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Human capital, mechanisms of technological diffusion and the role of technological shocks in the speed of diffusion. Evidence from a panel of Mediterranean countries

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resumo

Este artigo procura determinar a importância do capital humano para a difusão tecnológica num conjunto de países da Bacia Mediterrânica tendo por base as previsões da teoria do crescimento endógeno. Os resultados obtidos sugerem que a especificação não linear proposta por Benhabib and Spiegel (2002), que contempla quer a existência de convergência tecnológica quer de clubes de convergência, não se aplica a estes países, mas sim a especificação linear originalmente proposta por Benhabib and Spiegel (1994), com especial relevância do capital humano para as actividades de inovação tecnológica. Testámos também a possibilidade de complementaridade entre o capital humano e o IDE e a importância do primeiro para a difusão das TIC, mas apenas esta última hipótese prevaleceu. Para terminar, analisámos ainda a importância dos choques tecnológicos em termos de difusão tecnológica utilizando um modelo VAR, verificando-se a existência de complementaridade entre a PTF, o investimento em capital físico e o capital humano na absorção de qualquer um dos choques considerados.

résumé / abstract

Cet article essaie d'établir l'importance du capital humain dans la diffusion technologique pour un ensemble de pays du bassin méditerranéen, ayant pour base la théorie de la croissance endogène. Les résultats obtenus suggèrent que ce n'est pas la spécification non-linéaire proposée par Benhabib et Spiegel (2002) – recouvrant l'existence soit de la convergence technologique soit de clubs de convergence – qui s'applique à ces pays, mais la spécification linéaire originalement proposée par Benhabib et Spiegel (1994), surtout en ce qui concerne le capital humain dans les activités d'innovation technologique. La possibilité de complémentarité du capital humain et de l'IDE ainsi que l'importance du premier dans la diffusion des TIC a été testée, mais à peine la deuxième hypothèse a été confirmée. Finalement, à l'aide d'un modèle VAR, on analyse l'importance des chocs technologiques en termes de diffusion de technologies et le résultat confirme l'existence d'une complémentarité entre la PTF, l'investissement en capital physique et le capital humain dans l'absorption des chocs considérés.

The purpose of this paper is to assess the importance of human capital as a facilitator of technological diffusion in a sample of developing Mediterranean countries based on the predictions of endogenous growth theory. The evidence does not support the Benhabib and Spiegel (2002) non-linear specification that accommodates both the hypothesis of technological convergence and convergence clubs but the linear specification originally proposed by Benhabib and Spiegel (1994), confirming a role for human capital in both innovation and imitation activities. We also tested the complementarity between FDI, a form of embodied technology diffusion, and human capital but this hypothesis was not confirmed and investigated the importance of human capital for the diffusion of ICT confirming it is fundamental to benefit from these technologies. Finally, we analysed the importance of technological shocks for technological diffusion using a VAR model finding evidence of factor complementarity between TFP, physical capital investment and human capital in the absorption of any of the shocks considered.

1. Introduction

The purpose of this paper is to empirically assess the importance of human capital as a facilitator of technological diffusion in a sample of seven developing Mediterranean countries between 1960-2000. Developing Mediterranean countries are geographically and economically[1] close to developed European countries and their economic prosperity, together with their subsequent political stability, is of major importance to European countries. Knowing the sources of growth in these countries can help us derive implications for policies that promote growth and convergence in the Southern Mediterranean countries.

Productivity differences are an important source of income differences across countries (see for instance, Easterly and Levine, 2001; Hall and Jones, 1999; Klenow and Rodriguez-Clare, 1997), so in order to understand growth the sources of productivity growth across countries have to be identified. Endogenous growth theory provides the theoretical explanations for technological progress which is responsible for sustainable long-term growth. For instance, the models of Romer (1990a), Romer (1990b), and Aghion and Howitt (1992) emphasize the importance of domestic innovation initiatives. Technological change is the result of the activity of an R&D sector that primarily uses the existing stock of knowledge and human capital as inputs. Nelson and Phelps (1966), Grossman and Helpman (1992) and Barro and Sala-i-Martin (1997) on the other hand, stress the importance of imitation activities or technology diffusion in technological change: countries further away from the technological frontier have a potential for faster growth by adopting the inventions developed elsewhere in the world. There are, however, cross-country differences in the effectiveness with which countries adopt foreign technologies, which in turn determine income differences. Nelson and Phelps (1966) stress the importance of human capital in narrowing the gap between the level of technology in practise and the theoretical level of technology[2].

