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Production Fragmentation and Factor Price Convergence[1]

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Abstract

In this analysis, we empirically analyze if the nature of trade matters for international factor price convergence. In particular, we examine whether factor prices converge when country pairs involve with more bilateral production fragmentation arrangements. We apply panel fixed effect techniques using data for five EU countries. The analyses are controlled for alternative trade related indicators such as bilateral trade intensity and bilateral intra-industry trade as well as for industrial similarity variables. We find that bilateral production fragmentation plays a key role in labor cost converging effects of trade.

Keywords: international factor price convergence; production fragmentation; trade

JEL codes: J31, F14, F15, F41

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Non-Technical summary

The nature of international trade has become more closely related with the exchange of goods that are produced in internationally fragmented arrangements. Under these arrangements, some of the imported goods are used as intermediate inputs in domestic production, most of which are then exported to other countries either as processed or final consumption goods.

International factor price convergence theorem states that if two countries producing two goods with two different factors of production and having not too different production techniques then free trade would allow them to have the same goods prices that lead to the equalization of factor prices without the need for factor mobilization. Accordingly, the literature focuses on two channels as significant factors for factor price convergence: trade and similarity in factor endowment. However, the concept of trade in goods per se has not provided a sufficient explanation in changing factor prices. On the other hand, trade in intermediate goods differs from trade in final goods as it involves some kind of technology transfer generating a "productivity effect" that expected to stimulate wage changes between the trade partners.

This study differs from the literature by considering the independent impacts of the alternative forms of trade together on the movements of factor prices across the countries. It notes that including both trades in final goods and intermediate goods is important in detecting the appropriate impact of trade on factor prices. Using data for five EU countries that are similar in production technology we examine the impact of bilateral trade in value added on the unit labor cost convergence by controlling the analysis for the impact of bilateral trade intensity, intra-industry trade and industrial similarity indicators. All variables are computed at bilateral manner to investigate the extent of the linkage between trade and labor costs between countries. The analysis is also conducted for 2-digit manufacturing industries exhibiting different trade and industrial conditions. Panel fixed effect techniques are used to estimate relevant parameters.

Our empirical analysis suggests that the nature of trade matters in determining the cross country factor price convergence. Increases in trade in value added and intra-industry trade lead factor prices to converge between the country-pairs. However, there is no significant linkage between standard bilateral trade intensity indicator and factor price convergence. Use of alternative bilateral production fragmentation indicators, different models and estimation techniques in the analyses validated the main results.

1. Introduction

The nature of international trade has been changing and has become more closely related with the exchange of goods that are produced in internationally fragmented arrangements by which countries specialize at different stages of a production sequence. Under these international vertical production arrangements, some of the imported goods are used as intermediate inputs in the production of a country's domestic goods, most of which are then exported to other countries either as processed (intermediate) or final consumption goods. [2,3] As a result international production arrangements have initiated a complex cross-country flow of value added.

In this paper, we investigate empirically whether the nature of trade matters and international production fragmentation plays a prominent role, compared to the trade in goods, in the factor price convergence process across countries. Trade in intermediate or processed goods differs from trade in final goods as it involves some kind of technology transfer generating a "productivity effect" that stimulates wage changes in the countries engaging in production fragmentation arrangements (Jones and Kierzkowski, 1990; Grossman and Rossi-Hansberg, 2008; Acemoglu, Gancia and Zilibotti, 2012; Baldwin and Robert-Nicoud, 2014). Using data for five EU countries (i.e Belgium, France, Germany, Italy, Netherlands) we examine the impact of bilateral production fragmentation on the unit labor cost convergence by controlling the analysis for the impact of bilateral trade intensity, intra-industry trade and industrial similarity indicators. We use panel fixed effect models in our regression analyses to account for both cross-sectional and time fixed effects.

Our empirical analysis suggests that the nature of trade matters in determining the cross country factor price convergence. First of all, increases in trade in value added and intra-industry trade lead factor prices to converge between the country-pairs. This finding is consistent with the theoretical prediction that production fragmentation by generating productivity effects may lead to convergence of factor prices. Secondly, there is no significant linkage between standard bilateral trade intensity indicator and factor price convergence.

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[2] Hummels et al. (2001) provide compelling evidence on increased trade in intermediates and intensified global production networks across countries. Similarly, Feenstra and Hanson (2001) discuss how outsourcing has been decreasing the domestic content of value added in production by increasing the use of intermediate goods abroad in domestic production.

[3] Johnsen and Noguera (2012) and Koopmenn et al. (2010) document the volume of "value added" trade.

