	0.7150	0.1112	0.3134
GCln	0.3545	0.7223	0.1174	0.3095
IIT - Gross	0.0023	0.0032	0.0003	0.0007
IIT - VA L	0.0040	0.0046	0.0011	0.0016
TT - Gross	0.0042	0.0058	0.0013	0.0022
TT - VA L	0.0065	0.0075	0.0027	0.0037

Table 4	Comparison of main
variable	s before and after the
GFC	

<b>Table 5</b> Business cyclesynchronicity and intra-industry	Dep Var: GCreal	OLS	OLS		
trade, OLS	IIT: gross	0.011			
		(0.061)			
	IIT: VA L		0.089		
			(0.058)		
	SIS: ind. similarity	0.075	0.008		
		(0.818)	(0.980)		
	Product log GDP	-0.123	-0.154		
		(0.130)	(0.065)		
	Product log Pop.	0.538	0.628		
		(0.025)	(0.012)		
	Diff. log GDP p.c.:	-0.048	-0.028		
		(0.485)	(0.693)		
	FE: country-pair	Yes	Yes		
	FE: year yes	Yes	Yes		
	Observations	4536	4536		
	R squared (adjusted)	0.203	0.168		

intra-industry trade appears comparable to the ones reported by other authors, such as Duval et al. (2016), although Duval et al. use total trade intensity as their explanatory variable.

A positive coefficient by itself does not support the endogeneity hypothesis. If intra-industry trade intensity and business cycle synchronization were both falling at the same time, the coefficient would also be positive, but the underlying trade dynamics would rather resemble the predictions of the specialization hypothesis. Fortunately, we can preclude this case, since both business cycle synchronicity as well as total and intra-industry trade intensity have been rising over our observation period. Therefore, we believe these initial regression results could constitute some evidence that countries with a higher intra-industry trade intensity have more closely aligned GDP co-movement in the sample of the EU-28, much in line with the predictions of the endogeneity hypothesis.

#### 4.3 Regression results for total trade

These initial regression results are encouraging, but most economists providing empirical analyses on OCA theory, including Frankel and Rose, have primarily focused on total trade volumes, rather than intra-industry trade patterns specifically.

In a second step, we use same regression model as in step 4.2 with one difference. T represents the measurement for bilateral total trade intensity:

$$GC_t^{ab} = \alpha_{ab} + \alpha_t + \beta(T_{t-1}^{ab}) + \gamma(CONTROLS_{t-1}^{ab}) + \epsilon_t^{ab}$$

<b>Table 6</b> Business cyclesynchronicity and total trade,	Dep var: GCreal	OLS	OLS		
OLS	TT: gross	0.037			
		(0.169)			
	TT: VA L		0.023		
			(0.683)		
	SIS: ind. similarity	0.089	0.060		
		(0.784)	(0.855)		
	Product log GDP	-0.139	-0.109		
		(0.111)	(0.213)		
	Product log Pop.	0.540	0.544		
		(0.027)	(0.023)		
	Diff. log GDP p.c.:	-0.044	-0.045		
		(0.524)	(0.532)		
	FE: country-pair	Yes	Yes		
	FE: year	Yes	Yes		
	Observations	4536	4,536		
	R squared (adjusted)	0.207	0.195		

All other variables are exactly defined as in the previous section, including the set of additional control variables; and the country-pair and time fixed effects parameters  $\alpha_{ij}$  and  $\alpha_r$ .

When including this full set of control variables and fixed effects, the coefficients for both trade indices are insignificant and relatively low in absolute value. The results therefore do not confirm a strong and significant statistical link between the level of trade and GDP co-movement for the case of the European Union. This result is also quite robust for alternative measures of business cycle synchronicity (Table 6).

#### 5 Alternative specifications using industrial production

The result that intra-industry trade and business cycle synchronicity are significantly correlated for EU member states, but total trade intensity is not, initially appears contradictory. It seems to suggest that EU member states have developed according to Frankel and Rose's endogeneity hypothesis, while at the same time not representing an optimum currency area according to Mundell's original theory. However, there could be a way to reconcile the two results in case it is possible to identify a specific subset of economic activity for which intra-industry trade plays a predominant role; covers a significant share of total intra-industry trade of a country; but trade from these business sectors is not a sole determinant of total trade. Industrial production could fulfill all of these criteria. In case there is a statistically significant and robust link between industrial production synchronicity and both total industrial

trade and intra-industry industrial trade, this subset of economic activity would display features of an pan-EU optimum currency area in line with the endogeneity hypothesis.