The roles played by human capital, either as an input in innovation activities or as a facilitator of the diffusion of technology from abroad, have been extensively analysed and confirmed by empirical growth literature. The benchmark study in this area is probably Benhabib and Spiegel (1994) but many other examples can be found, some of which are specific to developing countries (see for instance Coe, Helpman and Hoffmaister (1997), Mayer (2001), Engelbrecht (2002), Dowrick and Rogers (2002), and Papageorgiou (2003)). In the developing Mediterranean countries that are involved in little R&D[3], technology diffusion is probably the most important source of productivity growth. It is therefore important to know whether the human capital stocks available in the developing Mediterranean countries constitute a break or promote technological convergence in these countries, in which case we would be in the presence of convergence clubs or poverty traps. The empirical growth literature either concentrates on wide samples of countries that include developed and developing countries, making it difficult to uncover specificities in certain groups of countries, or focuses on more restricted groups of countries, such as the OECD countries (see Temple (2001) for a review of empirical studies on human capital and growth focusing on OECD countries), Latin American countries (e.g., Easterly, Loyaza and Montiel

1 In November 1995, in Barcelona, there was an Euro-Mediterranean Conference of the Ministers of Foreign Affairs that marked the starting point of the Euro-Mediterranean Partnership (the Barcelona Process), a wide framework of political, economic and social relations between the Member States of the European Union and Partners of the Southern Mediterranean. This partnership led to the Euro-Mediterranean Association Agreements, whose main aim is the gradual establishment of a free-trade area.

2 "To put the hypothesis simply, educated people make good innovators, so that education speeds up the process of technology diffusion." Nelson and Phelps (1966), p. 70.

3 According to the World Development Indicators 2000, in the 1990s Egypt spent a maximum of 0.22% of its GNP on R&D, Cyprus 0.18%, Syria 0.2%, Tunisia 0.33% and Turkey 0.53%. Only Israel spent a amount of its GNP on R&D comparable to the levels spent by the developed countries, which reached 2.35% in 1997.

(1997)), or Sub-Saharan African countries (e.g., Easterly (1997), Hoeffler (2000)). Few, however, focus specifically on developing Mediterranean countries and none to our knowledge deal with the issue of human capital and technology diffusion, a gap we would like to fill.

To assess the importance of human capital in technological change and, in greater depth, in technological diffusion in these countries we began by replicating the Benhabib and Spiegel (2002) empirical methodology that extends their Benhabib and Spiegel (1994) study to accommodate the possibility that there are convergence clubs in the process of technological growth and convergence, in the tradition of Azariadis and Drazen (1990) and Durlauf and Johnson (1995). In addition to considering a different sample of countries, we extended their empirical analysis to a panel data framework, since it would have been impossible to use cross-section econometric techniques to analyse a sample of seven/thirteen countries.

In the Benhabib and Spiegel (1994) study the authors develop a model to explain the importance of human capital in growth, inspired by the Nelson and Phelps (1966) model in which the potential speed of technology diffusion is inversely related to the degree of technological backwardness of the follower country and its absorption capability for new technologies depends on its human capital level. They assume that the technological diffusion path is exponential, i.e. the technological leader acts as a locomotive for growth in the follower country, so that the follower always converges to the leader and empirically technological growth can be written as a linear function of human capital. The Benhabib and Spiegel (2002) study extends the framework of analysis in order to accommodate the possibility of the existence of human capital thresholds in which technological convergence may occur, i.e. the existence of convergence clubs. The empirical counterpart of this model is an equation for TFP growth non-linear in human capital: if there is convergence, the diffusion path is exponential, whereas if there are convergence clubs the diffusion path is logistic.

The replication of the Benhabib and Spiegel (2002) study did not produce good results. We estimated the Total Factor Productivity (TFP) growth rate non-linear specification proposed by Benhabib and Spiegel (2002) using traditional econometric methods, Non Linear Least Squares (NLLS), but there was no evidence that human capital influences TFP growth either directly through its impact on the domestic innovation rate or indirectly by speeding up technology diffusion. These results led us to conclude that the non-linear specification is not appropriate in explaining productivity growth in our samples, which might be due to the fact that the countries in our sample possess a human capital level that is already above the threshold necessary to exploit the advantages of technological backwardness, i.e. they are not in a poverty trap.