This paper is related to the literature investigating determinants of international factor price convergence. The factor price equalization (FPE) theorem states that if two countries producing two goods with two different factors of production and having not too different production techniques [4] then free trade would allow them to have the same goods prices that lead to the equalization of factor prices without the need for factor mobilization.[5] Thus, the literature generally focuses on two channels leading to factor price equalization: trade and similarity in factor endowment. Earlier studies focused on international trade in goods but in particular final goods as a main factor leading factor price equalization. However, in subsequent studies the concept of trade in goods per se does not provide sufficient explanation in changing factor prices. The impact of trade on intermediate goods and fragmentation began to appear in Heckscher-Ohlin type models in late 1970's and 1980's but Jones and Kierzkowski (1990) are deemed to be the first to note that fragmentation can be considered as technological progress and should therefore be expected to have complex wage effects. Fragmentation reallocates production efficiently towards countries where wages are lower (Acemoglu, Gancia and Zilibotti, 2012). Due to the labor augmented technological progress, production fragmentation (task trade) unlike trade in goods, induces a productivity effect, which increases the wages in low-skilled labor intensive countries taking part in international production chains. As a result, the wage gap between the country pairs engaging in production fragmentation is expected to fall (Grossman and Rossi-Hansberg, 2008). Baldwin and Robert-Nicoud (2014) integrate trade in goods and fragmentation (trade in tasks) literature and provide evidence for fragmentation to generate a productivity effect analogous to the factor price equalization theorem. In sum, theoretical literature provides many alternative models and conditions generating convergence and divergence of factor prices across and within countries due to international trade.[6] There is agreement that it is now largely an empirical issue to be analyzed with real data.

Empirical literature focuses on examining either the validity of the theorem across/within countries[7]; the factors having an impact on the convergence of cross/within country factor prices[8];

[4] That implies trading partners are similar in factor endowment, technology used in production and employment rate.
[5] Samuelson (1948), Lerner (1952),Ohlin (1933).
[6] In addition to those studies discussed above see also Feenstra (1998), Deardorff (2001), Venables(1999), Markusen (2006) ect.
[7] For instance Tovias(1982), Trefler (1993), Davis and Weinstein (2001), Deardoeff (2001) and Egger (2006) conduct empirical tests on factor price equalization across countries, while among others Thompson (2013),

the fragmentation impact on the wage gap between skilled and unskilled workers.[9] In the early stage, empirical studies mainly focus on the link between trade in goods and factor prices and mostly consider the case in developed countries (see Tovias, 1982; Gremmer, 1985; Mokhrari and Rassekh, 1989; Trefler, 1995), ignoring trade in intermediate goods and fragmentation.

Feenstra and Hanson (1996, 1999, and 2007) show that international fragmentation of production, which resulted in intensive trade in intermediate goods, is important in explaining wage dynamics both within and between countries.[10] Among recent literature, Egger and Egger (2002), and Egger and Pfaffermayr (2004) and Egger (2006) empirically investigate the international dimension of wage convergence and the role of cross-border fragmentation. Geishecker and Görg (2008) incorporate household panel and industry-level data to investigate the link between international fragmentation and wages. The existing empirical literature generally supports the hypothesis that trade in goods and international fragmentation imply different dynamics to wages and fragmentation has a significant impact on factor price convergence. [11]

None of the empirical studies, however, consider the independent impact of the alternative forms of trade together on the movements of factor prices across the countries. Trade in goods and international production fragmentation take place at the same time. Then, it is important to take alternative forms of trade into account when detecting the appropriate impact of trade on factor prices. Our empirical results suggest that bilateral production fragmentation plays a key role in the underlying convergence effects of trade.

Moreover, we account for the impact of factor endowment similarity, which is ignored in recent empirical literature on factor prices. In addition, intensity of trade and production linkages varies across the trade partners; therefore, we use bilaterally computed variables rather than the volume of trade in intermediates or the share of intermediate goods in imports or other forms of aggregates to focus on bilateral trade and labor cost relations. Doing this allows us to investigate

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Acemoglu and Autor (2011) and Feenstra and Hanson (1996, 2003) focus on factor price equalization within countries.

[8] Gremmer (1985), Mokhrari and Rassekh (1989), O'Rouke and Williamson (1992), Copeland and Thompson (2008) and Thompson (2013).

[9] Feenstra (1998), Acemoglu and Autor (2011) and Egger (2006).

[10] See also the teoretical references discussed in an earlier paragraph.

[11] Egger and Pfaffermayr (2004) and Geishecker and Görg (2008) suggest conditional convergence.

the extent of the link between trade and labor costs between countries integrating their production sequences at different stages. We also test how our benchmark results may change if we use data from 2-digit manufacturing industries exhibiting different trade and industrial conditions.

The rest of the paper is organized as follows. Section 2 explains the empirical model, measurement of variables and estimation methodology. Section 3 presents empirical results for manufacturing industry together with the additional regression analysis. Section 4 concludes the paper.

