Paper to be presented at the DRUID Academy conference in Rebild, Aalborg, Denmark on January

15-17, 2014

International Diffusion of Technology in the Manufacturing Industry:

Emerging Countries within the EU and Turkey

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I. Introduction

Following the early industrialization of Europe and the United States in the nineteenth century and of Japan in the mid-twentieth century, the importance of international technology transfer for economic growth has been demonstrated once again by the industrialization of the Four Asian Tigers in the past three decades. The growth rates of some developing (henceforth emerging)[1] countries accelerated substantially in the 1980s and 1990s. Accordingly, the growth of developed countries is no longer the sole engine of the world growth, as it was in the 1950s and 1960s. In other words, the relative impact of emerging countries on world economic growth recently has decreased while the impact of emerging countries has increased. The growth rates of emerging countries have led to a noticeable change in world economic growth (Freeman and Soete, 2003). In this respect, it is substantial for emerging countries to enhance their technological progress in order to boost productivity and achieve growth.

Developed countries have the competence to carry out their own research and development (R&D) activities via a highly-skilled labor force (Gomulka, 1990). Hence, developed countries have a proven record of inventing and innovating new technologies, thereby placing themselves at the frontiers of new technology. In contrast, emerging countries are not capable of inventing new technological knowledge. In general, they can carry out very few R&D activities, which are mostly not performed effectively by a low-skilled labor force. Hence, they need foreign technology in order to enhance their technological progress. In this respect, transferring new technologies from technology frontiers is highly crucial for emerging countries. In this regard, the significance of transferring technology from more developed countries becomes obvious for these countries. Nevertheless, many studies in the literature study this subject mostly for developed countries or without distinguishing between levels of development of the countries.

This study aims to examine the relative impact and magnitude of multiple international technology diffusion channels on the manufacturing industry of emerging countries within the EU plus Turkey[2] from 1994 to 2008. The study differs from those in the literature in that it does not limit the analysis to one diffusion

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[1] Since this study covers European Union, 'emerging' is used for developing countries. For EU countries, the use of 'emerging' is a more appropriate rather than that of 'developing'.

[2] Turkey is a candidate country.

channel. Similar to the work of Savvides and Zachariadis (2003), this study investigates the impact of multiple diffusion channels on TFP growth at the industrial level rather than at the aggregate level. The technology diffusion channels included in the analysis are as follows: foreign R&D intensity, import of technology goods, foreign direct investment inflows and human capital, which serves as a proxy to measure absorptive capacity. Domestic R&D expenditures are also included in the analysis to compare its impact with the abovementioned channels. This paper seeks to answer the following two research questions: Do all of these technology diffusion channels positively affect the productivity of the manufacturing industry in the emerging countries in the EU and Turkey? and Which of these channel(s) has/have the greatest impact?

II. Literature Review

In the mid of the twentieth century, technology was assumed as exogenous by neoclassical growth model. The endogenous growth models, which arose in the beginning of 1980s, differ from the formers by considering technology as an endogenous factor. In the endogenous growth models, two major properties of technology as an economic good are underlined. The first property is that technology is a non-rival good which can be identified as: more than one user can benefit from technology at the same time. The second property is that the 'returns of technology is partly private and partly public'. This statement points out that technology does not only return profit to the firms but also creates positive externalities that spill over other firms from the inventor one (Keller, 2004; and Romer, 1990). New technologies and innovations spill over from inventor countries (i.e., technology frontiers) to adopter countries through technology diffusion channels. As most countries, whether they are emerging countries or not, enhance their productivity by the use of foreign technology, the diffusion channels and their characteristics are of interest in the economic growth literature. International technology diffusion channels can include foreign R&D activities, trade, and foreign direct investments.

The domestic R&D activities of advanced countries lead to an increase in their productivity levels. With the effect of globalization, an increase in a country's productivity does not only depend on its R&D stock but also on foreign R&D stock. The latter can diffuse from one country to another through trade, foreign direct investment (FDI) and mobility of human capital (Coe and Helpman, 1995). There is a

vast literature on examining the impact of R&D on the productivity of countries (Coe and Helpman, 1995; Coe, Helpman and Hoffmaister, 1997; Eaton and Kortum, 1996; Bernstein and Mohnen, 1998; van Pottelsberghe de la Potterie and Lichtenberg, 2001; Keller, 2004; Barrio-Castro, Lopez-Bazo and Serrano-Domingo, 2002; Kim and Lee, 2004; Seck, 2012).