Industrial production has played a pivotal role in the historical development of the European Union ever since its inception as the European Union for Coal and Steel in the 1950 s. There has been a common European market for manufacturing goods since the 1960 s and integration significantly increased during the waves of globalization in the 1980 s and 1990 s, also across the (soon to be) new EU members in Central and Eastern Europe. Industrial production is, perhaps, one of the best integrated pan-European economic sectors until this day - representing between 62% (2000) and 57% (2014) of total trade during our observation period. In contrast, many other business sectors, such as most services, required significantly more time to integrate themselves across EU members and for some, integration during the observation period of 2000-2014 remained incomplete. In general, European policymakers have found it particularly hard to integrate their services sectors across the European Common Market: Even though the European Single Market was established in 1993, the 'Lisbon Strategy' of 2000 and the 'Europe 2020 Strategy' of 2010 addressed deficiencies in services trade; the European Banking Union was only fully established in 2014.

In addition, industrial production and manufacturing data has already been used in several analyses of international trade patterns and OCA theory (e.g., Frankel and Rose 1998; and Fidrmuc 2004). Running the regressions using industrial production could therefore also serve as a viable robustness check to confirm the initial findings:

- It is distinct enough from total trade and GDP statistics so that it does not represent a simple re-calculation of the same variables used in the previous section;
- industrial production has played a pivotal role in European economic integration. Manufacturing supply chains have spread rapidly across the EU over the past decades.

Parallel to the previous steps, we construct similar trade indices for the subset of industrial production. Tables 7, 8 give an overview of the results.

These initial results of the respective regressions confirm the results in Sect. 4 and generally exceed these in terms of statistical significance. The absolute value of the coefficient for intra-industry trade in value-added terms is almost twice as high when only considering data for industrial production; it is even more than seven times as high when comparing the two indices for total (industrial) trade. In both cases, the significance levels for the regressions using only industrial production data is much higher than those of the total data set and lie within the 1% confidence interval. Similarly to the trade data in value-added terms, the coefficients for gross industrial trade are significant for both intra-industry and gross trade indices. However, the absolute value and level of significance are comparable in the case of intra-industry (industrial) trade; they exceed the initial regression results in the case of total (industrial) trade, with a much higher absolute value and a significance level within the 1% confidence interval. Although levels

Table 7 Business cycle     synchronicity and intra-industry	Dep Var: GCreal	OLS	OLS
industrial trade, OLS	IP - IIT: gross	0.011	
		(0.069)	
	IP - IIT: VA L		0.173
			(0.000)
	SIS: ind. similarity	0.045	-0.046
		(0.889)	(0.887)
	Product log GDP	-0.100	-0.185
		(0.188)	(0.024)
	Product log Pop.	0.596	0.852
		(0.017)	(0.001)
	Diff. log GDP p.c.:	-0.046	-0.010
		(0.502)	(0.886)
	FE: country-pair	Yes	Yes
	FE: year	Yes	Yes
	Observations	4536	4,536
	R squared (adjusted)	0.167	0.105

Table 8Business cyclesynchronicity and total	Dep Var: GCreal	OLS	OLS
industrial trade, OLS	IP - TT: gross	0.145	
		(0.000)	
	IP - TT: VA L		0.178
			(0.001)
	SIS: industry similarity	0.072	0.067
		(0.818)	(0.837)
	Product log GDP	-0.191	-0.188
		(0.022)	(0.028)
	Product log population	0.809	0.752
		(0.001)	(0.002)
	Diff. log GDP p.c.:	-0.011	-0.009
		(0.861)	(0.897)
	FE: country-pair	Yes	Yes
	FE: year	Yes	Yes
	Observations	4,536	4,536
	R squared (adjusted)	0.116	0.130

FE: Fixed-effects; p-values in brackets

of  $R^2$  are generally lower in the regression using industrial production data compared to the full data set, they remain reasonably high given that the dependent variable reflects overall GDP growth correlation and the explanatory variable only covers a subset of overall economic activity.

#### 6 Regression results for the eurozone

The regression results of the EU-28, the full data set, appear encouraging regarding the assessment on whether EU member states displayed properties of an optimum currency area. But the EU-28 does not represent the actual current or past European Monetary Union on which many previous empirical analyses have focused.