2. Estimation methodology and definition of variables

2.1 Basic Model

The effect of bilateral production fragmentation on factor price convergence is examined empirically by estimating the following equation: [12]

$$CVulc_{hp,t} = \alpha_t + \beta_0 + \beta_1 BPF_{hp,t} + \beta_2 Z_{hp,t} + u_{hp} + \varepsilon_{hp,t} \qquad (1)$$

where $\varepsilon_{hp,t}$ =ρ$\varepsilon_{hp,t-1} + v_{hp,t}$ and $CVulc_{hpt}$ denotes coefficient of variation, a measure of dispersion in factor prices between home h and partner p countries, at time t (see section 2.2 for details). BPF_{hpt} stands for bilateral production fragmentation, and Z_{hpt} is a vector of other bilateral time-varying factors. Error term $u_{hp}$is assumed to be fixed therefore we have panel fixed effects model to capture country-pair heterogeneity. In order to account for possible correlation among variables we defined AR(1) process for disturbance term $\varepsilon_{hp,t}$. Disturbance term v_{hpt} is assumed to be iid. Specification also includes time fixed effects (α_t). The year fixed-effect is used to account for systemic changes across the sample in country pairs that influence factor price dynamics.

In addition to bilateral production fragmentation, we also focus on two key trade related indicators, including bilateral trade and intra-industry trade. Moreover, as noted above for the FPE theorem to hold, trading countries should share not too different production techniques. Therefore, to control for the effect of similarities in production techniques, we include the

[12] The model combines the Gremmen(1985) and Ng(2010) approaches.

correlation coefficient of capital/labor ratio. In addition, employment ratio (employment over labor force) is included to control for the full employment. Hence, Z_{hpt} in Eq(1) consists of the following variables: bilateral trade intensity (TI_{hpt}), bilateral intra-industry trade (IIT_{hpt}) and industrial (or production) similarity indicators such as capital/labor ratio and employment ratio.

We estimate Eq. (1) by using panel data for 5 European Union countries for the period of 1995-2011. These countries consist of Belgium, France, Germany, Italy and The Netherlands.

2.2 Measurements of variables

2.2.1 Factor price convergence

Problems related to the measurement of internationally comparable wage data have encouraged researchers to conduct tests that validate the implications of relative wage variation rather than differences in relative wages directly. Tovias (1982) notes that statistics on labor costs include social security payments; thereby, they are much more suitable measure of factor prices compared to wages or earnings. Thus, we use labor cost data taken from OECD STAN database to compute our measure for factor prices. Because we are interested in the relative dispersion of labor costs at different periods of time, we use nominal values as in Tovias (1982) and Gremmen (1985). Then in order to account for productivity difference across the pairs of countries as Dollar and Wolf (1988) and Trefler (1993) note, we divide labor costs by output to obtain unit labor cost *ULC* variable. Then as a measure for factor price convergence we follow Tovias (1982) and Mokhtari and Rassekh (1989) to compute the bilateral coefficient of variation in *ULC*, $CVulc_{hpt}$, between home *h* and partner *p* countries at time t:

$$CVulc_{hpt} = \sigma(ulc_{ht}, ulc_{pt})/\mu(ulc_{ht}, ulc_{pt}) \qquad (2)$$

A decrease in the $CVulc_{hpt}$, indicates convergence of *ULC* in relative terms between pairs of countries.

Alternatively Gremmen (1985) employs log of relative labor costs while Mokhtari and Rassekh (1989) use coefficients of variation of wages across countries to obtain time series indicator for factor price convergence. Tovias (1982) also computes the coefficient of variation in labor costs across countries to analyze relative dispersion of wages at different periods of time.

Egger and Pfaffermayr (2004) propose the use of β-convergence while Egger (2006) proposes the σ-convergence approach to compute convergence trends in factor prices.

Our approach is closer to Mokhtari and Rassekh (1989) and Tovias (1982) who form time series data, but we adopt 3-year moving coefficient of variation in ULC of home and partner country to form a panel data involving country pairs and time dimension. To do that the first element of the moving CV is obtained by computing CV of the initial 3 years observation of the home and partner country ULC. Then the CV is modified by excluding the first year observation and including the next year observation of ULC's. For instance we compute $CVulc_{hpt}$ between Germany and France for the periods 1995-1997, 1996-1998, etc. By doing this, we would be able to capture medium to long-term trends in the convergence period[13], and at the same time include both cross sectional and time dynamics into our models. The 3-year moving CV approach not only allows us to capture rapidly changing patterns but also smooth out year-on-year unexpected changes. The use of a CV also mitigates problems related to measuring comparable labor costs variables across the countries. In addition, since labor market relations may vary from country to country we compute bilateral ULC coefficient of variations.

2.2.2 Trade Related Indicators

In this paper, we use three different trade related indicators to analyze the impact of alternative trade linkages on international factor price convergence: trade intensity, intra industry trade and production fragmentation. The impacts of trade in goods and trade in intermediate goods are investigated separately in the existing empirical literature. For instance, Gremmen (1985) shows that although pre-trade differences in wages are determined by the scarceness of labor relative to that of other factors of production, trade intensity leads to convergence in factor prices. Mokhtari and Rassekh (1989) argue that trade openness also decreases variation in wages while Feenstra (1998) focuses on the significance of intermediate goods trade.[14] Baldwin et al. (2014) note that the nature of international trade is changing in a way that both trade in goods and trade in tasks or fragmentation arise at the same time that the later involves technology transfer. Hence, a study

[13] Due to Tovias (1982), who notes that in a converging process, we are interested in long-term trends.
[14] Given the scope of our paper, we do not discuss the literature investigating the link between commodity prices and factor costs.

investigating the link between trade and international factor prices has to include both trade in goods and an indicator for international fragmentation into the analysis to decompose impacts of different forms of trade on factor prices. In the following section, we explain how we compute our three trade related indicators.

