J. F. Kennedy sq. 6
10000 Zagreb, Croatia
Tel +385(0)1 238 3333
www.efzg.hr/wps
wps@efzg.hr

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Josip Tica
Luka Šikić

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Josip Tica
jtica@efzg.hr
Faculty of Economics and Business
University of Zagreb
Trg J. F. Kennedy 6
10 000 Zagreb, Croatia

Luka Šikić
luka.sikic@pilar.hr
Institute of Social Sciences Ivo Pilar
Marulićev trg 19
10000 Zagreb, Croatia

Abstract

The goal of the paper is to estimate relative importance of channels of technological diffusion between new member states and core EU countries. Based on neoclassical growth theory and extensive literature survey on technological diffusion we explore movements in the relative TFP in EU member states and try to identify relative importance of channels of technological diffusion as suggested by theory: imports, exports, FDI, R&D, human capital and fixed capital formation, etc. In the first step we employ Phillips and Sul (2007) log *t* test which has power to detect convergence even in the absence of cointegration between time series. In the second part we employ Abrigo and Love (2016) PVAR model in order to detect channels of diffusion of technology. The data is sampled from Eurostat and PWT repository and covers the period from 1995-2016 for all EU member countries. Contrary to conventional wisdom, our preliminary results suggest that trade openness as an important channel for TFP diffusion. The overall results point that productivity gap reduction is a heterogeneous process, country specific problem, but on average it can be supported through various economic policies focused on openness. Relative importance of other factors of technological convergence is statistically less relevant or even has opposite direction of causality. Peculiar results for relative importance of FDI and R&D is further explored in terms of the structure and general nature of FDI flows during the investigated transition and accession period.

Key words

TFP, channels of diffusion, convergence

JEL classification

D72, H50, P16

Endogenous Convergence and International Technological Diffusion Channels

Josip Tica[*a] and Luka Šikić[†b]

[a]Faculty of Economics and Business, University of Zagreb
Trg J.F.Kennedyja 6 10000, Zagreb, Croatia
[b]Institute of Social Sciences Ivo Pilar
Marulićev trg 19, 10000 Zagreb, Croatia

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JEL Codes: F43, O47, O33

[*]E-mail: jtica@efzg.hr, Office: +385.1.2383.162
[†]E-mail: luka.sikic@pilar.hr

1 Introduction

It is well recognized that differences in productivity levels explain a significant portion of international income per capita variation and that technology is one of the main determinants of productivity levels (Hall and Jones, 1999). Expanding technology levels is possible either through the autonomous technology creation that is usually related to RnD, or some sort of technology transfer. Since most of the technology creation happens in developed and rich countries, the international diffusion of technology plays a major role for technology absorption in developing countries and transition economies. This finding is confirmed by the large body of theoretical and empirical literature on the topic of international technology transfer (Keller, 2009) where majority of evidence suggests that FDI and international trade serve as major channels of international technology diffusion.

Technology is considered to be one of the major determinants of (economic) performance at the firm, industry or aggregate level. This finding has received a wide empirical support in the growth literature. However, not much technology is created in a wide cross section of countries, probably due to resource, infrastructural and institutional constrains on the innovation process. Since creation of new technology only occurs in a small number of very rich countries, the developing countries can benefit that process if the technology successfully diffuses internationally.

The aim of this analysis is to identify channels of international technological transfer and investigate how they affect the reduction of the productivity gap relative to the technological frontier in the sample of European transition countries and old EU member countries. We focus on the European transition countries as they do not create a lot of technology within the local economy but rather through the technology transfer with the rest of European Union (Merikll et al., 2013). Taken the complexity of the convergence process of European transition countries, we contribute the debate on the transfer of technology by investigating how several most important channels of technological diffusion affect the reduction of productivity gap relative to the European Union. Furthermore, we try to account for the role of absorption factors in our empirical model whenever data allows for that.

We employ innovative methodological approach. First, using Phillips and Sul (2007) *log t test* we try to endogenously determine convergence clubs within EU and in the second step we use Abrigo and Love (2016) PVAR model in order to investigate channels of technology transfers between EU members and within and between endogenously identified convergence clubs.

The main empirical difficulty in the analysis of technology stems from difficulties related to measuring technology and similar variables. Several measures on the aggregate and disaggregate level have been used in the literature (Keller, 2004). Usually, R&D expenditure serves as a proxy for technological intensity but this measure may misrepresent the technological process since many R&D projects fail or technology gets discovered outside of R&D. Furthermore, R&D data is not available for a wide cross section of countries. The other frequently used measure of technology are patents, probably due to the good data availability and relatively long time series. On the down side, there is a significant variation in the quality and value of patents so estimations based on that data might be biased. Also, some important new technological breakthroughs might not be patentable which makes overall results less reliable.

On a broader level, changes in a countrys or firms productivity are also used as a derived measures of technology (Keller, 2009) since there is a wide consensus about the importance of technology for increasing the productivity. TFP based measures are easily available for a large sample of countries and firms but on the downside, they potentially contain a wide and non-identifiable set of factors not exclusively related to the technological process. In this analysis we follow the TFP based measure of technology where the reduction of the productivity gap relative to the technological frontier (Nelson and Phelps, 1965) approximates the intensity of international technological transfer. Innovation and technology raise productivity through new goods and improvement of existing goods, implementing new organizational structures and processes, raising institutional quality and improving legal framework. In a wider sense, the productivity gap reduction will therefore capture the improvement of the countrys technological capacity.

The source of variability in the literature on technology transfer dominantly stems from the empirical side of the analysis. The first empirical problem is the measurement of variables of interest like technology or absorptive capacity. Many authors rely on the industry specific measures of technological capacity or assume that firms can access the foreign technology equally (Blalock and Gertler, 2008; Javorcik and Spatareanu, 2008) which can be a restrictive assumption. Since different authors use different measures, the overall results are not directly comparable. The problem with absorptive capacity measures is mainly related to the commonly used productivity gap measures that are prone to the measurement error due to the fact that productivity gap can be affected by the shocks that are not related to the absorptive capacities of the firm (Girma and Grg, 2007). Some studies (Ottaviano and Mayer, ated; Nicolini and Resmini, 2010) also pointed to the problem of differences in methodology used to study technological transfer and respective lack of comparability across different studies.

The issue stays mainly unresolved, especially since many of the papers surveyed rely on the different data sets making the comparison even more difficult. The other empirical problem is related to the difficulty of drawing general conclusions about the technological transfer across different papers mainly because the channels of technological diffusion are analyzed separately. For example, most papers on FDI and productivity analyze how direct investments affect productivity through spillovers but do not take the role of international trade into account (Keller, 2004). On the other side, trade studies analyze productivity without taking FDI into account so the comparative evidence is missing, especially taken that firms often engage in these activities simultaneously. The difficulties related to the empirical analysis also stem from the fact that there might be a significant number of other factors that influence technological transfer other than international exposure through FDI and trade and might even have negative effects (Harrison and Aitken, 1999). Finally, it is hard to sort out the causality between participation in the international activity and productivity and evidence does confirm that most productive firms might self-select into exporting (Melitz, 2003).

Technological transfer is a complex process happening through multiple formal and informal channels. Part of the technological transfer happens through voluntary transactions but a significant amount occurs through non-market transactions and different spillovers. This creates further measurement issues and makes formal analysis somewhat difficult. Some of the major channels of technological transfer recognized in the literature are international trade and FDI flows. Trade of goods and services contributes to the technological capacity of a country through reverse engineering, learning about production methods and designs but also through effects on the market structure and organization of production. These effects are most obvious in the imports of capital and intermediate goods but exports also serve as an important channel of technological transfer, for example through contacts of sellers with buyers.

FDI, after trade, is the second major channel of technology transfer of advanced or new technology from the host firm to the subsidiary. The technological firm level spillovers that happen in that process are expected to benefit the aggregate economy as well. Other channels recognized in the literature include licensing, joint ventures and movement of (skilled) workers whereas the effects of them might also be interdependent. Big part of technological transfer happens unofficially and includes imitation, international movement of employed persons, university exchange or unofficial patent applications which are all difficult to measure and account for. The interdependence between formal and informal channels further increases the measure and identification issues.

Given the host of methodological problems in the analysis of technological transfer, most of the empirical work has focused on particular channels and in that sense disregards the full structure of the process. We tend to fill this gap in the literature by examining several of the most important channels of technological transfer within the coherent analytical framework. Although there is a significant empirical literature on the topic of international technology transfer and productivity convergence, our motivation is related to the mixed evidence on this topic (Grg and Greenaway, 2004) as well as lack of evidence on the relative importance of different channels of diffusion (Keller, 2004).

The main contribution of the paper is that it analyzes main channels of technological transfer in the coherent new innovative methodological framework and within the converging and non-converging group of countries. In the Section 2 we provide literature review, in the section 3 data and methodology is presented and in the last two sections present results and conclusions.