In light of the above results, we tested the linear specification of the original Benhabib and Spiegel (1994) study since this might be the one best suited to the evidence on human capital and TFP growth in our samples. We called this linear specification the Nelson and Phelps (1966) methodology and used Ordinary Least Squares (OLS) with robust errors, fixed effects models and random effects models to estimate it. The results confirmed the two influences of human capital on productivity growth, although surprisingly the direct effect on the domestic innovation rate is much stronger that the indirect effect through technology diffusion. This is good news since, according to this specification, the technological followers will always converge to the leader.

The low impact of human capital on imitation activities, however, led us to explore the hypothesis that human capital is more important for TFP growth through embodied technology diffusion than through disembodied technology diffusion, represented before by the TFP gap to the technological leader. Technology diffuses through many channels but the availability of data for our seven developing Mediterranean countries made us restrict our analysis to the study of the complementarity between human capital and technology transfers through FDI. We also analysed the role of human capital as a facilitator of the diffusion of a particular type of technology, Information and Communication Technologies (ICTs), which play a major part in productivity growth. In both cases we took Borensztein, Gregorio and Lee (1998) and Lee (2001) as the basic framework for our estimations. The results, however, did not show any complementarity between the diffusion of technology through FDI and human capital, although again they confirmed its importance in innovation activities. On the other hand, human capital is fundamental to the diffusion of ICTs, especially human capital acquired through higher education.

Finally, in the last part of the paper, we attempt to understand the importance of technological shocks in the process of technological diffusion and the role of human capital in the absorption of these shocks. The speed of technological diffusion and consequently the evolution of cross--country differences in GDP growth rates and levels depend, to a large extent, on exogenous shocks. We modelled technological shocks through a simple Vector Autoregression (VAR) model with four variables. The main result was that almost all of the seven countries showed evidence of factor complementarity in technology, physical capital and human capital in the absorption of any of the three types of shocks considered, with this new methodology also confirming the importance of human capital in technological progress.

The paper is divided into five sections. In the next section we describe the theoretical background that explains the relationship between human capital and productivity growth and develop an empirical analysis of this relationship, based on the methodologies of Benhabib and Spiegel (2002) and Nelson and Phelps (1966). Section 3 analyses the relationship involving the complementarity between human capital and FDI as a channel of technological diffusion, on the one hand, and the importance of human capital in the diffusion of a particular type of technology, ICTs. Section 4 analyses the relationship between technological shocks and technological catch--up. In Section 5 we conclude.

2. Technological catch-up and the role of human capital: the Benhabib and Spiegel (2002) and the Nelson and Phelps (1996) methodologies

2.1. Theoretical considerations

Renewed interest in the theme of economic growth in the eighties with the seminal articles of Romer (1986) and Lucas (1988) led to research on the possible different influences of human capital on growth. Human capital plays a very important role in endogenous growth theory: it is the source of sustained long term growth due to externalities in human capital accumulation, either in production, as in the Lucas (1988) model, or in innovation, as in the Romer (1990a) model.

Mankiw, Romer and Weil (1992) (MRW) empirically challenged the predictions of the endogenous growth literature. MRW used Solow's neoclassical growth theory to show that most of the observed cross-country income differences could be explained by a neoclassical growth model augmented to include human capital as an additional input in final goods production. Since the human factor is viewed as just another input, it has two growth effects: a permanent level effect on real GDP per capita and a transitory growth effect on GDP growth rate. MRW estimated what is commonly known as a β-equation[4] and concluded that almost 80% of cross-country income differences can be explained by differences in the rates of accumulation of physical and human capital and the population growth rate. However, when the analysis is restricted to the OECD countries there is evidence of the very slight influence of human capital on growth and sometimes even the estimated coefficient has the wrong sign. This study gave rise to numerous other studies that tried to improve on it in order to ascertain the correct influence of human capital on growth. Three different methods were basically followed as well as a mixture of all three: a) improved databases and human capital proxies (e.g., Klenow and Rodriguez-Clare, 1997; Temple, 1998); b) new econometric methodologies for the estimation of growth equations

4 The β-equation or convergence regression is derived from the neoclassical growth model in the neighborhood of the steady state predicting that output growth depends negatively on initial income due to the assumption of diminishing returns to reproducible inputs and positively on the determinants of the steady state income level, among which human capital is included. The symbol β refers to the coefficient on initial income predicted to be negative for there to be convergence.