Measure of Bilateral Production Fragmentation

There are different approaches used extensively to measure the degree of fragmentation in production. Feenstra and Hanson (1996) define the extent of fragmentation or specialization in production as "imported input embodied in gross output as a share of total gross output" to point out the rising trends in outsourcing. Hummels et al. (2001) define it as "a share of imported input embodied in its exported goods in total exports" to measure the growth of vertical specialization. OECD and WTO, on the other hand, emphasize the contribution of value added by each country in production chains and jointly release "trade in value added" data to assess the intensity of international production fragmentation.

OECD TiVA (Trade in Value Added) database contains a range of indicators measuring the value added content of international trade flows and final demand. Indicators are computed by using input/output tables for each country. Therefore, the main difference between OECD-WTO measure of fragmentation and other two is the first one focuses on trade in value added while other two take into account volume of intermediate goods trade. Hence, we use OECD-WTO data to construct our production fragmentation index for our benchmark regression analysis. However, in the following section we also check if our results are robust to the alternative measures of vertical specialization.

Trade in Value Added

Daudin, Rifflart and Schweisguth (2011), Koopman, Power, Wang and Wei (2010) and Johnson and Noguera (2012) bring the discussion of the concept of value added trade in the literature and

state that value added trade better tracks global production networks and supply chains.[15] For this purpose, OECD and WTO jointly release the Trade in Value Added (TiVA) database. TiVA indicators are derived from OECD Input Output Tables linked together using the Bilateral Trade Database in goods by industry and the end-use category and estimates of bilateral trade flows in services. There are 39 indicators provided in TiVA for the years 1995, 2000, 2005, 2008, 2009, 2010 and 2011. We use "value added embodied in gross exports ($TiVA^x$)" to compute our bilateral value added embodied in gross exports data for our benchmark analysis as:

$$BPF_{hpt}^{TiVA} = \ln(va_{hpt} + va_{pht}) \tag{3}$$

where va_{hpt} (va_{pht}) is the value added embodied in the gross exports of country h (p) sourced from country p (h) . Higher BPF indicates stronger production fragmentation.

Bilateral intra-industry trade

We construct an index of bilateral intra-industry trade using the Grubel-Lloyd formula. The index measures the average deviation of net exports as a share of total exports at time t:

$$IIT_{hpt} = 1 - \frac{|x_{hpt} - m_{hpt}|}{x_{hpt} + m_{hpt}} \tag{4}$$

where $x_{hpt}(m_{hpt})$ denotes home country h's exports (imports) to (from) partner country p. Lower values of net exports (i.e close to zero) indicate a higher extent of trade in similar goods. Then, IIT will be higher.

Bilateral trade intensity

As for the bilateral trade intensity, we follow the literature to construct the ratio of the bilateral trade to the sum of the country-pairs output:

$$TI_{hpt} = \frac{x_{hpt} + x_{hpt}}{y_{ht} + y_{pt}} \tag{5}$$

[15] See Baldwin and Lopez-Gonzalez (2013) for the discussion on the comparison of the indicators used for fragmentation. Amador and Cabral (2009) also suggest a relative measure which combines information from Input-Outpu matrices and international trade data for measuring the extent of vertical specializaiton.

where, y_{ht} (y_{pt}) denotes country h *(p)* gross production. *TI* captures bilateral trade between county h and p relative to total output in both countries.

2.2.3. Measures for production technology similarity

We use standard bilateral similarity of factor endowment between country pairs to capture similarity of production structure. The indicator is computed as bilateral capital/labor coefficient of variation as follows:

$$CVkl_{hpt} = \sigma(kl_{ht}, kl_{pt})/\mu(kl_{ht}, kl_{pt}) \quad (6)$$

where kl_{ht} and kl_{pt} stand for home h's and partner p's capital stock and employment ratio at time t, respectively. Similar to the computation of bilateral ULC coefficient of variation, the bilateral coefficient of variation in capital/labor ratio between countries h and p is computed by using the 3-year moving windows method. Mokhtari and Rassekh (1989) use real capital stock and employment, whereas Gremmer (1985) uses physical capital per worker in computations. Different from them, we generate panel data. We use gross capital formation (investment) instead of capital stock in our computations. [16]

The second indicator, bilateral employment ratio E_{hpi} (sum of employment/labor force (E_i) in partner countries) is included into the analysis in order to account for the full employment assumption as indicated in the FPE theorem:

$$E_{hpt} = (E_{ht} + E_{pt})$$

3 Empirical Analysis

3.1 Potential estimation issues

Tovias (1982) argues that a test on FPE or convergence theorem must account for what actually happens after free trade is established. Thereby, country selection for the empirical analysis is important as free trade conditions are difficult to take place in real world. Tovias focuses on five EU members (Belgium, France, Italy, Germany and the Netherlands) as these countries satisfy