2 Literature Review

Even though the theoretical literature (Markusen and Venables, 1999; Grg and Greenaway, 2004; Coe and Helpman, 1995; Greenaway and Kneller, 2007) is well developed and the empirical evidence on the topic of technology transfer is very large, much of this literature is ambiguous and hard to generalize upon. Best literature surveys on the topics of international technological transfer through both trade and FDI are Keller (2004, 2009) through FDI are Barba Navaretti and Venables (2006); Greenaway and Kneller (2007) whereas Wagner (2007) focuses on the trade. Generally, the evidence supports the idea that FDI is an important channel for international technological transfer. There is a good amount of evidence pointing that imports are a significant channel of international technology diffusion and somewhat more mixed and heterogeneous evidence supporting the role of exports.

International trade serves as the major channel of technology transfer, primarily because imported intermediate goods can contain a significant technological component (Broadberry, 1992). Coe et al. (1997) point to several other channels through which imports serve as a way to transfer technology internationally. Namely, imported intermediate goods raise domestic productivity; learning about better production methods, product design or organizational structures might result in more efficient domestic production; imitation of new products and new technology can significantly increase domestic technological capacity, adjustment and improvement of new products can improve quality of goods produced domestically.

Furthermore, interactions with foreign companies provide information about new products and practices (Greenaway and Kneller, 2007) as well as the technical assistance (Pack and Saggi, 2001) to local firms that allow them to produce at lower cost and higher quality. This effect might be of a higher importance for developing countries. Finally, higher competition in the international market might serve as an incentive to increase efficiency (Greenaway and Kneller, 2007). Exports also play an important role in the international technological diffusion since they contain information from international buyers about frontier design specifications and production techniques, as well as securing a competitive environment.

The literature on the role of trade in the international technological diffusion has focused on both firm (industry) and aggregate level analysis. Aggregate level studies suggest that domestic and foreign knowledge stocks influence domestic productivity. Coe and Helpman (1995) analyze the importance of imports in facilitating R&D spillovers in the sample of OECD countries. First they create a measure of the stock of foreign knowledge and then they regress TFP on the foreign and domestic stock of knowledge. The results point that both stocks of knowledge are important for productivity increases but the foreign stock is more important for bigger countries. Coe et al. (2009b) use somewhat different approach to calculate the stocks of knowledge and find only weak evidence for foreign knowledge spillovers.

Authors suggest that using bilateral import weights or simple averages produces better results than random weights when constructing the stock of knowledge. Different approaches to calculating the stocks of knowledge and trade weightings have also been suggested in the literature, for example Xu and Wang (1999) use capital goods imports as weights instead total imports and Funk (2001) and Falvey et al. (2004) use exports rather than imports. Kao et al. (1999) also criticize the results of Coe and Helpman (1995), especially due to the small estimated coefficients and low statistical significance, and use non-stationary panel approach to examine the significance of foreign knowledge spillovers. The results confirm positive spillover effects but the coefficient of interest is still not significant. Coe et al. (2009b) investigate spillovers from North to South and confirm that spillovers are an important source of productivity growth, where imports play the most important role. The importance of spillovers has been confirmed (Keller, 2000), although on the more disaggregated sample.

The literature recognized that simply providing for trade is not enough for a country to benefit from a foreign technology. Other conditions related to absorptive capacities need to be satisfied for the technological diffusion to be successful in the sense of both absorption and implementation in the production process. Crespo Cuaresma et al. (2004) confirm that spillover effects are stronger in countries that invest more in R&D and have more human capital in domestic economy where Coe et al. (2009a) point to the importance of the institutional framework and legal protection for the R%D spillovers. Some authors used the patent data because it identifies well the technological capacity. Sjholm (1996) uses patent data to conclude that there is a positive correlation between patent data and imports which points to the importance of trade for technological spillovers.

Significant number of papers investigated the role of trade for technological transfer on the disaggregated, industry or firm level. The main focus of empirical papers has been to analyze why some firms export while others focus on the domestic market exclusively and to investigate the relationship between exporting and productivity. Girma et al. (2004) conclude that in the presence of the market research costs, product modification costs, compliance and other sunk costs, the firms will engage in international markets only if the present value of their profits exceeds the costs of foreign market entry. The consensus in the literature about the relationship between exporting and firm productivity is that best firms self-select into exporting (Fryges and Wagner, 2007; Isgut, 2001) as well as that there are strong effects of learning through exporting (Aw et al., 2000; Renard, 2002) as they create information flows with international buyers, allow access to better institutional framework and incentives to raise productivity.

The other strand of literature pointed to the productivity gains that come from an increased competitive pressures in the international market which forces firms to increase their productive capacity. However, the most studies conclude in favor of self-selection argument rather than learning by exporting. It is important to point that this conclusion is very dependent on the sample used. For example, the evidence of learning effects tends to be much stronger in developing countries. The issue of causality has been an important empirical difficulty in this line of research, namely, if firms, or treated units, are not drawn from the random sample but are rather selected or self-selected according to some a-priori criteria, the effect of the treatment cannot be statistically taken into account and results will be biased. Girma et al. (2003) and Girma et al. (2004) propose the matching approach as a remedy which has proven to be a very promising research line.

Fryges and Wagner (2007) suggest that the export intensity might play an important role in boosting the firms productivity mainly due to the intensity of contacts with foreign customers where authors claim that more contact implies more intensive spillovers. Authors also point to the potential of incurring increased costs of exporting in terms of organization, coordination and control costs. Some authors (Damijan et al., 2004) pointed to the importance of destination in the process of exporting, for example, De Loecker (2007) finds evidence that Slovenian firms incur gains in productivity only when they export to the more advanced country.

Although the dominant focus of the empirical firm-level literature was on the connection between exports and firm productivity, the imports might also bring significant benefits to productivity growth. Imported capital and intermediate goods can bring in new knowledge and technology that can improve countries productivity through intermediates of better than domestic quality, using complementary intermediates where different combinations of intermediates creates gains that are more than just a sum of its parts. Halpern et al. (2011) use data on Hungarian firms to investigate the effect of imported inputs on productivity and their results confirm that imports can bring significant positive effects for productivity and that there are many complementarity effects in that process. On the other hand, Keller and Yeaple (2009) dont find much evidence supporting the view that spillovers related to imports are important in the sample of US firms.

Apart from trade, the FDI is the second major channel of technology transfer and received a lot of attention in the literature. The FDI usually implies a direct transfer of technology from the parent firm abroad but the technology within the FDI process can also spill over to the domestic firm from a foreign competitor, customer or supplier, for example, through learning about new business practices and products or through the employment of workers that have foreign experience. However, there is some indication that FDI might be a suboptimal channel for technological diffusion mainly due to the fact that FDI keeps the technology within the firm and the technology might be difficult to diffuse.

FDI can be vertical, where the subsidiary produces output that is used as an input of another subsidiary or even the parent company itself, or horizontal, in which the subsidiary produces the product similar to the parent firm. FDI is usually a characteristic of technologically more advanced industries where knowledge and technology play an important role. The motivation for FDI is therefore related to the ease of transferring knowledge and technology internationally due to possibility of using the same technology on many different locations without any loss of its characteristics. The literature suggests that FDI is dependent on the location, market size, availability of skilled workforce, availability of resources and distance from markets of interest as well as production costs.

There are many channels within FDI through which technology diffuses. For example, productivity spillovers can result from FDI but also from the impact of FDI on the market structure (Blomstrom and Kokko, 1998) so the evidence from both horizontal and vertical spillovers can be vague. Important channel of technology diffusion through FDI are also backward linkages of domestic firms with local suppliers (Pack and Saggi, 2001).

Some authors focused on the aggregate level data to examine the effect of FDI on productivity. The evidence using that data is quite mixed. The effect is confirmed in Borensztein et al. (1998) that finds evidence about positive impact of FDI on growth in countries with sufficient human capital. Blomstrom and Kokko (1994) and Alfaro et al. (2004) confirm that result but add that effects are stronger in rich countries. On the other side, Xu (2000) find little evidence that inward FDI brings important technological benefits but some evidence suggesting that outward FDI might have a bigger role. This result is confirmed in Globerman et al. (2000) that use different type of data set, mainly focusing on patent citation data.

Next to aggregate level studies, there is a significant literature that focused on industry and firm level data when analyzing the relationship between FDI and economic performance. The research has focused on investigating whether domestic firms benefit from the presence of foreign firms in their industry or geographical location. Due to significant differences between foreign and domestic firms, especially in terms of specific knowledge about production, management and marketing techniques, export contacts and specific relationship with buyers and suppliers, the researchers have analyzed if these differences make for a better business performance of foreign firms relative to their domestic counterparts but also if there are spillovers from foreign firms to domestic firms, industries or country. The first research line is related to the analysis of specific advantages of foreign owned firms that make them have a comparative advantage relative to domestic ones.