Trade is a diffusion channel that enables new technological knowledge and advanced technologies to spread between countries, especially when they import intermediate capital goods (Teixeira and Fortuna, 2010). Since technology is embodied in intermediate capital goods, the transmission of these goods provides transmission of advanced technology (Kim and Lee, 2004). The effect of exports on productivity is considered as weaker than that on imports (Keller, 2004). This study examines only the imports in the matter of trade. There are many studies in the literature which focus on trade as a diffusion channel. Some of them are studied by Funk (2001), Madden et al. (2001), Bitzer and Geishecker (2006) and Madsen (2007).

In addition to the abovementioned diffusion channels, FDI is another major diffusion channel that conveys technologies from one country to another through multinational corporations (MNCs). Once a MNC enters a host country, it transfers its own advanced technology, competitive power and skilled workforce to the host country (Liu and Wang, 2003). In this aspect, FDI should be considered as more than just movement of capital since it contributes more to growth rates through technology transfers than through increasing accumulation of capital (Borensztein, Gregorio and Lee, 1998). Some of the studies that examine the impact of FDI on productivity are Li, Liu and Parker (2001), Sadik and Bolbol (2001), Lai, Peng and Pao (2006).

It is not adequate only to acquire new technology, but also having the ability to implement acquired technology is essential, especially for emerging countries. Without this proficiency, a country is unable to benefit from new technology and enhance its technological progress. A country's absorption capacity for new technologies is measured by its human capital (Nelson and Phelps, 1966), which is usually quantified by a population's average years of schooling and tertiary or secondary education enrollment. Since a country's ingenuity in adopting transferred technologies and deriving benefit from them is closely related to its absorption capacity, the level of human capital in a country is indeed one of the main factors determining the country's competence to acquire and use transferred technology (Borensztein, Gregorio and Lee, 1998). In the literature, there are many studies that have explored the effect of human capital on productivity gains (Engelbrecht, 1997;

Barrio-Castro, Lopez-Bazo and Serrano-Domingo, 2002; Nieto and Quevedo, 2005; Leahy and Neary, 2007; Mancusi, 2008).

International technology diffusion channels are highly significant for emerging countries since such countries need foreign technology to enhance technological progress and boost productivity. Yet most studies in the literature have focused on diffusion channels for developed countries, and while some of the studies have examined a panel of both developed and emerging countries without distinguishing between levels of development of the countries. In more recent years, a growing body of research has considered this distinction; however, the number of studies focusing on developed countries still outnumbers those analyzing emerging countries. Empirical research focusing on the technology diffusion channels of solely emerging countries includes the studies of Coe et al. (1997), Mayer (2001), Savvides and Zachariadis (2003), Mastromarco and Ghosh (2009), McNeil (2010) and Seck (2012).

III. Model, Explanation of Variables and Data

In this study, I examine the relative impact and magnitude of multiple international technology diffusion channels on manufacturing industry total factor productivity (TFP) of emerging countries within the EU plus Turkey, which is included as a candidate country. The analysis is similar to the focus of a study by Savvides and Zachariadis (2003). However, Savvides and Zachariadis' analysis covers the period from 1965 to 1992. In an effort to complement that study and contribute to the literature, this study examines data from nine emerging countries[3] during a more recent period (1994-2008) using recent econometric techniques.

As an initial step in the estimation of the main model, TFP is computed as the Solow residual using the growth accounting methodology:

$$\ln TFP = \ln Y - \alpha\, lnK + (1 - \alpha)lnL$$

where Y is output, K is net capital stock, L is labor and α and (1-α) are capital and labor shares, respectively. Using the studies of Chenery et al. (1986) and Coe et al.