[16] A similar measure is used in Trefler(1993).

several conditions that FPE theorem points out: (1) Establishment of free trade to have common commodity prices; (2) Similarity in factor endowments, technology and employment rate to have not too different production techniques; (3) Production of almost similar goods; (4) Similarity in demand patterns; (5) Low transportation costs due to geographical nearness and strong communication networks. Therefore, we follow Tovias and use data from these five countries to test impact of trade on FPE among these countries. Because, free trade relationship has been established since early 1970's we have good amount of data to examine the link between trade and factor prices. However, trade in value added data has been available as of 1995 till 2011, thus we focus only on the period in which there is a well-established trade linkage between the country pairs.

In our analysis we seek to determine whether labor costs in these countries converged. Thus, we use CV as a measure of convergence. Doing this may also solve potential reverse causality from labor costs to the explanatory variables as well as potential measurement errors related to the computation of factor price convergence.

Use of panel-fixed effect techniques which includes both time and country-pairs fixed effects parameters may deal with other potential endogeneity issues related to time specific changes and time-invariant unobservable factors that expected to influence factor price dynamics within the sample countries.

3.2 Benchmark results

Explanatory variable BPF^{TiVA} is available only for the years 1995, 2000, 2005, 2008, 2009, 2010 and 2011. We use linear interpolation method to compute BPF^{TiVA} values for the missing years. Since we use 3-year moving CV we use first three years to have first observation of dependent variable in the regression analysis. Therefore, in our empirical analysis time dimension starts at 1997. All explanatory variables (BPF, IIT, TI, E) are measured by their corresponding years' values.

Table 1 presents summary statistics for our key variables. Both dependent and independent variables exhibit considerable variability. The mean of dependent variable CV_{ulc} (CV_{kl}) is 0.21 and it varies within the range of 0.01-0.78. Variability among the trade related

variables is largest for TI with the mean 0.03 and the range 0.01-0.11. The average bilateral production fragmentation or bilateral value added is 7.85, and it has a range between 6.34 and 9.86.

Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev	Min	max
Bilateral coefficient of variation in ULC (*CVulc*)	150	0.203	0.134	0.010	0.513
Bilateral coefficient of variation in capital/labor ratio (*CVkl*)	150	0.263	0.136	0.049	0.571
Bilateral production fragmentation (BPF)	150	7.867	0.967	6.344	9.860
Intra Industry Trade (IIT)	150	0.825	0.105	0.569	0.999
Trade Intensity (TI)	150	0.032	0.021	0.011	0.110
Bilateral employment ratio (E)	150	0.306	0.050	0.197	0.425

Table 2: Results of the Panel Fixed Effect (Within) Estimation

	1	*2*	*3*	*4*	*5*
BPF				-0.161***	-0.178***
				0.044	0.043
IIT		-0.237**	-0.241**		-0.202**
		0.097	0.107		0.102
TI	0.572		-0.007		0.171
	0.681		0.765		0.722
CV*kl*	0.100	0.071	0.069	0.128	0.116
	0.062	0.063	0.063	0.061	0.061
E	-0.017	-0.148	-0.170	0.182**	0.116*
	0.752	0.762	0.770	0.728	0.730
# of Obser.	150	150	150	150	150
Country-pairs	10	10	10	10	10

Note: Each regression includes a constant term and time fixed effect parameter. Disturbances are assumed to have AR(1) process. Two-step estimation is conducted. The values in italic are the standard errors. Numbers with asterisks "***", "**", "*" are statistically significant at 1%, 5% and 10% respectively.

We began our analysis with the estimation of Eq. (1) and added three trade related variables one at a time into the regression analysis. Table 2 presents the panel fixed effect estimation results. Regression includes both country-pair and time fixed effects parameters.

Table 2 shows that when other trade related variables are not included in the analysis, TI does not have a significant impact on CV*ulc*. This result is in line with the literature suggesting a weak linkage between trade and factor costs, rather emphasizing the factor endowment similarities. On the other hand, results in column two find a significant impact of IIT on CV*ulc*. This finding is consistent with the literature documenting a positive effect of IIT on the reduction in dispersion of labor costs. The sign and the significance of the coefficients of TI and IIT do not change noticeably when we include the two variables together in the regression analysis (column 3).

Column 4 suggests a negative and significant association between BPF and CV*ulc*. In column 5 the impact of *BPF* does not change even if we add other trade related explanatory variables. The coefficient is significant at the 1% level. This finding is consistent with the theoretical prediction that stronger production fragmentation linkages across the countries could have a converging effect on international wages. IIT has a significant negative impact on factor price convergence. The impact is significant at the 1% level. TI has ignorable influence on convergence of labor costs across the country pairs. TI involves trade in both final and intermediate goods. It appears that both *BPF* and IIT capture the effect of trade in final and intermediate goods on factor prices, leaving an insignificant impact of TI.