It is important to note that FDI might also reduce the productivity of domestic firms, for example, because of increased competition (Harris, 2009). The negative effects for both foreign and domestic firms might be stronger in the beginning phase of the business and are expected to last only for short term. These negative effects might be related to the process of acquiring a specific knowledge about the business in the local country which can reduce the business efficiency or decision of a foreign company to keep their value-added operations in their home market, keeping the lower value operations in the host country (Javorcik, 2004) . All this can lead to lower productivity of local plants.

The analysis of relative performance between foreign and domestic companies has also been in the focus of number of papers. Griffith et al. (2004) uses the sample of UK companies to show that foreign companies do not outperform domestic ones. Harris (2002) criticizes these findings on the basis of a sample selection bias and confirms that foreign owned companies are significantly more productive. Harris and Robinson (2003) methodologically extend the Harris (2002) approach to confirm that the foreign owned companies (from US) perform better than domestic ones. The evidence for the global sample shows that foreign firms do not necessarily outperform. These results are also confirmed for transition economies (Yasar and Morrison Paul, 2007). Interestingly, the analysis of exporting firms shows that exporters perform better in terms of productivity and that foreign owned exporting firms perform better than domestically owned exporters.

Spillovers from FDI have also been recognized as an important way the technology diffuses in the country. The difficulty with diffusion of FDI spillovers is related to the reluctance of foreign firms to pass over the advanced technology to competing local firms, exactly because this technology makes for their competitive edge relative to local firms. However, not all technology is possible to keep within the firm and diffusion takes place through imitation, acquiring of new skills, increased competition and others. Imitation seems to be a very important way for the technology to spill over from FDI into the industry and the rest of the economy. It is important to note that imitation includes not only product imitation but also the imitation of organizational and managerial processes, reverse engineering or simply the employment of skilled workforce from abroad.

Falvey et al. (2004) stresses the new skills acquisition as an important way the spillovers occur and Blomstrom and Kokko (1998) point to the role of foreign companies in bringing the new products which can serve as a signal for local companies to engage in developing similar products. Bernard et al. (2007) stress the importance of information exchange between foreign and local companies for later to start the exporting activity. Namely, foreign owned companies are expected to have a know-how about more efficient production methods and export markets which can reduce costs of engaging in exporting for local firms. However, the absorption of new technology and efficiency of spillovers absorption might be crucially related to the technological gap where countries (companies) that are characterized by a bigger technological gap could have difficulties in applying the frontier technology in their local economies (Findlay, 1978).

Significant positive effects of FDI spillovers are confirmed in large number of studies (Grg and Greenaway, 2004). This result might be conditional on the sample choice as well as methodology used. Some studies confirmed the positive effect of spillovers only in the sample of developed countries (Haskel et al., 2007; Keller and Yeaple, 2009). However, it is important to note that many of the studies that find positive effects are based on cross-sectional data which suffer from the aggregation problem and as such do not take into account time invariant differences of productivity across different sectors of economy. The results might therefore be biased. Panel studies allow for fixed effects and produce significantly less evidence in favor of positive FDI spillovers which might be an another evidence that many of the results in the literature are methodologically dependent. The size of the sample, the level of aggregation and the data span of the analysis might have also influenced the consensus about the importance of spillovers. This is confirmed in the meta study of Havranek and Irsova (2010) and Wooster and Diebel (2010)) that review significant number of different studies.

3 Data and Methodology

In our analysis we dominantly use Eurostat database (Gonalves, 2015) and Penn World Table 8.1 database (Feenstra et al., 2015). The series on TFP and Human capital are collected from PWT 8.1 database and refer to the variable RTFP that is calculated by to obtain productivity growth rates for each country in a way that is convenient for cross-country comparisons over time and HC variable that is an estimate of human capital based on average years of schooling and returns to schooling. The data is obtained on a yearly frequency spanning the period from 1950 until 2014.

When it comes to Eurostat, direct investment in the reporting economy, both flows and stocks (tipsbp90, tipsbp100) expressed as % of GDP are used in the analysis as a proxy for FDI channel of diffusion. Gross domestic expenditure on research and development (R&D) expressed as % of GDP (tipsst10) is used as an proxy for R&D activity in the member state. Gross fixed capital formation (investments as % GDP) is used as a proxy for real investments (tec00011) and exports and imports of goods and services (nama_10_gdp, P6 and P7) are used as an proxy for openness. All Eurostat data has been download using Gonalves (2015) approach.

Entire time span is used for log t test, while in the PVAR model only data after 1995 are employed due to data availability of data for other variables. We have decided to use all variables expressed in terms of the GDP share in order to control for the relative size of EU economies.

3.1 Log t test

We employ Phillips and Sul (2007) log t test in order to identify endogenous TFP convergence clubs within our sample of countries. Authors start from the basic premise that panel data decomposition where q_{it} embodies systematic component (cross-section dependence) and a_{it} that represents transitory component.

$$X_{it} = g_{it} + a_{it} \tag{1}$$

Furthermore, they transform equation 1 in order to separate common μ_t from idiosyncratic component δ_t in the panel,

$$X_{it} = (\frac{g_{it} + a_{it}}{\mu_t}) = \delta_{it}\mu_t \tag{2}$$

Thus, δ_{it} represents individual economic distance between common trend component μ_t and X_{it}. In order to avoid problems with estimation of δ, a common factor μ is removed from equation 2 by scaling

$$h_{it} = \frac{X_{it}}{1/N\sum_{t=1}^{N} X_{it}} = \frac{\delta_{it}}{1/N\sum_{t=1}^{N} \delta_{it}} \tag{3}$$

which measures loading coefficient δ_{it} in relation to panel average at time t (under assumption that panel average differ from zero). h_{it} represents transition path of economy and measures the individual behavior in relation to other economies (common growth path). In the case of convergence, parameter h_{it} converge to unity and it's cross sectional variance $H_t = 1/N \sum_{i=1}^{N}(h_{it} - 1)^2$ converge to zero.

To test for the convergence, Phillips and Sul (2007) suggest to use cross section variance ratio H_1/H_t in order to estimate following regression:

$$\begin{aligned} log(H_1/H_t) - 2logL(t) &= \hat{a} + \hat{b}logt + \hat{u}_t \\ t &= rT, rT+1, ..., T \end{aligned} \tag{4}$$

r is between zero and 1 and the fitted coefficient of log t is $\hat{b} = 2\hat{\alpha}$, where $\hat{\alpha}$ is estimate of α in the null hypothesis. Phillips and Sul (2007) suggest using $L(t) = logt$ and $r = 0.3$ for small samples beneath $T = 50$. The null hypothesis of convergence imply that $\delta_i = \delta$ and $\alpha \geq 0$, while alternative hypothesis implies that $\delta_i \neq \delta$ and $\alpha < 0$. The null hypothesis is rejected if $t_{\hat{b}} < -1.65$ at 5% significance level.

If the convergence for the entire group of countries is rejected, tests of convergence are conducted for the subsamples of countries. First, subgroup of countries G_k consisting of k countries is formed using last observation ordering. In the second step convergence test statistics is calculated $t_k = t(G_k)$ for the subgroup. Group size is chosen by maximizing t_k over k under the condition $min(t_k) > -1.65$ in order to ensure that subgroup is converging.

Steps are repeated until all convergence clubs have been identified. In the final test, convergence between subgroups is also tested. The countries that do not belong to subgroups are considered to be diverging countries.

One of the key advantages of this method is the fact that log t test can detect convergence even in the case of transitional divergence, where other methods such as stationarity or convergence tests fail (Phillips and Sul, 2007, p.1778).

3.2 PVAR model

After the convergence test, we use panel VAR model in order to identify channels of technological diffusion. A reduced form panel VAR model is employed to examine the dynamic effects between TFP and diffusion channels such as openness, investment, R&D, FDI, etc.

$$\begin{aligned} TFP_{i,t} &= \alpha_{1i} + \gamma_t + \rho_{11}TFP_{i,t-1} + .. + \rho_{1k}TFP_{i,t-k} + \beta_{11}X_{i,t-1} + .. + \beta_{1k}X_{i,t-k} + e_{1it} \\ X_{i,t} &= \alpha_{2i} + \gamma_t + \rho_{21}X_{i,t-1} + .. + \rho_{2k}X_{i,t-k} + \beta_{21}TFP_{i,t-1} + .. + \beta_{2k}TFP_{i,t-k} + e_{2it}. \end{aligned} \tag{5}$$

Unlike the usual time series VAR model, one complication of estimating these panel VAR models lies in how to deal with the terms for unobserved heterogeneity, α_{1i} and α_{2i}. We employ the GMM estimation procedure of Holtz-Eakin et al. (1988) following procedure by Abrigo and Love (2016) in order to minimize loss of data points used within the estimation.