(e.g., Islam, 1995; Caselli, Esquivel and Lefort, 1996); and c) new specifications for human capital in growth models based on the predictions of endogenous growth literature (e.g., Benhabib and Spiegel, 1994; Engelbrecht, 2003; Papageorgiou, 2003).

Endogenous growth literature has focused its research agenda on the explanation of TFP, that is, on the factors and mechanisms that cause technical progress and influence TFP growth. In this new theoretical setting human capital has two new roles: it determines the domestic innovation rate and it is a facilitator of technological catch-up. It is the level of human capital that is relevant in both roles. Human capital has permanent growth effects in the first case and transitory growth effects in the second one. In fact, in a steady state growth (SSG) model of technical diffusion, the transitory growth effects will last until the follower country reaches the TFP growth rate of the leader country.

In this paper we consider that human capital influences growth through these two roles, in the spirit of the Nelson and Phelps (1966) model which was given an empirical formulation by Benhabib and Spiegel (1994). According to Nelson and Phelps (1966), the shifting of the technological frontier towards the northeast depends on the rate of invention, whilst TFP growth depends on the rate of technological diffusion, which is positively related to the technological gap, the distance between the TFP level of the leader country and that of the follower country. In order to study the technological diffusion process in two countries it is assumed that the leader country is on the technological frontier or closer to it than the follower country. The technological catch-up hypothesis means that the TFP growth rate of the follower is positively related to its technological backwardness. This is a potential economic advantage for the follower but, as the authors have pointed out, the speed at which the technological gap is closed depends on the level of human capital available in the follower country. Abramovitz (1986) designates this potential for a country to benefit from technological backwardness its 'social capability', so that "(...) a country's potential for rapid growth is strong not when it is backward without qualification, but rather when it is technologically backward but socially advanced." p. 382. The term 'social capability' has been replaced in this literature by the term "absorptive capacity" referring to the various factors that influence the ability of a country to benefit from technology developed abroad. Abramovitz (1986) and Abramovitz (1994) describe some of the factors that determine absorptive capacity, pointing out that "It includes personal attributes, notably levels of education, an attribute that is subject to measurement, however imperfectly." (Abramovitz (1994), p.88).

In their 1994 study, Benhabib and Spiegel developed a model to explain the importance of human capital for growth inspired by the Nelson and Phelps (1966) and the Romer (1990a) models, where technological progress is explained by the domestic innovation rate, which is dependent on the level of human capital and the potential speed of technology diffusion that is inversely related to the degree of technological backwardness of the follower country and its absorption capability for new technologies, which is determined by its human capital level. They assume that the technological diffusion path is exponential, i.e. the technological leader acts as a locomotive for growth in the follower so that the follower always converges to the leader. These assumptions translate into an empirical formulation in which technological growth can be written as a linear function of human capital.

Benhabib and Spiegel (2002) extended their initial model of technological diffusion in order to allow for technological diffusion following a logistic path. This extension has the advantage of reconciling the theory with some stylised facts. Technological divergence between the follower and the leader is now possible if the level of human capital of the follower is lower than a critical threshold. The introduction of a threshold of this kind reconciles the model with convergence clubs results, in the tradition of Azariadis and Drazen (1990) and Durlauf and Johnson (1995). The empirical counterpart of this model is an equation for TFP non-linear growth in human capital: if there is convergence the diffusion path is exponential, whereas if there are convergence clubs the diffusion path is logistic. In the first generation of models for technological transfer, as in Nelson and Phelps (1966), Dowrick and Nguyen (1989), and De la Fuente (1995), the micro-foundations of innovation and imitation are absent. Second generation models introduce explicit agents that respond to market incentives, as in Barro and Sala-i-Martin (1997). Although the Benhabib and Spiegel (2002) model does not deal specifically with the agent behaviour that is related to their innovation and imitation activities, they prove that their results can be derived from the Barro and Sala-i-Martin (1997) model.

2.2. Empirical analysis

We replicated the Benhabib and Spiegel (2002) and the Nelson and Phelps (1966) empirical methodologies for a sample of seven developing Mediterranean countries, Algeria, Cyprus, Egypt, Israel, Syria, Tunisia and Turkey, due to the availability of human capital data. Although small, we consider this an interesting group of countries to study since it contains some degree of data variability, with Israel and Cyprus, for instance, registering relatively high levels of income and education that allow for the identification of the relevant coefficients. Additionally, we considered a wider sample of thirteen countries by adding the European Mediterranean countries, France, Greece, Italy, Portugal, and Spain, and Ireland. These six additional countries are all Mediterranean except for Ireland which, to a certain extent, allows us to control the influence of the geographical factor on productivity growth. On the other hand, four of the six European countries, Greece, Ireland, Portugal and Spain, have undergone a process of catching-up with the initially richer European countries which may reveal similarities with the eventual process of convergence occurring in the Southern Mediterranean countries.