Using the information given in Table 1 and Table 2, we find that an increase in IIT by one standard deviation, keeping the values of other variables constant, decreases coefficient of variation in ULC by -0.02(-0.2*0.11), while one standard deviation in *BPF* decreases it by -0.17(-0.18*0.97), hence the overall significant impact of trade on coefficient of variation in ULC is estimated to be -0.19(-0.02-0.17).

The coefficients of factor endowment variation and employment ratio are positive, and only employment ratio is significant at 1% level when we include all trade related indicators into our regressions. Countries we are analyzing have very similar labor cost dynamics as well as factor endowment and employment ratio. Therefore, we do not expect large deviations in

industrial similarity indicators that would affect convergence of labor costs. For all that, trade related variables take role in advance stages of the convergence process.

3.2. Additional Analysis

In this section we perform additional regression analyses to further examine the linkage between trade and factor prices. To do that, we check how our results change with respect to the following modifications: alternative specifications of fragmentation, using non-interpolated bilateral TiVA based fragmentation indicators, non-crossing 3-year rolling windows CV, all variables obtained in3-year rolling window, using 5-year rolling windows CV, alternative specifications of dependent variables and use of 2-digit sub-industry level data.

3.2.1 Alternative description of bilateral production fragmentation

We compute three additional measures for the intensity of international production fragmentation to check if our benchmark results are sensitive to the alternative formulations of the dependent variable.

Value Added Embodied in Final Demand ($TiVA^{FD}$)

In the benchmark analysis we use TiVA "value added embodied in gross exports" data to compute our BPF indicator. Alternatively, instead of gross export we may use "value added embodied in final demand" and using the same formula in Eq.3, construct our bilateral value added embodied in final demand indicator.

Hummels, Ishii, and Yi (HIY)

According to Hummels et al. (2001) fragmentation or vertical specialization in international trade is present if production takes place in two or more sequential stages, two or more countries add value, at least one country uses imported inputs and part of the final output is traded internationally. Ng (2010) develops bilateral production fragmentation where each country specializes in particular stages of goods production. Similar to Ng (2010), we can define a bilateral production fragmentation in a pair of countries where each country specializes in a particular stage of the production process. Then, the imported inputs from country *p* that are embodied in country *h's* exported goods at time *t* can be expressed as:

$$vs_{hpt} = \mu_{hpt} * x_{hpt} \quad (10)$$

where $\mu_{hpt} = m_{hpt} / y_{ht}$, m_{hpi} denotes country h's imported input share in gross output from country p, x_{ht} is country h gross output, so that μ_{hpt} is the imported input from country p that are embodied in country h's gross production. Multiplying μ_{hpt} with x_{hpt} country h's exports to country p in Eq. (10) we have vs_{hpt} which measures the imported input content of exports of country h to country p. $vs_{hpt} = 0$ if country h does not import intermediate inputs from country p or does not export part of production of the same sector.

Following Ng (2010), the measure of bilateral production fragmentation between countries h and p can be defined as the intensity of bilateral imported input embodied in their total exported goods and formulated as:

$$BPF^{HIY}{}_{hpt} = \frac{vs_{hpt} + vs_{pht}}{x_{ht} + x_{pt}} \quad (11)$$

where x_{ht} and x_{pt} are total exports of country h and p, respectively.

Feenstra and Hanson(FH)

Feenstra and Hanson (1996) define the extent of fragmentation or specialization in production as "imported input embodied in gross output as a share of total gross output", so Eq. (10) can be modified as follows to reproduce Feeensta and Hanson (1996) description of the extent of the vertical specialization index.

$$vs^{FH}{}_{hpt} = \mu_{hpt} * y_{ht} \quad (12)$$

Then, by using the Ng (2010) approach, bilateral production fragmentation can be computed as:

$$BPF^{FH}{}_{hpt} = \frac{vs_{hpt} + vs_{pht}}{y_{ht} + y_{pt}} \quad (12)$$

First three columns of Table 3 report that the results of our benchmark estimation are sensitive to the measurement of the BPF. In the benchmark model BPF is measured as a volume

of trade in value added in exports and we concluded that as value added by trade partner's increases factor prices tend to converge. HIY and FH measure of BPF is based on volume of intermediate goods trade thus does not necessarily indicate how much each partner contributes to the total value added. Coefficient of $TiVA^{FD}$ is estimated to be negative but insignificant. These results emphasize the role of trade in value added in export market in the factor price convergence process. Columns 4 and 5 suggest that results would not change even if we use non-interpolated TiVA. [17]

Table 3: Results with alternative BPF indicators: $TiVA^{FD}$, HIY and FH Production Fragmentation Indexes