4 Results

Tables 1 presents log t test results for 28 EU member states in the second column. Estimated coefficient is negative and t statistics is below critical value implying the rejection of null hypothesis.

Third and fourth column of the Table 1 present results of the log t test for the two endogenously estimated convergence clubs. Members of two endogenously formed convergence clubs are presented in Table 2. In the first convergence club there are 16 countries, mostly EU-15 old members with exception of Malta, Hungary and Poland. In the second club, members are mostly new EU members while Portugal and Greece are part of the convergence club although they are old EU members.

Estimated statistics for both clubs (3rd and 4th column in Table 1) imply that null hypothesis of convergence can not be rejected. Coefficients are positive and t statistics is higher than critical values.

Table 3 presents results of the test of convergence between means of the endogenously estimated convergence clubs presented in Table 2. Results are positive and indicate rejection of null hypothesis between two clubs of countries.

Table 4 presents the members of endogenously estimated convergence clubs if four non-EU countries are added to our sample as a robustness test. Addition of Norway, Switzerland, Iceland and Russia to our sample, results in the third convergence club. A new club had Cyprus, Lithuania and Norway as members, Iceland and Russia converge to new Europe club and Switzerland to the EU old members.

Addition of three more non-EU countries (Serbia, Moldova and Ukraine) breaks new Europe convergence club into two convergence groups. A new convergence club has Iceland, Portugal, Romania, Russia and Slovakia (Table 5).

Table 6 presents results for the estimated PVAR model together with Granger causality test results for all EU member states. Natural log of deviation of TFP from cross-section mean is dependent variable in all six models and one lag models are estimated using the Abrigo and Love (2016) PVAR procedure.

In the second to last row of Table 6 p-values for the Granger causality test for the variables that proxy channels (Human capital, Export, FDI flow, GFCF, Imports, FDI stock and R&D) of diffusion are presented. The null hypothesis is rejected for FDI stocks and R&D expenditure. Furthermore, statistical sign for the estimated coefficient is positive and significant at 1%.

The last row of Table 6 shows p-values of the Granger causality test for the reverse direction of causality going TFP to channels of diffusion. The null hypothesis is rejected for Exports, GFCF, Imports as well as FDI stocks.

Having in mind the results for endogenous clubs of EU countries. Estimation is repeated using the data for the 16 countries from the club 1 (Core EU members) from the Table 2. Table 7 presents results of the PVAR model and Granger Causality test for the Core group of countries.[1]

P-values for the null hypothesis that proxies for the channels of diffusion of technology does not Granger cause TFP are presented in the second to last row of the Table 7. The null hypothesis is rejected at conventional levels of significance for the Exports, FDI flows, Imports and FDI stocks. Estimated coefficients in the PVAR model are significant for all four variables, but the estimated sign is opposite to the theoretically expected sign in all

[1] Club 1 includes mostly EU-15 old members with addition of Malta, Hungary and Poland and without Portugal and Greece.

cases.

Obviously, although these variables Granger cause TFP their growth does not affect TFP in the positive way. Having in mind that TFP is expressed as log difference from the cross-section mean, our results might imply that most of the TFP is not diffused in classical way within this group of countries.

When it comes to Periphery countries (Club 2 from Table 2), Table 8 presents results of PVAR model and Granger causality test. Again, p-values for the null that diffusion variables do not Granger cause TFP are shown in the second to last row of the table. The null hypothesis is rejected for Human capital, Imports and R&D expenditures. On the other hand, estimated coefficients are positive and statistically significant for Human capital and imports while the sign of R&D expenditure is opposite to to theory.

Impulse response functions for all EU member countries are presented in the Figure 3. The results are in line with results in Table 6. FDI stocks and R&D expenditures have positive and statistically significant effect on the TFP that lasts more than 5 periods.

In the case of the Core group of countries, impulse response functions are in line with Table 7 results for Exports, Imports and FDI stocks, while FDI flows' IRF is statistically insignificant. On the other hand, effect of the first three variables on the TFP is significant, but negative (opposite to the theoretical expectation).

In the Periphery group of countries impulse response functions indicate that impact of Human capital and imports are statistically significant and positive, while R&D expenditure is significant but of a wrong sign (compared to theory).

5 Conclusion

This paper examines the convergence of TFP within the European Union. We employ a log t test and data sets to endogenously estimate convergence clubs within the EU and Europe, and test for their significance and robustness. Our results indicate that there are two to four TFP convergence clubs in Europe and conclusion is sensitive to number of countries (non-EU vs. EU) included into analysis.

Furthermore, we employ PVAR test in order to investigate channels of diffusion between European Countries. We find that the level of FDI stocks and R&D expenditures are important channels of diffusion of technology on the EU-wide level. Within the periphery group of countries imports and Human capital are major drivers of TFP growth. Obviously, Human capital as absorption constraint is an important factor of technology transfer in the periphery, while the importance of imports might be connected with the imports of capital goods. One of the stylized facts of transition was a huge current account deficit in accession countries that was strongly correlated with investment to savings ratios (not that much with budget deficits).

On the other hand, when it comes to core countries the theory is not supported by facts. Four indicators have causal effect going into direction of TFP, but all estimated coefficients are of the "wrong sign" indicating more complex dynamics within the core countries.

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Tables

Table 1: Covergence Test

TFP	convergence	test	
log(t)	All Countries	Club1	Club2
Coeff	-0.664	0.391	0.393
t-stat	-14.52	25.52	5.365

Table 2: Members of the Convergence Clubs

Club 1:16 countries					
Austria	Belgium	Denmark	Finland	France	Germany
Hungary	Ireland	Italy	Luxembourg	Malta	Netherlands
Poland	Spain	Sweden	United Kingdom		
Club 2:12 countries					
Bulgaria	Croatia	Cyprus	Czech Republic	Estonia	Greece
Latvia	Lithuania	Portugal	Romania	Slovakia	Slovenia

Table 3: Convergence Club Merging

TFP	convergence	test
log(t)	Club1+2	
Coeff	-0.664	
T-stat	-14.52	

Table 4: Members of the Convergence Clubs - EU plus Norway, Switzerland, Iceland and Russia

Club 1:17 countries					
Austria	Belgium	Denmark	Finland	France	Germany
Hungary	Ireland	Italy	Luxembourg	Malta	Netherlands
Poland	Spain	Sweden	Switzerland	United Kingdom	
Club 2:3 countries					
Cyprus	Lithuania	Norway			
Club 3:12 countries					
Bulgaria	Croatia	Czech Republic	Estonia	Greece	Iceland
Latvia	Portugal	Romania	Russia	Slovakia	Slovenia

Table 5: Members of the Convergence Clubs - all Eurostat countries

Club 1:17 countries					
Austria	Belgium	Denmark	Finland	France	Germany
Hungary	Ireland	Italy	Luxembourg	Malta	Netherlands
Poland	Spain	Sweden	Switzerland	United Kingdom	
Club 2:3 countries					
Cyprus	Lithuania	Norway			
Club 3:5 countries					
Iceland	Portugal	Romania	Russia	Slovakia	
Club 4:10 countries					
Bulgaria	Croatia	Czech Republic	Estonia	Greece	Latvia
Moldova	Serbia	Slovenia	Ukraine		

Table 6: PVAR model and Granger Causality Test - all EU members

	H.C.	Exp.	fFDI	GFCF	Imp.	sFDI	RnD
dTFP2							
L.dTFP2	0.870***	1.017***	1.010***	1.007***	1.031***	1.019***	1.028***
	(15.29)	(67.21)	(312.74)	(397.27)	(77.21)	(194.68)	(100.88)
L.hc2	0.168						
	(0.79)						
L.exp2		0.002					
		(0.96)					
L.fFDI2			-0.000				
			(-0.08)				
L.gfcf2				-0.002			
				(-0.99)			
L.imp2					-0.005		
					(-0.75)		
L.sFDI2						0.005***	
						(3.19)	
L.RnDa2							0.019***
							(4.00)
hc2							
L.dTFP2	0.000						
	(0.07)						
L.hc2	0.895***						
	(24.67)						
exp2							
L.dTFP2		0.322***					
		(4.39)					
L.exp2		0.304*					
		(1.73)					
fFDI2							
L.dTFP2			26.486				
			(1.36)				
L.fFDI2			0.662***				
			(9.41)				
gfcf2							
L.dTFP2				-0.009**			
				(-2.19)			
L.gfcf2				0.995***			
				(590.46)			
imp2							
L.dTFP2					0.143**		
					(2.56)		
L.imp2					-0.028		
					(-0.27)		
sFDI2							
L.dTFP2						-0.613**	
						(-2.41)	
L.sFDI2						0.334***	
						(3.68)	
RnDa2							
L.dTFP2							0.070
							(0.70)
L.RnDa2							0.764***
							(9.37)
N	1325	565	347	196	565	325	479
grangerX	0.427	0.336	0.933	0.323	0.456	0.001	0.000
grangerTFP	0.946	0.000	0.174	0.028	0.010	0.016	0.486

t statistics in parentheses
* p<.10, ** p<.05, *** p<.01

Table 7: PVAR model and Granger Causality Test - Core (Club 1)