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[3] Czech Republic, Estonia, Hungary, Latvia, Poland, Slovak Republic, Slovenia, Romania and Turkey (candidate country). Bulgaria and Lithuania are not included in the analysis due to missing observations in the data. The classification of emerging countries was made based on the IMF World Economic Outlook Report 2007.

(1997) as guidelines, α is set to 0.4. Due to the lack of data for net capital stock of emerging countries, gross fixed capital formation data is used to construct a series using the perpetual inventory methodology (PIM) (Barro and Sala-i Martin, 2004):

$$K_{i,t+1} = K_{it} + I_{it} - \delta K_{it}$$

where $K_{i,t+}1$ denotes net capital stock for sector i, I_{it} denotes gross fixed capital formation and δ is the depreciation rate. Since the analysis examines the manufacturing industry, the depreciation rate is set to 0.04 based on the work of Liao et al. (2007). To apply this method, an initial level of net capital stock (K_0) is required. However, initial net capital stock data for emerging countries are not widely available at the sectoral level. Hence, the formula below is used to calculate the initial capital stock levels:

$$I_{i0} = I_i/(g_i + \delta)$$

where I_{i0} represents gross fixed capital formation for the first year and g_i is the average growth of capital formation for the first five years. The year 1987 is selected as a benchmark year based on the availability of gross fixed capital formation series data (Liao et al., 2007).

The output (Y), labor (L) and gross fixed capital formation data are collected from the UNIDO Industrial Statistics 2 Database (INDSTAT2) 2012 Edition. Y is production, L is the number of employees in the manufacturing industry. The gross fixed capital formation data is expressed in current US dollars. The series is converted into national currency using the exchange rate data collected from the Organization for Economic Co-operation and Development (OECD). Then, the data are deflated and converted into purchasing power parity (PPP) dollars using 2005 as the base year. The data conversion from US dollars to PPP dollars is made to eliminate different price levels between the countries. The deflator data are collected from IMF International Financial Statistics (IFS), and PPP$ exchange rate data are collected from the OECD.[4]

After computation of TFP, the following model is used to analyze the impact of technology diffusion channels on manufacturing TFP:

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[4] The exchange rate for Latvia is from IMF International Financial Statsistics (IFS) because it is not available in the OECD database.

$$lnTFP = \beta_{it} + \sum_{k=1}^{K} \gamma_{it} \, lnFRD_{it-k} + \sum_{k=1}^{K} \pi_{it} \, lnIMP_{it-k} + \sum_{k=1}^{K} \delta_{it} \, lnFDI_{it-k}$$

$$+ \sum_{k=1}^{K} \theta_{it} \, lnHCAP_{it-k} + \varepsilon_{it}$$

where $i=1,...n$ denotes countries; $t=1,...,T$ denotes time $k=1,...K$ denotes lags, TFP is the growth of total factor productivity, FRD is the foreign R&D intensity, IMP is the import of technology goods, FDI denotes FDI inflows and HCAP denotes human capital, a proxy for absorptive capacity. All of the variables were expressed as natural logarithms.

To construct the FRD variable, I use each emerging country's bilateral import shares with G7[5] countries. Each of these bilateral shares is then multiplied by the R&D intensities of the G7 countries. The computation is expressed in mathematical form as follows:

$$FRD = \sum_{j=1}^{7} \frac{M_{ijt}}{M_{it}} RDint_{jt}$$

$$M_{it} = \sum_{j=1}^{7} M_{ijt}$$

where i denotes emerging countries, j denotes G7 countries, t denotes time and M_{ijt}s denotes the bilateral import shares of technology goods from each of the G7 countries to emerging countries. The technology goods import data are classified using Standard International Trade Classification (SITC) 7: Machinery and Transportation Equipment, which is maintained by the United Nations (UN).[6] Since data from developed countries are more accurate and widely available, the data for M_{ijt} and M_{it} are collected in the form of exports from each G7 country to each of the selected emerging countries. M_{it}s are the sums of M_{ijt}s, thus the sum of bilateral import shares are equal to 1 for each emerging country. $RDINT_{jt}$ is the R&D intensity expressed as gross domestic R&D expenditures as a percentage of GDP for each of the G7 countries. Hence, foreign R&D intensity is a proxy for the diffusion of the R&D

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[5] G7 countries are Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.
[6] Coe and Helpman (1995) and Xu and Wang (1999) demonstrated that technology goods import provides a more effective diffusion mechanism than total imports.

activities conducted in G7 countries to other countries. This variable indicates that the more an emerging country imports technology goods from a G7 country with a higher R&D intensity, the more it benefits from the advanced country's high level of technological knowledge (Coe et al., 2009). The import of technology goods data are classified as SITC7 exports from each G7 country to each emerging country and collected from the OECD International Trade by Commodity Statistics (ITCS) database. The R&D intensity data are from the OECD statistics.