				Non-interpolation	
	$TiVA^{FD}$	*HIY*	*FH*	$TiVA^{X}$	$TiVA^{FD}$
	1	*2*	*3*	*4*	*5*
BPF	-0.127	0.945	0.580*	-0.217	-0.210**
	0.078	0.824	0.504	0.054	0.117
IIT	-0.610**	-0.587**	-0.577**	-0.633	-0.944
	0.179	0.174	0.181	0.316	0.375
TI	-0.315	-2.547	-1.279	0.457	0.304
	0.952	1.968	1.189	1.868	1.774
CV*kl*	-0.044	-0.074	-0.070	0.059	0.014
	0.095	0.102	0.102	0.053	0.107
E	-2.024*	-1.776	-2.019	-0.510*	-1.967
	2.033	2.000	2.094	1.945	2.451
# of Obser.	140	140	140	50	50
Country-pairs	10	10	10	10	10

Note: Each regression includes a constant term and time fixed effect parameter. Disturbances are assumed to have AR(1) process. Two-step estimation is conducted. The values in italic are the standard errors. Numbers with asterisks "***", "**", "*" are statistically significant at 1%, 5% and 10% respectively.

[17] The purpose of the use of interpolation in computation of TiVA for the missing years in our benchmark analysis is to increase number of observation in our analysis. 3-year non-crossing CV is computed by using ULC of 1995-1997, 1998-2000, ...2007-2009 and 2010-2011.Use of 5-year moving CV increases our time perseption.

Table 4: Additional Analysis

	Non-crossing CV3	*All Variables are computed by 3-year moving windows*	*non-crossing moving windows*	CV5
	1	*2*	*3*	*4*
BPF	-0.132***	-0.297***	-0.290***	-0.177***
	0.039	0.056	0.074	0.050
IIT	-0.579	-0.310*	-0.430	-0.608***
	0.198	0.164	0.294	0.114
TI	-0.010	1.827	2.321	-0.914
	0.941	1.436	2.147	1.336
CV*kl*	-0.006	0.154***	0.117	-0.058
	0.084	0.056	0.103	0.095
E	-1.022	-0.153	-1.143	-0.165
	1.642	0.925	1.627	1.363
# of Obser.	50	140	50	120
Country-pairs	10	10	10	10

Note: Each regression includes a constant term and time fixed effect parameter. Disturbances are assumed to have AR(1) process. Two-step estimation is conducted. The values in italic are the standard errors. Numbers with asterisks "***", "**", "*" are statistically significant at 1%, 5% and 10% respectively.

Table 4 shows the results when alternative formations of variables are used in the regression analysis. Results suggest that use of non-crossing 3-year moving windows CV, computation of all variables in moving windows sense or use of 5-year moving windows will not change the results for the BPF. However, even though the coefficient of IIT is negative the impact may become less significant.

3.2.2 Alternative labor cost specifications

In the next analysis, we check if our results are sensitive to the alternative labor cost specifications used in the literature.

Gremmer Panel Fixed Effect Model

We begin with the Gremmer (1985) analysis, which focuses on the consequences of direct trade involvement for factor price equalization, by testing if log differences in national wage levels in country-pairs, given their capital/labor endowment ratio, will be smaller when their trade involvement is higher. In column 1 of Table 4, we applied the Gremmer model to our data to compare our results with Gremmer (1985)'s results. Note that the Gremmer (1985) model includes a trade related variable and factor endowment ratio to explain the log of the labor cost difference between country pairs.[18] The trade variable is measured as: imports of country A from B over output of country A plus imports of country B from A over output of B. Factor endowment is represented by the log difference of physical capital per worker. We followed a similar approach in measuring labor cost and factor endowment differences across country pairs but diverge from Gremmer by adding our own trade related variables in addition to other factor similarity indicators.

Gremmer (1985) found that trade plays a significant role in decreasing wage dispersion. Table 4 column 1 reports that even if we measure factor price convergence as a relative log difference in unit labor costs, coefficients for BPF is negative and significant at the 5% level. Hence, BPF plays a significant role in decreasing labor costs difference between country pairs. The significance of IIT changes compared to the benchmark results in Table 3. However, note that the Gremmer (1985) definition of labor cost difference involves sort of a short term perspective.

[18] The dependent variable is measured as ln (labor cost in A/labor cost in B). The sequence in the observation per year is chosen so that labor cost in A > labor cost in B so that the ratio is positive.

Table 5: Gremmer (1985) and Mokhtari and Rassekh (1989) models' estimates

	Gremmer (1985)	*Mokhtari and Rassekh (1989)*
	panel Fixed effect model	*time series model*[b]
Dependent variable:	*dulc*	*CVulc*
	1	*2*
BPF	-0.121**	-0.014***
	0.043	0.005
IIT	-0.235	-0.401
	0.208	0.336
TI	-0.788	-0.271
	1.855	1.419
dkl	0.036	
	0.063	
CV*kl*		0.160
		0.228
E	-2.353	1.064***
	2.038	0.288
# of Obser.	164	17
Country-pairs	10	

Note: Each regression includes a constant term. The values in italic are the standard errors. Numbers with asterisks "***", "**", "*" are statistically significant at 1%, 5% and 10% respectively. (a) The model includes both country-pair and time fixed effects. The values in parentheses are the heteroskedasticity-robust standard errors. (b) The values in parentheses are Newey-West standard errors, and the autocorrelation structure includes 3 lags.