	H.C.	Exp.	fFDI	GFCF	Imp.	sFDI	RnD
dTFP2							
L.dTFP2	0.956***	1.047***	0.999***	1.014***	1.043***	1.017***	1.027***
	(17.94)	(91.49)	(213.26)	(183.83)	(89.48)	(211.12)	(136.65)
L.hc2	-0.002						
	(-0.01)						
L.exp2		-0.012***					
		(-5.24)					
L.fFDI2			-0.000**				
			(-2.02)				
L.gfcf2				-0.002			
				(-0.40)			
L.imp2					-0.012***		
					(-4.19)		
L.sFDI2						-0.001***	
						(-2.76)	
L.RnDa2							0.001
							(0.51)
hc2							
L.dTFP2	-0.000						
	(-0.08)						
L.hc2	0.973***						
	(38.63)						
exp2							
L.dTFP2		0.033					
		(0.57)					
L.exp2		0.621***					
		(4.35)					
fFDI2							
L.dTFP2			63.112				
			(1.44)				
L.fFDI2			0.348***				
			(3.97)				
gfcf2							
L.dTFP2				-0.053***			
				(-4.08)			
L.gfcf2				0.950***			
				(67.42)			
imp2							
L.dTFP2					-0.027		
					(-0.48)		
L.imp2					0.413***		
					(3.11)		
sFDI2							
L.dTFP2						-1.774***	
						(-6.16)	
L.sFDI2						0.339***	
						(7.04)	
RnDa2							
L.dTFP2							0.069
							(0.42)
L.RnDa2							0.853***
							(7.82)
N	916	349	205	112	349	193	276
grangerX	0.992	0.000	0.043	0.689	0.000	0.006	0.613
grangerTFP	0.937	0.568	0.149	0.000	0.628	0.000	0.678

t statistics in parentheses
* p<.10, ** p<.05, *** p<.01

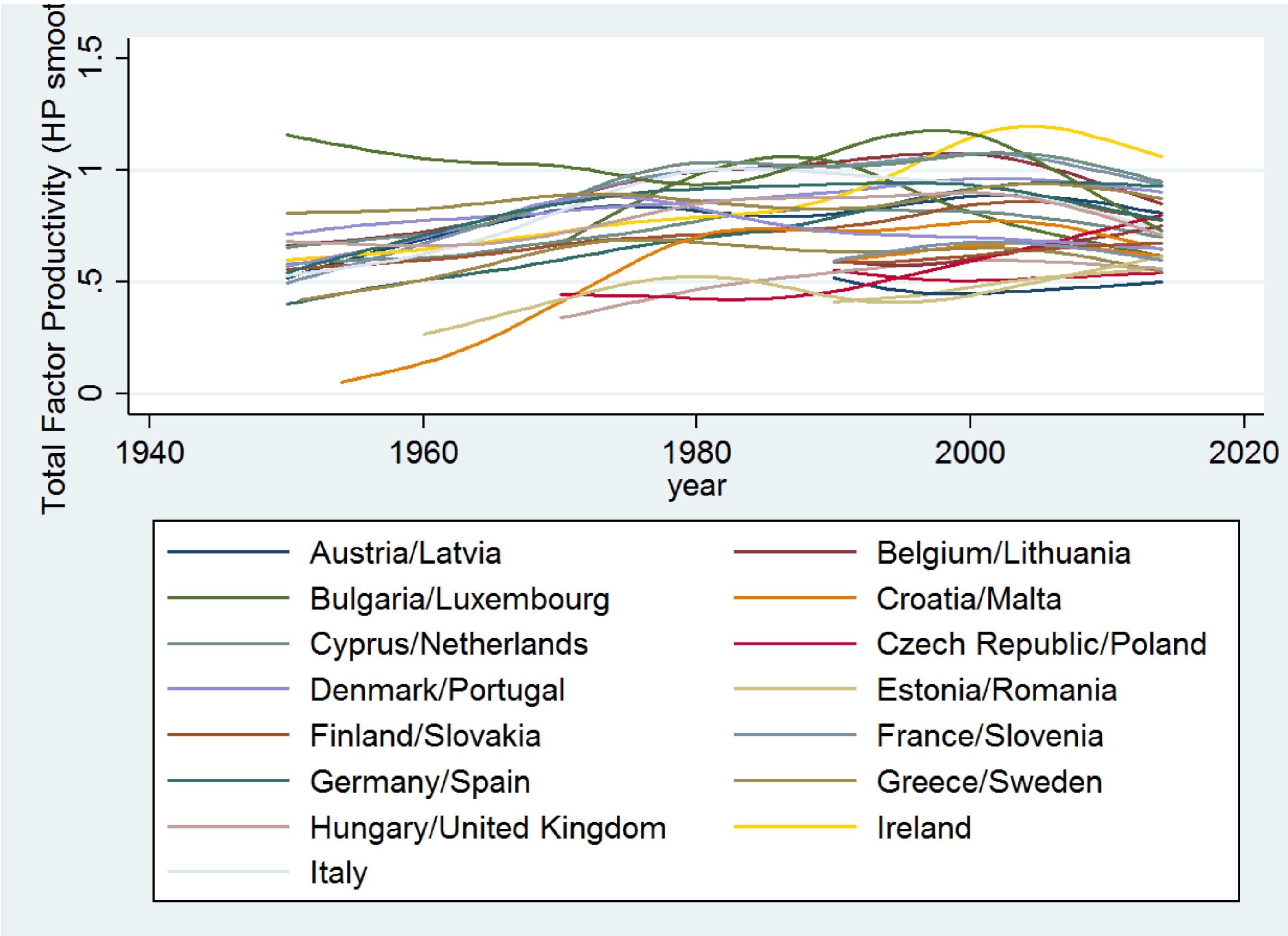
Table 8: PVAR model and Granger Causality Test - Periphery (Club 2)

	H.C.	Exp.	fFDI	GFCF	Imp.	sFDI	RnD
dTFP2							
L.dTFP2	0.953***	1.052***	0.996***	1.008***	1.040***	1.038***	1.023***
	(14.17)	(113.63)	(81.87)	(340.72)	(140.23)	(55.96)	(110.53)
L.hc2	0.713***						
	(6.11)						
L.exp2		0.013*					
		(1.77)					
L.fFDI2			-0.000				
			(-1.16)				
L.gfcf2				0.001			
				(0.47)			
L.imp2					0.025***		
					(5.52)		
L.sFDI2						0.004*	
						(1.67)	
L.RnDa2							-0.025***
							(-5.31)
hc2							
L.dTFP2	-0.038*						
	(-1.68)						
L.hc2	0.838***						
	(11.85)						
exp2							
L.dTFP2		-0.024***					
		(-3.52)					
L.exp2		0.981***					
		(221.75)					
fFDI2							
L.dTFP2			-0.982				
			(-0.25)				
L.fFDI2			0.777***				
			(7.92)				
gfcf2							
L.dTFP2				-0.003			
				(-0.49)			
L.gfcf2				0.977***			
				(229.12)			
imp2							
L.dTFP2					0.036		
					(1.42)		
L.imp2					0.926***		
					(24.16)		
sFDI2							
L.dTFP2						-0.733	
						(-1.26)	
L.sFDI2						-0.026	
						(-0.45)	
RnDa2							
L.dTFP2							-0.181*
							(-1.68)
L.RnDa2							0.680***
							(7.49)
N	409	216	142	84	216	132	203
grangerX	0.000	0.077	0.248	0.637	0.000	0.096	0.000
grangerTFP	0.094	0.000	0.806	0.621	0.156	0.209	0.093