We therefore rerun the regressions for the eurozone (the EZ-19). The goal is to identify whether this specific country group exhibited similar characteristics of an optimum European currency area, in line with Mundell (1961) and Frankel and Rose (1998) predictions. Similar to the previous approach, the EZ-19 includes countries that were a eurozone member at the end of our observation period in 2014. This means that countries that joined the eurozone between 2000 and 2014 are included for the entirety of the observation period - e.g., the Baltic countries.

#### 6.1 Regression results for intra-industry trade and total trade

Overall, the regression results using the subsample of the eurozone members produce largely similar results as the regressions using the full country sample, the entire EU-28. There is one notable exception: Intra-industry trade intensity in gross terms is still positively correlated with our measure of business cycle synchronicity (even within the 5% confidence level); the same coefficient is statistically insignificant for intra-industry trade intensity measured in value-added terms. In the regressions using total trade intensity, both measures of total trade intensity produce no significant results, similar to the results of the previous section (Tables 9 and 10). The levels of  $R^2$  are generally higher for the EZ-19.

Although we do not want to over-interpret this particular regression result, we believe there are several potential explanations why the full data set of the EU-28 displayed somewhat clearer properties of an OCA than the actual currency union, the EZ-19. One explanation could be somewhat higher internal economic divergence between specific members of the eurozone and the rest of the currency union and among themselves. These countries could have a higher influence on the overall regression results in the smaller sample of the EZ-19 than in the full data set. In our data sample, the eurozone periphery countries could constitute a potential source of economic misalignment within the eurozone. We note that the regressions using intraindustry trade in value-added terms produce statistically significant and negative coefficients for the country sample of the eurozone periphery.

#### 6.2 Regression results for industrial production

As a last step, we also run the same regressions for the reduced data set of industrial production to see if we can identify a similarly strong effect of industrial supply chains across the eurozone. The results are in tables 11 (intra-industry trade) and table 12 (total trade).

Table 9 Business cycle     synchronicity and intra-industry	Dep Var: GCreal	OLS	OLS		
trade, OLS	IIT: gross	0.018			
		(0.030)			
	IIT: VA L		0.000		
			(0.998)		
	SIS: ind. similarity	-0.021	-0.063		
		(0.970)	(0.910)		
	Product log GDP	-0.189	-0.140		
		(0.181)	(0.330)		
	Product log Pop.	0.367	0.398		
		(0.275)	(0.234)		
	Diff. log GDP p.c.:	-0.213	-0.214		
		(0.044)	(0.046)		
	FE: country-pair	Yes	Yes		
	FE: Year	Yes	Yes		
	Observations	4536	4,536		
	R squared (adjusted)	0.351	0.304		

Table 10   Business cycle     synchronicity and total trade,	Dep Var: GCreal	OLS	OLS
OLS	TT: Gross	0.009	
		(0.811)	
	TT: VA L		-0.049
			(0.512)
	SIS: ind. similarity	-0.046	-0.105
		(0.925)	(0.847)
	Product log GDP	-0.154	-0.098
		(0.325)	(0.528)
	Product log Pop.	0.401	0.384
		(0.225)	(0.234)
	Diff. log GDP p.c.:	-0.213	-0.224
		(0.048)	(0.039)
	FE: country-pair	Yes	Yes
	FE: year	Yes	Yes
	Observations	4536	4,536
	R squared (adjusted)	0.310	0.290

FE: Fixed-effects; p-values in brackets

Generally speaking, the results for the country sample of the EZ-19 are broadly similar to the ones for the EU-28 and exceed these: The respective coefficients are even higher in absolute value and level of significance. For intra-industry (industrial) trade, the absolute values of the coefficients are between 30%-60% higher and

<b>Table 11</b> Business cyclesynchronicity and intra-industry	Dep Var: GCreal	OLS	OLS
industrial trade, OLS	IP - IIT: gross	0.018	
		(0.036)	
	IP - IIT: VA L		0.225
			(0.000)
	SIS: ind. similarity	-0.105	-0.049
		(0.844)	(0.930)
	Product log GDP	-0.114	-0.223
		(0.399)	(0.094)
	Product log Pop.	0.485	0.755
		(0.166)	(0.033)
	Diff. log GDP p.c.:	-0.196	-0.175
		(0.062)	(0.104)
	FE: country-pair	Yes	Yes
	FE: year	Yes	Yes
	Observations	4,536	4,536
	R squared (adjusted)	0.225	0.141