Mokhtari and Rassekh (1989) Time Series Model

The Mokhtari and Rassekh (1989) model is different from Gremmer (1985) in the sense that they adopt the idea in Tovias (1982) and state that convergence is a long term phenomenon, which should therefore be measured as a relative dispersion of labor costs. Then they compute the cross country mean and standard deviations to generate a time series of coefficients of variation in labor costs. Convergence in factor endowment is computed in the same way.

Mokhtari and Rassekh (1989) model explains the coefficient of variation in labor costs by trade openness, the coefficient of variation in factor endowment and the cross country employment ratio. They show that trade openness plays a substantial role in decreasing wage variation among countries.

In the next analysis, we adopt their specification of labor cost convergence and factor endowment similarity but use our trade related and other explanatory variables to estimate Eq 1. Results are reported in column 2 of Table 5. Once again, our results show that the long term impact of trade on labor cost convergence depends on the nature of trade. Production fragmentation or trade in value added embodied in gross exports has a significant impact on the fall in the labor costs variation across countries, while other trade related indicators remains ineffective.

3.2.4 Manufacturing Sub-Industries

Globalization has been increasing trade intensity and facilitating vertical production linkages across countries. However, the degree and complexity of production fragmentations as well as trade intensity are not uniform across industries. Various factors including *inter alia*, production technologies, factor and product market structures, transportation costs, levels of barriers to international trade, domestic demand pattern, etc. are prominent factors in forming industrial differences. It is the question of this part to investigate how labor costs across countries are linked when we consider manufacturing sub-industry dynamics. We analyze our benchmark model by using 2-digit industry level data. We include those industries which have 10 or higher trade share in manufacturing goods among the five European countries. Food, beverages and tobacco is not included, even though it accounts for about 10% of the total manufacturing goods trade within these countries, due to the intense of regulations on food prices. According to the OECD technology intensity classification; basic metals have medium-low technology; chemicals and chemical products, machinery and equipment n.e.c and motor vehicles have medium-high technology intensive; computers, electronic and optical products have high technology intensive production process.

The estimation results reported in Table 6 show that though industry specific coefficients are broadly consistent with the results obtained for the broad manufacturing industry, impact of

trade on industry specific labor cost convergence depends on the nature of trade. All estimated coefficients of production fragmentation are negative and significant at 5% or better level, except for other transport equipment. The coefficients of IIT are in general insignificant. All significant coefficients for TI are positive suggesting that increase in trade volume tend to weaken convergence in general. Industrial endowment similarity is significant and has convergence effect in basic metals, electronics and food. The sign of the coefficients for chemicals motor vehicles and other transport equipment are unexpectedly negative. The employment ratio is not a strong explanatory variable in the labor cost convergence process in general. The coefficient of the employment ratio is positive and significant in electronics but negative in other transports.

Table 6: Results for the Manufacturing Sub-industries

	Basic Metals	Chemicals	Electronics	Food	Machinery	Motor Vehicles	Other Transport Eqp.	Textiles
BPF	-0.12***	-0.11**	-0.09**	-0.01	-0.19***	-0.12***	0.04	-0.06*
	0.031	0.05	0.04	0.06	0.04	0.04	0.03	0.03
IIT	-0.08	0.02	-0.06	-0.05	-0.05	-0.02	0.01	-0.03
	0.05	0.07	0.10	0.09	0.06	0.06	0.03	0.06
TI	0.71***	0.17	0.45	1.00	1.09***	1.05***	-0.22	-0.11
	0.28	0.30	0.42	0.80	0.30	0.45	0.19	0.15
CV*kl*	0.04*	-0.14**	0.17***	0.26***	-0.03	-0.17***	-0.09*	0.03
	0.02	0.07	0.05	0.09	0.04	0.04	0.04	0.03
E	-1.87	9.91	33.11**	-6.43	0.40	3.87	-56.50**	4.96
	2.76	14.99	13.32	5.62	5.10	9.06	27.21	3.37
# of Obser.	140	140	140	140	140	140	140	140
Country-pairs	10	10	10	10	10	10	10	10

Note: Each regression includes a constant term and time fixed effect parameter. Disturbances are assumed to have AR(1) process. Two-step estimation is conducted. The values in italic are the standard errors. Numbers with asterisks "***", "**", "*" are statistically significant at 1%, 5% and 10% respectively.

4. Conclusion

This paper explores how labor costs are correlated in pairs of countries engaging in bilateral production fragmentation. We examine the independent impact of bilateral production

fragmentation, intra industry trade and trade intensity by controlling for factor endowment similarity and the employment ratio between the country pairs.

Existing empirical literature documents a positive effect of trade expansion on the convergence of labor costs across countries. In this paper, we show that the nature of international trade matters in explaining the appropriate impact of trade on the dynamics of international labor costs. International fragmentation measured in terms of value added involves technology transfer, which increases the productivity of labor that initiates labor cost adjustments across countries.

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