We extended the Benhabib and Spiegel (2002) empirical analysis to a panel data framework since it would have been impossible to use cross-section econometric techniques to analyse a sample of seven/thirteen countries. In this way we were able to explore a richer information set, with time series as well as cross section information that allowed for an even greater degree of freedom and therefore improved the efficiency of the estimators; furthermore we were able to control the omitted variable bias (see Baltagi, 2001). Adding countries to our original sample of seven developing Mediterranean countries further improves the efficiency of the estimators. In the empirical analysis we used four panel databases resulting from the use of annual data and data at 5-year intervals to reduce the impact of business cycle effects for the period 1960-2000.

Data for real GDP (rdgpl), investment shares as a ratio of the GDP (ki) and population (POP) were taken from the Penn World Tables (PWT) Mark 6.1. Human capital was proxied by the average years of schooling of the population aged 15 and over (TYR) taken from Barro and Lee (2000). Annual data for human capital, provided originally at 5-year intervals, was annualised through non-linear interpolation[5]. The data that was unavailable for Cyprus (1997-2000) and Tunisia (1960) was computed using ARIMA models for each variable.

We used TFP growth as a proxy for the technological growth rate. The TFP index is computed in logs from a Cobb-Douglas aggregate production function as the difference between real GDP and primary input use, physical capital and labour (proxied by population), weighted by their income shares, α and (1-α) respectively:

$$a_{it} = y_{it} - \alpha k_{it} - (1-\alpha) l_{it} = y_{it} - \frac{1}{3} k_{it} - \frac{2}{3} l_{it} \qquad (1)$$

where a_{it} is the log of the country's TFP level (i) at time t, y_{it} is the log of the country's real GDP (i) at time (t), k_{it} is the log of the physical stock of the country's capital (i) at time (t) and l_{it} is the log of the population of country (i) at time (t)[6], and α is assumed to take the value 1/3. Since there was no physical capital data available we computed physical capital stocks following the

5 This was done by using the RATS' procedure DISTRIB.rsc that computes the distribution of a series changing its frequency to a higher one. We have assumed that the original series follows a random walk.

6 The Lee (2001) method was also used but the results are not considered here since they were economically meaningless.

Klenow and Rodriguez-Clare (1997) methodology through the perpetual inventory method using investment data[7]. Having obtained the series for the TFP levels at annual and 5-year intervals, we computed the TFP growth rates.

To determine the appropriate estimation procedures for our panel data analysis we studied the unit root characteristics of the TFP growth rate series using unit root panel tests. To overcome the problem of spurious regressions, that is, to be able to apply classical econometric procedures, we had to verify whether our TFP growth series was I(0), i.e. it did not have a unit root. The Appendix contains the results for the panel unit root tests proposed by Levin and Lin (1993) and Im, Pesaran and Shin (2003) which allowed us to reject the null hypothesis of the presence of a unit root in the TFP growth series. We thus estimated the Benhabib and Spiegel (2002) non-linear specification using NLLS, including a constant, a trend or individual constants. As for the Nelson and Phelps (1966) linear equation, OLS with robust errors was used, including a constant, a trend or individual constants. Fixed effects as well as random effects models were also used.

2.2.1. Empirical findings using the Benhabib and Spiegel (2002) methodology

The Benhabib and Spiegel (2002) empirical formulation for the relationship between TFP growth and human capital that we tested is given as equation (2) below:

$$g_{(TFP)it} = b + \left(g + \frac{c}{s}\right)h_{it} - \left(\frac{c}{s}\right)h_{it}\left(\frac{A_{it}}{A_{mt}}\right)^{s} + \varepsilon_{it} \qquad (2)$$

where $g_{(TFP)it}$ is the TFP growth rate of country (i) at time (t); b is the constant term; h_{it} is the stock of human capital for country (i) at time (t) in logarithms; A_{it} is the TFP level of the follower country (i) at time (t); and A_{mt} is the TFP level of the leader country (assumed to be the USA)[8].