Table 12 Business cycle   synchronicity and total industrial   industrial trade, OLS OLS	Dep Var: GCreal	OLS	OLS
	IP - TT: gross	0.261	
		(0.000)	
	IP - TT: VA L		0.270
			(0.002)
	SIS: industry similarity	-0.002	-0.090
		(0.997)	(0.871)
	Product log GDP	-0.277	-0.302
		(0.047)	(0.054)
	Product log population	0.941	0.724
		(0.004)	(0.030)
	Diff. log GDP p.c.:	-0.132	-0.168
		(0.183)	(0.119)
	FE: country-pair	Yes	Yes
	FE: year	Yes	Yes
	Observations	4536	4,536
	R squared (adjusted)	0.110	0.171

the significance level of the coefficient for gross trade now lies within the 5% confidence interval (the coefficient for value-added trade remains at the highest level of statistical significance). The increase in absolute value of coefficients is even more pronounced in the regressions using total trade intensity for the EZ-19. In fact, these are the highest absolute values of coefficients we observe across all regression specifications. Coupled with the very high significance levels - both coefficients are well within the 1% confidence interval - indicates the prominence of industrial supply chains across the EZ-19, even compared to the entire EU-28. The levels of  $R^2$  are slightly higher for the EZ-19 compared to the EU-28.

#### 7 Robustness

We run a series of alternate specifications of the regression analysis in order to find further evidence of the robustness of the results. Using a different calculation of the main dependent variable (difference in log GDP) in order to verify these findings. This does not impact the most important findings, especially regarding intra-industry trade. It rarely changes the coefficients' level of significance or their absolute value to a meaningful degree and never result in a change of sign.

Although the inclusion of country-pair fixed effects does not fully resolve all concerns regarding potential omitted variable bias this by itself, they do effectively address time-invariant omitted variables (such as geographical proximity or common language). However, given the country sample, it is not possible to use standard instrumental variable regressions, which generally focus on bilateral tariffs or trade agreements - both of which are harmonized across the entire European Common Market.

#### 8 Conclusion

The European Union has been the subject of numerous debates in the context of optimum currency area theory and whether increasing trade flows across the common market also result in higher economic alignment. However, many analyses linking business cycle synchronicity and trade intensity have previously only considered gross trade data, omitting the contribution of intermediary products in national and regional supply chains. Few analyses specifically consider intra-industry trade as a major determinant of economic alignment, despite its prominent role in the context of Frankel and Rose's endogeneity hypothesis. This empirical analysis focuses on both of these aspects of OCA theory. There is no statistically significant correlation between total trade intensity and GDP co-movement within the EU once we include standard control variables and fixed effects for years and country-pairs. However, there is significant correlation between business cycle synchronicity and intra-industry trade across EU members, even under these restrictive regression frameworks. Ultimately, the regressions produce significant and positive coefficients when using a subindex of industrial production - an economic sector which had been at the center of pan-European economic integration for several decades before the observation period and for which cross-border supply chains are particularly prominent. The statistically significant correlation of trade and GDP co-movement exists primarily for the whole European Union and for the eurozone.

In our view, the regression results indicate some evidence that higher trade intensity can be associated with a higher degree of economic alignment within the EU and the eurozone, particularly regarding intra-industry trade. The fact that intraindustry trade and industrial production produce the clearest results in this regard indicate the importance of pan-European supply chains, much in line with Frankel and Rose's endogeneity hypothesis.

Although preferable to simple analyses using gross trade statistics, we nevertheless note that further work might be required to improve the assessment of bilateral trade relations in the context of input–output data. More specifically, a better understanding of the pan-European supply chains could improve the assessment of the nature and degree of economic alignment between EU and EZ member states over time. In addition, the analysis only covers the period until 2014 due to data constraints. However, much of the European economic integration occurred after the Global Financial Crisis and the Eurozone Crisis. This is particularly true for the CEE European Union member states in the time-frame of 2017–2020, which was characterized by extensive export growth, FDI inflows from fellow member states, and economic convergence supported by high EU grant absorption in the region. Similar research covering this period specifically could provide further evidence for the findings of this analysis.

#### A Scatterplots

See Figs. 2, 3.



Fig. 2 Full data set with 2008 and 2009 highlighted (unlagged data; real GDP growth)



Fig. 3 Scatterplot of EU-28 (full unlagged data sample without 2008 and 2009)

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