t statistics in parentheses
* p<.10, ** p<.05, *** p<.01

Figures

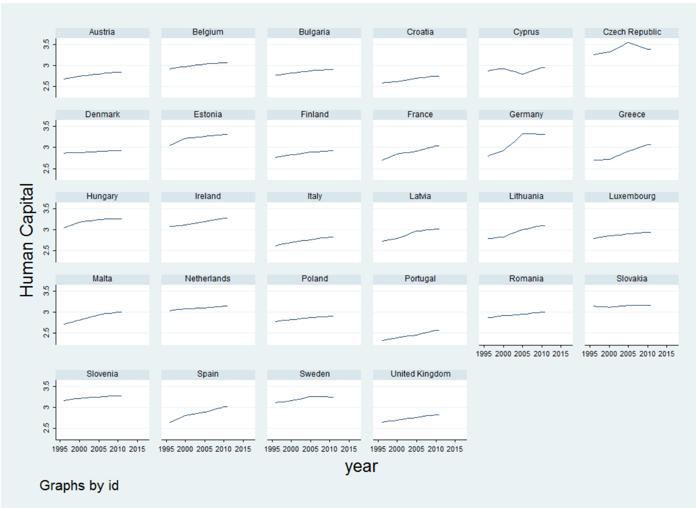
Figure 1: Total Factor Productivity



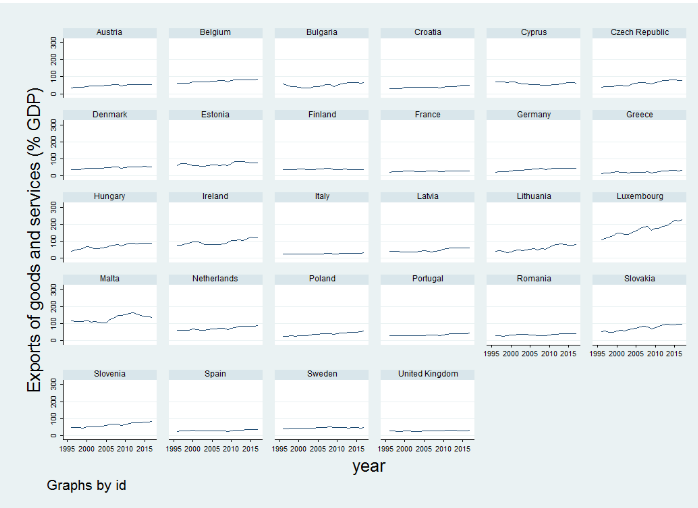
Source: Feenstra et al. (2015)

Figure 2: Dataset

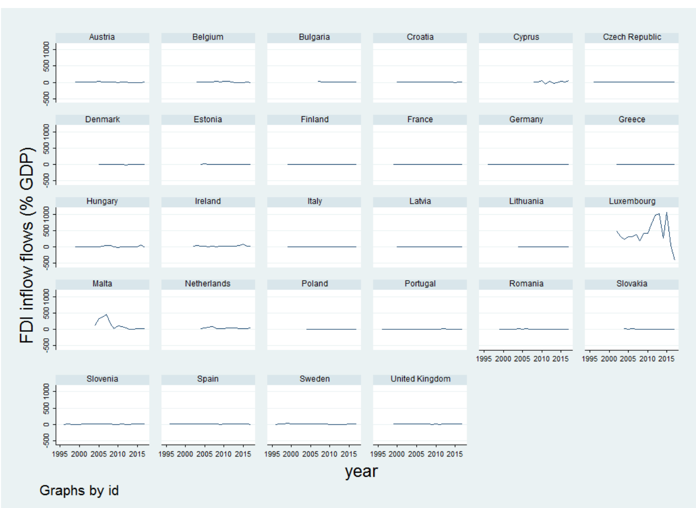
(a) *Human Capital*



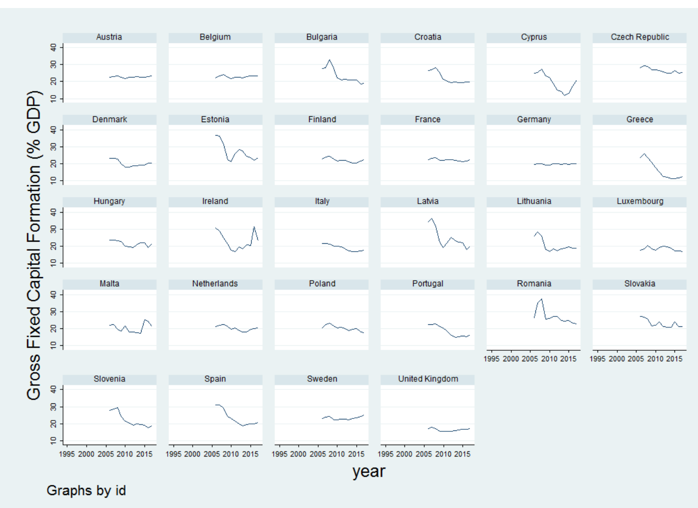
(b) *Export*



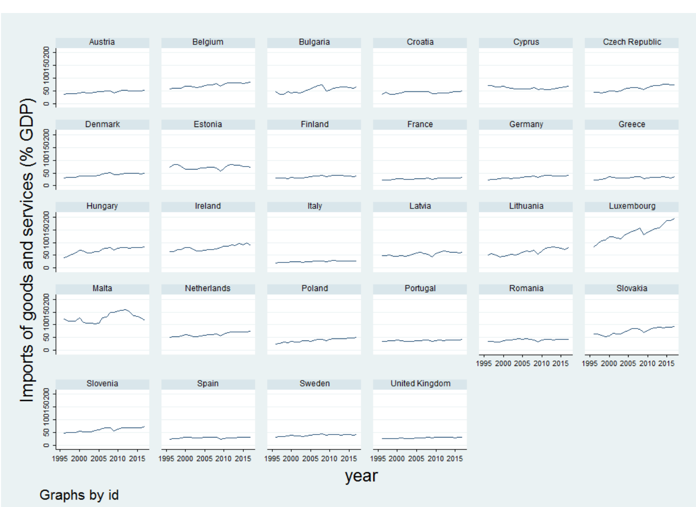
(c) *FDI flow*



(d) *GFCF (Investment)*



(e) *Import*



(f) *FDI Stock*

Figure 2: Dataset - continued

(g) *R&D* (h) *TFP*

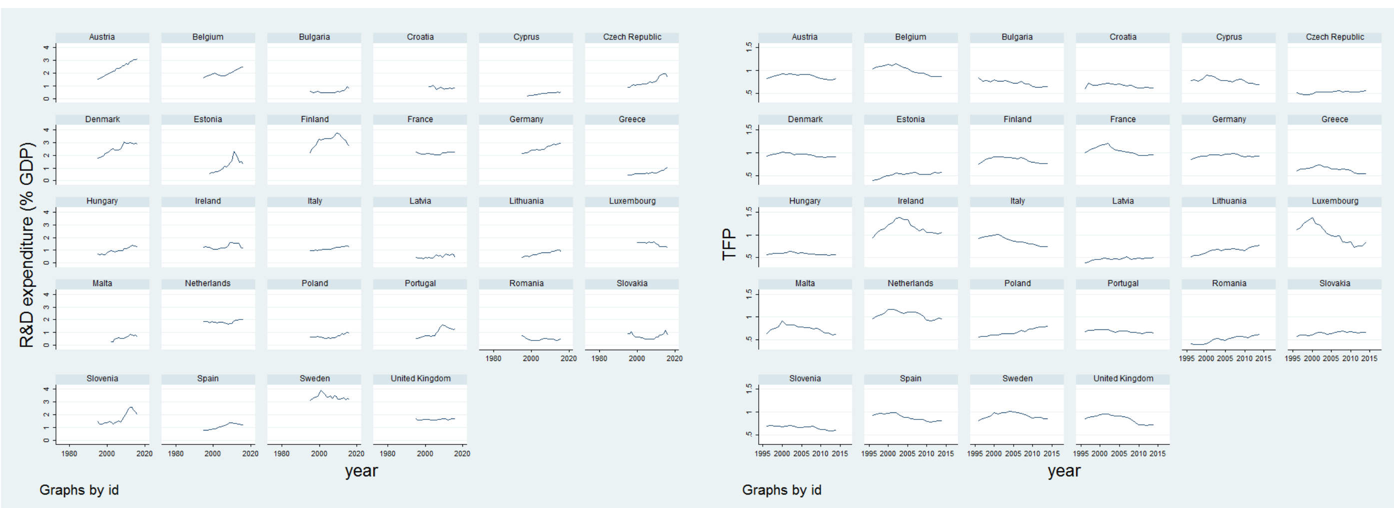
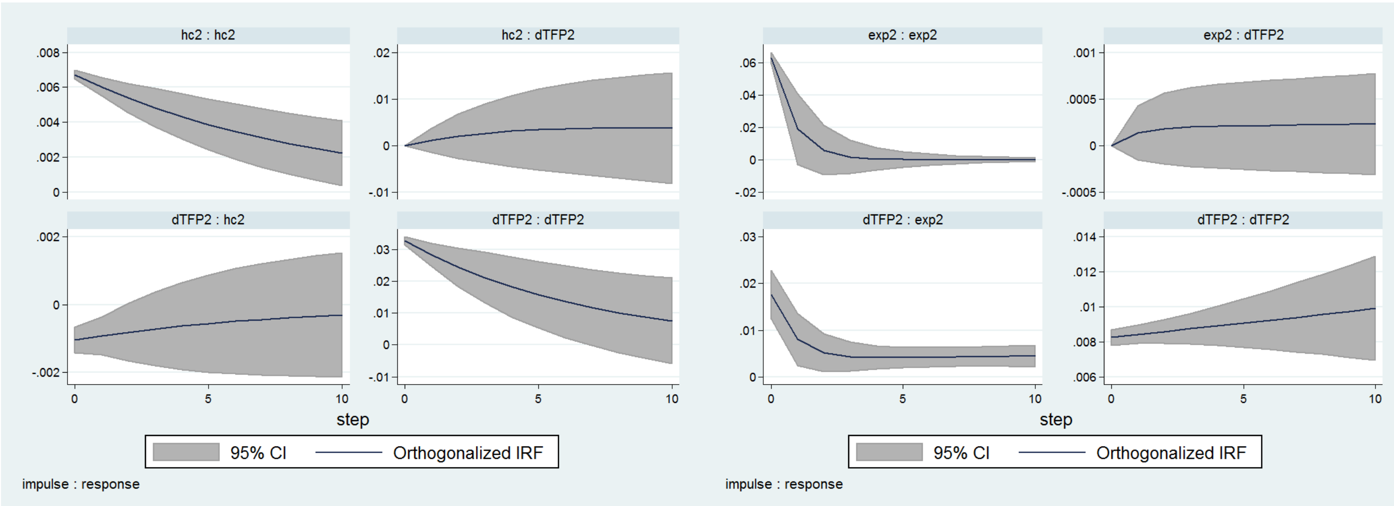
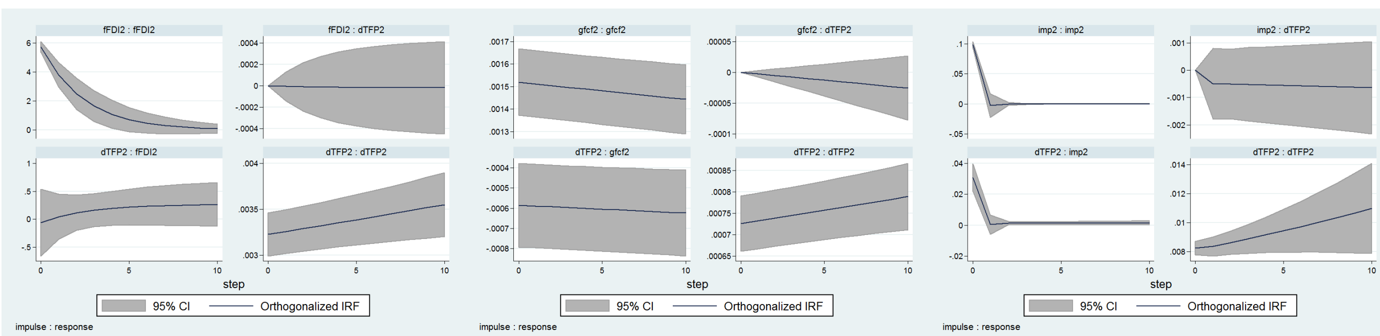