According to equation (2), the TFP growth rate of country (i) at time (t) depends: i) on a constant term b; ii) positively on the level of human capital whose coefficient is [g + (c/s)], with the expression $[g + (c/s)]h_{it}$ capturing the contribution of the innovation process of country (i) at time (t) to its TFP growth rate; iii) negatively on the degree of technological backwardness, taking into account its interaction with the level of human capital whose coefficient is [-(c/s)], with the expression $[-(c/s)]h_{it}(A_{it}/A_{mt})$ capturing the contribution of the diffusion process of country (i) at time (t) to its TFP growth rate; and iv) on the error term that is i.i.d distributed. Equation (2) allows us to control the two types of technological diffusion paths described before – exponential (s = -1) or logistic (s = 1). In this way we can determine whether the Mediterranean countries will converge to the USA or whether they are caught in a poverty trap due to low human capital levels.

We estimated different versions of equation (2). We called each estimated version models A and B: model A uses annual data for the stock of human capital whilst model B considers the initial human capital stock average for the period 1960-1965. We estimated models A and B for both samples, considering annual data and three cases: with constant term, with trend, and with individual constants. In the case of model A, estimations were also performed for all three cases using 5-year data. The results are presented in tables 1, 2 and 3. After inspecting the results, the main conclusion is that we cannot accept the Benhabib and Spiegel (2002) specification for either of the samples. In fact, the results obtained are very weak. Let us briefly interpret the results obtained in each of the tables.

7 See the Appendix for details on the computation of the physical capital stock series.

8 Please refer to Benhabib and Spiegel (2002) for more details on the variables and equations used.

Table 1 – Seven countries (Benhabib and Spiegel, 2002)

	TFP Annual Growth Rate					
NLLS	**Model A** with constant	**Model A** with trend	**Model A** with C_{is}	**Model B** with constant	**Model B** with trend	**Model B** with C_{is}
b	-0.044 (3.84***)	-0.043 (4.14***)	–	-0.001 (0.17)	-0.042 (4.36**)	–
g	0.026 (0.36)	0.010 (1.27)	0.056 (5.24***)	0.008 (1.23)	0.007 (1.18)	-0.233 (0)
c	0.014 (0.04)	-0.00000002 (0.21)	-0.00002 (0.43)	-0.000008 (0.38)	-0.0000005 (0.27)	-0.0006 (1.03)
s	2.182 (0.06)	-12.5 (3.66***)	-7.75 (4.36***)	-8.883 (4.34***)	-10.963 (3.99***)	-5.899 (7.43***)
b_1	–	–	-0.052 (3.65***)	–	–	-0.001 (0.14)
b_2	–	–	-0.090 (4.13***)	–	–	0.396 (25.56***)
b_3	–	–	-0.049 (3.51***)	–	–	0.008 (0.78)
b_4	–	–	0.122 (4.82***)	–	–	0.427 (37.62***)
b_5	–	–	0.0025 (1.35)	–	–	0.191 (11.71***)
b_6	–	–	0.036 (2.53***)	–	–	-0.037 (3.35***)
b_7	–	–	-0.077 (4.78***)	–	–	0.0165 (13.58***)
trend	–	0.001 (3.31**)	–	–	-0.002 (5.24***)	–
see	0.071	0.068	0.067	0.074	0.031	0.073
n-k	276	275	270	276	52	270

*significant at 10% level; **significant at 5% level; *** significant at 1% level; in brackets t-student values; trend – time effect coefficient.

Table 1 presents the results of the estimation of models A and B for the sample of seven Mediterranean countries with annual data. The estimated values of the coefficients g and c are not significant and the coefficient [-(c/s)] has the wrong theoretical sign in models A and B with constant. As for s, it is significant at the 1% level only in model B but its value neither confirms a logistic path, nor an exponential path. The results for models A and B with trend improve: in model A the estimated value for coefficient s becomes significant and in model B, the estimated value for coefficient b becomes significant; in any case, however, c is not significantly different from zero, an extremely implausible result from a theoretical point of view since it dismisses any influence of technology diffusion on TFP growth. Like the previous models, [-(c/s)] has the wrong sign and again the value of s is neither equal to one or minus one. As for model A with individual constants, the results have improved compared with those obtained with the model with trend: g becomes significant at the 1% level, nonetheless c is not significantly different from zero and s is not equal to minus 1. In model B with individual constants, the results have not improved in terms of the model with trend.