The import of technology goods (IMP) variable is computed using machinery and transportation equipment (SITC7) import classification, hence it is the sum of M_{ijt}s, which is equal to M_{it}s. Although M_{it} is used to construct both the FRD and IMP variables, the correlation between the two variables is low (0.109),[7] similar to that reported by Savvides and Zachariadis. Hence, it is improbable that the FRD variable captures trade-related effects. (Savvides and Zachariadis, 2003). Coe and Helpman also reported that using import data in the form of weights that add up to one does not accurately represent the import level (Coe and Helpman, 1995).

The FDI inflow data (FDI) were collected from OECD statistics and the values are expressed as percentages of the GDP.[8] For the human capital variable, the average numbers of years of schooling data from Barro and Lee's 1950-2010 dataset is used. These data are given in 5 year increments; hence, the data are interpolated to obtain annual values.

The domestic R&D expenditures (DRD) variable is also included in the analysis in an additional model. Although the primary focus of this study is the diffusion of technology from the developed countries into the emerging ones; DRD is included in a model in order to examine the relative impact and magnitude of this variable compared with international diffusion channels. The DRD data are collected as R&D expenditures expressed as percentages of GDP from the OECD database.[9]

Lichtenberg (1992) stated that time is required for a country to benefit from diffused foreign technology. Hence, model to be estimated indicates that the sums of lagged variables are used to construct explanatory variables. Savvides and

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[7] Correlation coefficients are shown in Table 2.

[8] The data for Latvia are from World Bank Databank because they are not available in the OECD database.

[9] The data for Latvia are collected from the World Bank database since they are not available in the OECD database.

Zachariadis (2003) used the sum of lagged variables in their study. In this study, three lags are used to estimate the results.

The summary statistics and correlation matrix for all of the variables are presented in Table 1 and Table 2, respectively. All the variables are presented in plain format, and explanatory variables do not include the sum of the lags in order to show the characteristics of the data more clearly. Among these variables, IMP (in PPP$) has an extremely high standard deviation. The FDI also varies considerably among countries and across time. The difference between the minimum and maximum values of HCAP is also notable. Although the minimum and maximum values may change over time, in general, education is not likely to change excessively over time in a specific country. Thus, the difference in the HCAP values is remarkable. The minimum HCAP value was found in data from Turkey, whereas the maximum value was found in data from Czech Republic. The difference between the average numbers of years of schooling in these two countries is also notable; between 1994 and 2008, the average number of years of education in the Czech Republic is 12.18 compared with 5.58 years in Turkey.

Table 1.
Summary Statistics (1994-2008) for nine emerging countries

	TFP	FRD	IMP	FDI	HCAP	DRD
Obs.	130	135	135	133	135	128
Mean	1.130	14.492	7890	5.250	10.229	0.785
Std. Dev.	0.355	0.690	7630	6.649	1.929	0.356
Min	0.455	13.005	137	0.314	4.754	0.269
Max	2.100	15.946	36600	51.896	13.090	1.716

Notes: TFP (2000=1) is total factor productivity and it is the dependent variable, FRD is the product of bilateral import shares and R&D intensities of G7 countries, IMP is million PPP$, FDI and DRD are reported as percentages of GDP, and HCAP is the average number of years of schooling.

The correlation coefficients between all of the variables are shown in Table 2. Among the explanatory variables, lnFDI has the highest correlation with the dependent variable lnTFP, whereas lnTFP has the lowest correlation with lnDRD. In general, lnFDI has a relatively high correlation with other explanatory variables except lnIMP and lnDRD.