Figure 3: Impulse response functions from PVAR model - all EU countries

(a) *Human Capital* (b) *Export*



(c) *FDI flow* (d) *GFCF (Investment)* (e) *Import*



(f) *FDI Stock* (g) *R&D*

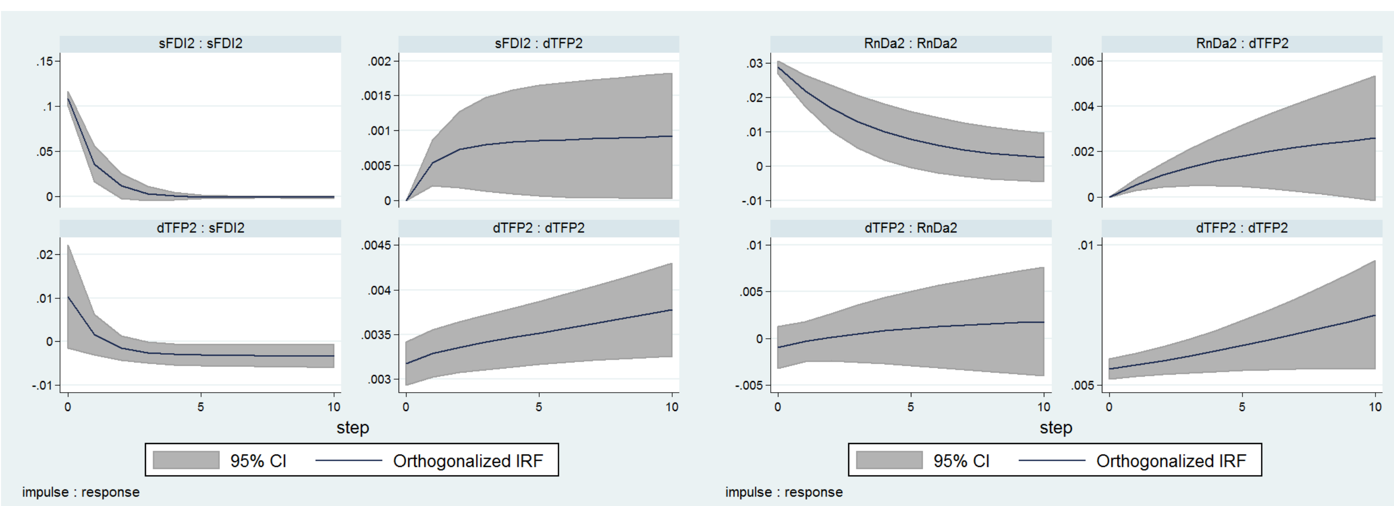
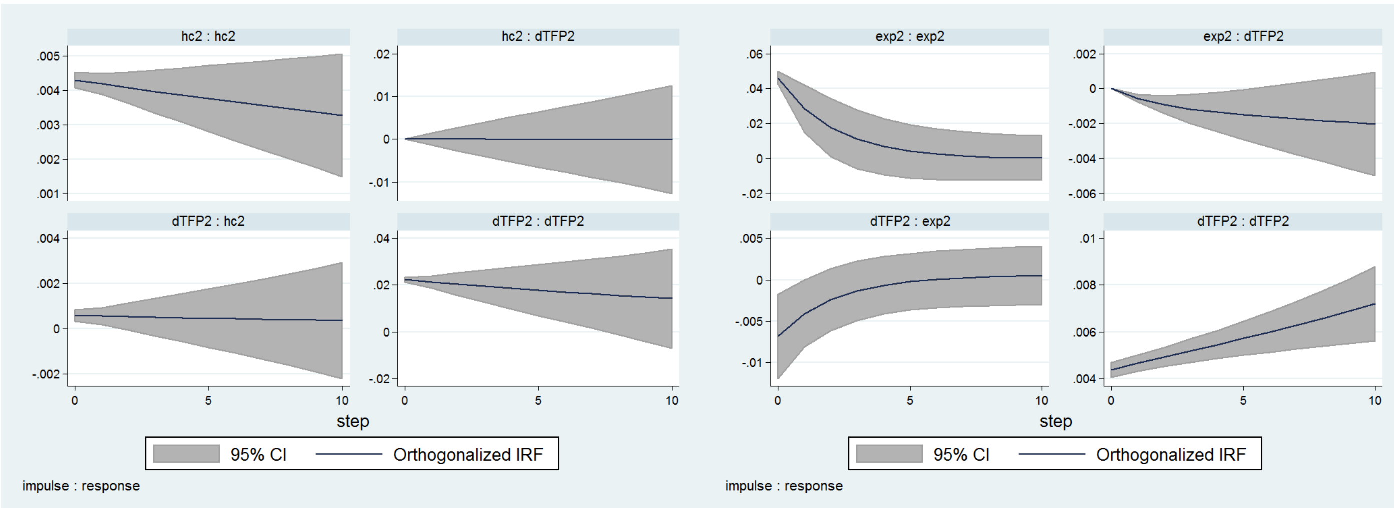
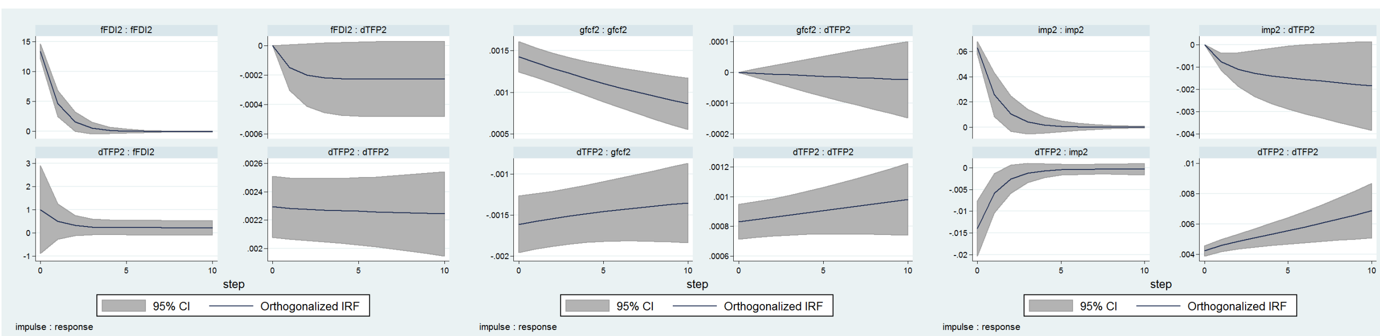