Table 2 – Seven countries (Benhabib and Spiegel, 2002)			
	TFP 5-year average growth rate		
NLLS	Model A	Model A with trend	Model A with C_{is}
b	-0.046 (3.69***)	-0.057 (4.84***)	–
g	1.231 (0.02)	-77.05 (0.13)	0.073 (5.42***)
c	-23.052 (0.02)	2812.618 (0.13)	-0.002 (0.65)
s	19.204 (0.11)	36.50 (0)	-3.457 (2.42**)
b_1	–	–	-0.057 (3.89***)
b_2	–	–	-0.109 (4.91***)
b_3	–	–	-0.056 (3.97***)
b_4	–	–	-0.153 (5.77***)
b_5	–	–	-0.044 (2.36**)
b_6	–	–	-0.050 (3.47 ***)
b_7	–	–	-0.086 (5.47***)
trend	–	0.001 (3.09***)	–
see	0.034	0.032	0.028
n-k	52	51	46

*significant at 10% level; **significant at 5% level; *** significant at 1% level; in brackets t- student values; trend – time effect coefficient.

Table 2 presents the results of the estimation of model A for the sample of seven Mediterranean countries with data at 5-year intervals. The results have improved in comparison to those using annual data. In fact, all the individual constants are now significant and the Standard Error of the Estimate (SEE) is now 2.8% as opposed to 6.7% in the previous estimations. Nonetheless, the coefficient c is again not significantly different from zero.

Table 3 – Thirteen countries (Benhabib and Spiegel, 2002)

	TFP Annual Growth Rate			TFP 5-year average growth rate		
NLLS	**Model A**	**Model A** with trend	**Model A** with C_{is}	**Model B**	**Model B** with trend	**Model B** with C_{is}
b	-0.041 (5.15***)	-0.049 (6.25***)	–	-0.051 (4.41***)	-0.052 (5.71***)	–
g	0.074 (1.74*)	0.042 (0.85)	4.544 (1.09)	0.029 (4.59***)	0.010 (1.52)	0.003 (0.85)
c	-0.490 (0.66)	-0.410 (0.36)	-649.319 (1.07)	0.004 (0.29)	-0.000 (1.17)	-0.011 (0.30)
s	10.057 (1.23)	12.163 (0.66)	144.734 (0)	-0.956 (0.14)	54.76 (0)	9.399 (0.65)
b_1	–	–	-0.068 (5.81***)	–	–	-0.012 (0.88)
b_2	–	–	-0.100 (5.93***)	–	–	0.007 (0.51)
b_3	–	–	-0.061 (5.34 ***)	–	–	-0.008 (0.61)
b_4	–	–	-0.126 (6.88***)	–	–	-0.005 (0.37)
b_5	–	–	-0.077 (5.90***)	–	–	-0.006 (0.41)
b_6	–	–	-0.054 (4.68***)	–	–	0.0004 (0.03)
b_7	–	–	-0.083 (6.40***)	–	–	-0.013 (0.93)
b_8	–	–	-0.115 (6.95***)	–	–	0.950 (0)
b_9	–	–	-0.112 (6.72***)	–	–	0.928 (0)
b_{10}	–	–	-0.117 (6.66***)	–	–	0.902 (0)
b_{11}	–	–	-0.105 (6.57***)	–	–	4.377 (0)
b_{12}	–	–	-0.074 (5.60***)	–	–	0.910 (0)
b_{13}	–	–	-0.101 (6.50***)	–	–	0.640 (0)
trend	–	0.002 (6.22***)	–	–	-0.001 (5.35***)	–
see	0.058	0.0056	0.057	0.032	0.028	0.36
n-k	516	515	504	100	99	88

*significant at 10% level; **significant at 5% level; *** significant at 1% level; in brackets t- student values; trend – time effect coefficient.

Table 3 presents the results of the estimation of model A for the extended sample of thirteen countries with annual data and data at 5-year intervals. Considering the results with annual data for the model with constant, g is now significant at the 10% level but c and s are not significantly different from zero. For the models with trend and individual constants the results are worse. For model A with trend, s is no longer significant compared to the same model for the smaller sample. As for model A with individual constants, g and s are no longer significantly different from zero. Model A with constant is thus the model with the best results, although it is still very weak. In fact, only g and b are significant at the 10% level. Turning to the results using data at 5-year intervals, these are an improvement since g and b are now significant at 1% level. If we compare the results obtained with model A and 5-year data for the larger sample with those of the smaller sample, the results are better for the model with constant and worst for the model with individual constants.