Table 2.
Correlation Matrix (1994-2008) for nine emerging countries

	lnTFP	lnFRD	lnIMP	lnFDI	lnHCAP	lnDRD
lnTFP	1					
lnFRD	0.191	1				
lnIMP	0.066	0.109	1			
lnFDI	0.476	0.495	-0.063	1		
lnHCAP	0.356	0.098	-0.297	0.595	1	
lnDRD	0.040	-0.129	0.005	0.071	0.599	1

The dependent variable is lnTFP. All variables are expressed as natural logarithms. The explanatory variables are computed as the sum of 3 lags.

IV. Methodology and Empirical Findings

In this study, a two-way fixed effects model is used based on the results of a Hausman test. For the estimation of the two-way fixed effects model, all of the variables are demeaned from the time dimension as an initial step, and then the parameters are estimated using within estimator. Next, the model is tested for the presence of heteroscedasticity, serial correlation and cross-sectional dependence. I find that heteroscedasticity and serial correlation exist in the model, and hence clustered robust standard errors are estimated to overcome these deviations. The findings are shown in Table 3.

Three different models are shown in Table 3. In the first model, the impact of education is omitted. Hence, three diffusion channels; foreign R&D intensity (lnFRD), import of technology goods (lnIMP) and foreign direct investment inflows (lnFDI) are included in the model in order to examine the impact of these channels on manufacturing TFP. The findings indicate that lnFRD and lnIMP have a significant and positive effect on TFP. Among the two diffusion channels, lnFRD has a larger effect on the productivity of manufacturing productivity than lnIMP, which also boosts manufacturing TFP but too a much lesser extent. FDI exerts no effect on manufacturing TFP for the selected group of emerging countries.

In the second model shown in Table 3, domestic R&D expenditures (lnDRD) variable is included in the model to analyze the impact of a country's own R&D

efforts on manufacturing TFP. Although this variable is not directly related to the subject of international technology diffusion, this model is examined in order to compare the impact and magnitude of this variable on TFP with the effect of international technology diffusion channels. The estimates indicate that domestic R&D expenditures (lnDRD) do not have a significant effect on manufacturing TFP, whereas R&D activities conducted in G7 countries have a significant positive impact on manufacturing TFP for the selected group of countries. The import of technology goods also have a modest positive effect on productivity, similar to that observed with the first model. FDI do not exert any effect on manufacturing TFP in the second model.

Table 3.
Estimation Results: Two-way Fixed Effects Models (1994-2008) for nine emerging countries[a]

lnTFP	Model 1	Model 2	Model 3
lnFRD	1.203** (0.38)	1.328*** (0.37)	1.266*** (0.31)
lnIMP	0.072** (0.03)	0.060** (0.02)	0.076** (0.02)
lnFDI	-0.013 (0.01)	-0.010 (0.01)	-0.003 (0.01)
lnDRD		0.074 (0.05)	
lnHCAP			0.311* (0.15)
constant	-0.054*** (0.01)	-0.069** (0.02)	-0.050*** (0.01)
R-squared	0.372	0.385	0.406
Obs.	125	117	125

[a]The dependent variable is lnTFP. The explanatory variables are the sum of 3 lagged variables. Numbers without parentheses are the estimated parameters, and the numbers in the parentheses are clustered standard errors. Stars indicate the following significance levels: * p-value < 0.10, ** p-value < 0.05 and *** p-value < 0.01.

The third model includes the human capital variable as a proxy for absorption capacity and three international technology diffusion channels. The empirical estimates indicate that the average number of years of schooling has a positive impact on manufacturing TFP. Foreign R&D intensity and the import of technology goods also have positive effects on manufacturing TFP in the third model, similar to that

observed with the first and the second model. As is seen in the findings in the third column, foreign R&D intensity has an extremely high impact on TFP, whereas the effect of technology goods import is low. The magnitude of the effect of education is higher than that of import of technology goods and lower than that of foreign R&D intensity. Similar to the findings with the first two models, FDI exerts no effect on manufacturing TFP.