Figure 4: Impulse response functions from PVAR model - Core EU countries

(a) *Human Capital* (b) *Export*



(c) *FDI flow* (d) *GFCF (Investment)* (e) *Import*



(f) *FDI Stock* (g) *R&D*

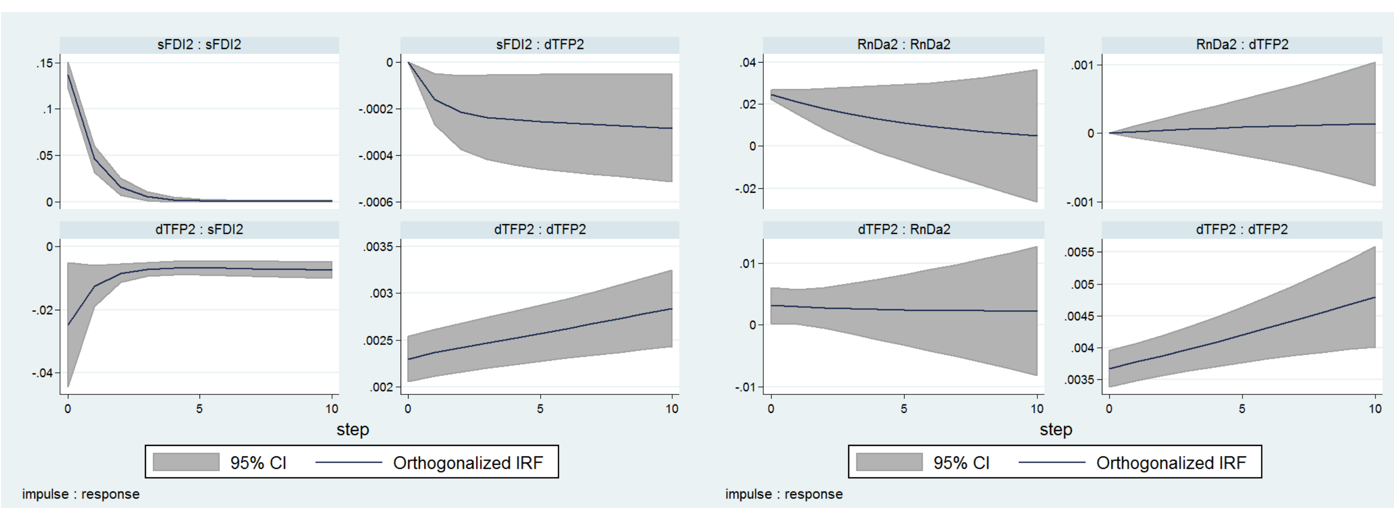
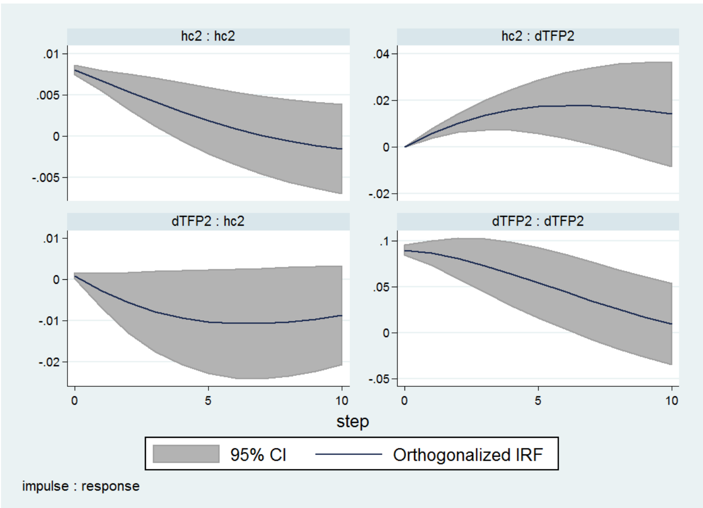
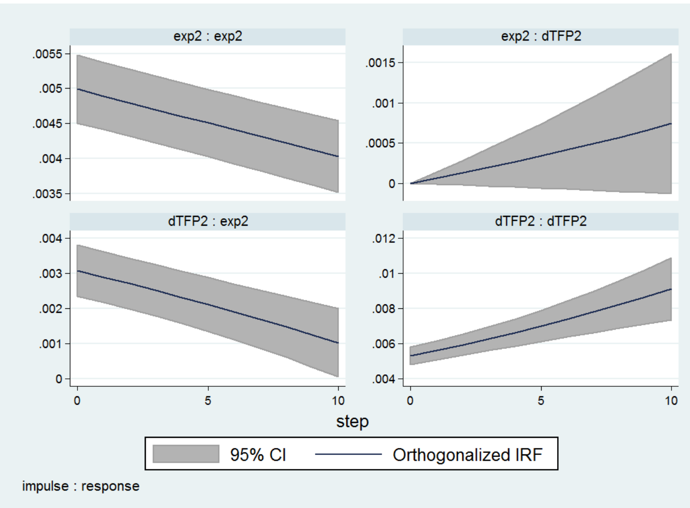


Figure 5: Impulse response functions from PVAR model - Periphery EU countries

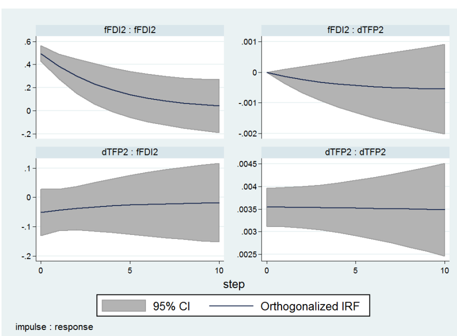
(a) *Human Capital*



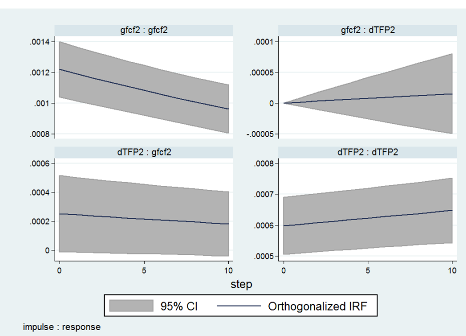
(b) *Export*



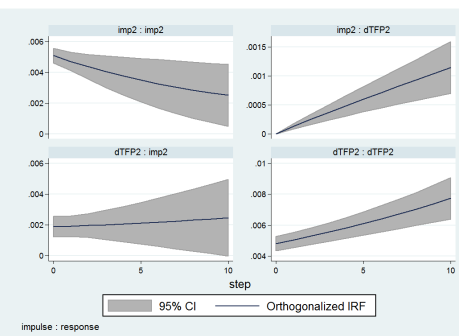
(c) *FDI flow*



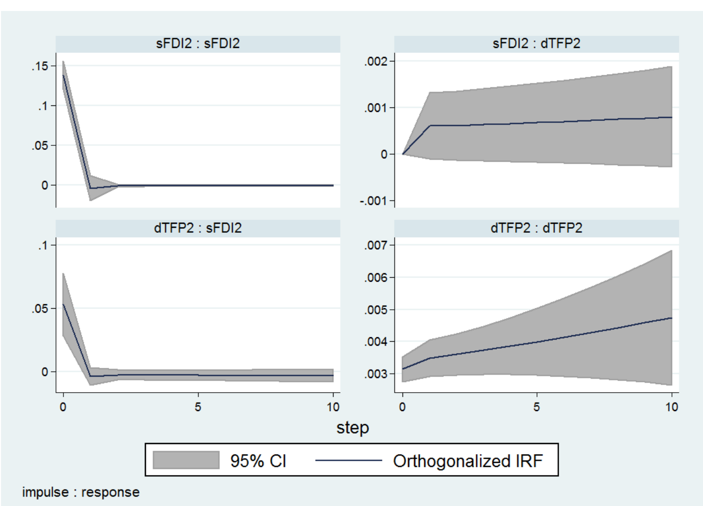
(d) *GFCF (Investment)*



(e) *Import*



(f) *FDI Stock*



(g) *R&D*