Table 4.
Estimation Results: Two-way fixed effects models including interaction terms (1994-2008) for nine emerging countries[a]

lnTFP	Model 4	Model 5	Model 6
lnFRD	1.298***	1.286***	1.291***
	(0.30)	(0.29)	(0.31)
lnIMP	0.076**	0.069*	0.071**
	(0.02)	(0.03)	(0.03)
lnFDI	-0.001	-0.002	-0.002
	(0.01)	(0.01)	(0.01)
lnHCAP	0.367*	0.393*	0.297
	(0.17)	(0.20)	(0.17)
lnHCAP*lnFRD	-0.452		
	(0.60)		
lnHCAP*lnIMP		-0.010	
		(0.02)	
lnHCAP*lnFDI			-0.023
			(0.02)
constant	-0.045**	-0.054**	-0.033
	(0.02)	(0.01)	(0.02)
R-squared	0.415	0.410	0.415
N	125	125	125

[a]The dependent variable is lnTFP. The explanatory variables are the sum of 3 lagged variables. The numbers without parentheses are the estimated parameters, and the numbers in parentheses are clustered standard errors. The stars indicate the following significance levels: * p-value < 0.10, ** p-value < 0.05 and *** p-value < 0.01.

Models 4, 5 and 6 in Table 4 include interaction terms of human capital and each of the three international technology diffusion channels. In these models, the impact of each international technology diffusion channel's interaction with human capital on manufacturing TFP is assessed. In other words, these models examine the

mutual effects of human capital and international technology diffusion channels on TFP. The interaction terms for human capital and foreign R&D intensity (lnHCAP*lnFRD), import of technology goods (lnHCAP*lnIMP) and FDI (lnHCAP*lnFDI) are included separately in the fourth, fifth and the sixth models, respectively. The estimates of the three models indicate that the interaction of each international technology diffusion channel and human capital (lnHCAP*lnFRD, lnHCAP*lnIMP and lnHCAP*lnFDI) together do not have any effect on manufacturing TFP. These findings also show that in models 4-6, foreign R&D intensity (lnFRD) and import of technology goods (lnIMP) positively affect productivity. Human capital (lnHCAP) mostly has a significant and positive effect on manufacturing TFP. Similar to the findings shown in Table 3, the magnitude of lnFRD is the highest whereas the magnitude of lnIMP is the lowest. In other words, the abilities of foreign R&D and the import of technology to boost productivity do not stem from their interaction through education. FDI inflows (lnFDI) exert no effect on TFP in models 4-6, consistent with the findings shown in Table 1.

V. Conclusion

Emerging countries typically do not possess an adequate capability to invent technologies; very little domestic R&D activity is carried out, and the R&D that does occur is often not performed effectively. Hence, such countries need foreign advanced technology in order to boost their productivity and benefit from the accompanying economic growth. One of the ways to acquire advanced technology is the mechanism of international technology diffusion which enables emerging countries to benefit from technology invented by more technologically advanced countries. The diffusion process occurs through international technology diffusion channels.

In this study, I examine the relative impact and magnitude of multiple international technology diffusion channels on the manufacturing TFP of emerging countries within the EU plus Turkey. My research focuses solely on the manufacturing industry between 1994 and 2008. The diffusion channels included in the empirical analysis are foreign R&D intensity, import of technology goods and FDI, as well as human capital as a proxy for absorptive capacity. The primary focus of this study is international technology diffusion; however, a domestic R&D expenditures variable is also included in one of the models in order to examine the effect of this variable compared to that of international diffusion channels.

The findings show that foreign R&D intensity, import of technology goods and human capital all have a positive impact on manufacturing TFP, whereas FDI and domestic R&D expenditures do not exert any effect on manufacturing TFP for the emerging countries included in this study. Among foreign R&D, import of technology goods and human capital, foreign R&D intensity has the largest impact on TFP and the import of technology goods has the lowest impact. The magnitude of the impact of foreign R&D intensity on TFP is extremely high compared with the effects of the other two variables. Three interaction terms that reflect the mutual effect of human capital and foreign R&D intensity, human capital and import of technology goods, and human capital and FDI do not exert any effect on manufacturing TFP. These findings suggest that human capital and diffusion channels do not interact together to effect manufacturing TFP.

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