These weak results led us to conclude that the non-linear technological diffusion specification of Benhabib and Spiegel (2002) is not suitable for our samples[9]. The fact that the three coefficients of their empirical specification, g, s and c are never significant at the same time, nor do they display simultaneously the signs predicted by theory; the fact that the coefficient c is never significantly different from zero and also the fact the value of s is not equal to one or to minus, made us believe that the non-linear specification for TFP growth as a function of human capital is not suitable for describing the technological diffusion process in our sample of countries. In particular, the logistic path for the technological diffusion process seems not to apply to our two samples. One possible explanation is that in the smaller sample the level of human capital is not constrained by a threshold, which would probably occur if we had worked with a larger sample, as the authors did, which included the poorest countries in the world.

In view of these results we decided to check whether the linear specification adopted by Benhabib and Spiegel (1994), inspired in turn by the Nelson and Phelps (1966) model, is better suited to explaining TFP growth in our sample. We call this the Nelson and Phelps (1966) methodology to distinguish it from the Benhabib and Spiegel (2002) methodology.

2.2.2. The Nelson and Phelps (1966) methodology

According to the Nelson and Phelps (1966) model, technology diffusion follows an exponential diffusion path so that the follower always converges to the leader. Assuming that this exponential path applies to all countries, Benhabib and Spiegel (1994) derive the following linear specification for the behaviour of TFP growth, adding the predictions of the Romer (1990a) model as to the influence of the level of human capital on the domestic innovation rate[10]:

$$g_{TFPit} = gH_{it} + cH_{it}\left(\frac{A_{m(t)}}{A_{it}} - 1\right) + \varepsilon_{it} \qquad (3)$$

According to equation (3), the rate of technical progress depends on the rate of innovation, which is a positive function of the stock of human capital (gH_{it}), and on a technological catch-up term, which is also a positive function of the stock of human capital. The rate of technical progress is now positively related to the degree of technological backwardness of the economy, due to the definition of technological backwardness now used ($\frac{A_{m(t)}}{A_{it}}$). The estimated equation is not equation (3) but equation (4) below, obtained after normalising the values of human capital and of the technological gap (deviations from the average value).

9 We also estimated the different models using ML methods, with one variance and individual variances, assuming an AR1 process but the results were not good.

10 Please refer to Benhabib and Spiegel (1994) for more details on the variables and equations used.

$$g_{TFPit} = gH_{it} + c_i Z_{it} + \varepsilon_{it}$$
$$Z_{it} = (H_{it} - \bar{H}) \left[\left(\frac{A_{m(t)}}{A_{it}} - 1 \right) - \left(\overline{\frac{A_{m(t)}}{A_{it}} - 1} \right) \right] \quad (4)$$

Since equation (4) is linear, we estimated it using OLS with robust errors, fixed effects and random effects models. We only estimated model A. Tables 4 to 6 present the results of the estimation of equation (4) for the sample of developing Mediterranean countries using annual data as well as data at 5-year intervals[11].

Table 4 – Seven countries (Nelson and Phelps, 1996, equation)

	TFP Annual Growth Rate			TFP 5-year average growth rate		
NLLS	Model A with constant	Model A with trend	Model A with C_{is}	Model A	Model A with trend	Model A with C_{is}
B	-0.032 (2.88***)	-0.047 (3.67***)	–	-0.035	-0.051 (4.46***)	–
g	0.009 (3.76***)	0.004 (1.51)	0.001 (1.11)	0.008	0.004 (1.36)	0.001 (0.87)
c	0.007 (2.50**)	0.004 (1.48)	0.004 (1.48)	0.006	0.003 (1.01)	-0.003 (1.36)
b_1	–	–	0.046 (2.75***)	–	–	0.009 (0.31)
b_2	–	–	-0.006 (2.06***)	–	–	-0.007 (2.29**)
b_3	–	–	0.026 (1.94*)	–	–	0.025 (2.76***)
b_4	–	–	0.009 (0.40)	–	–	0.009 (0.33)
b_5	–	–	0.029 (2.19**)	–	–	0.018 (7.11***)
b_6	–	–	0.009 (1.93*)	–	–	0.011 (2.32**)
b_7	–	–	-0.045 (2.05**)	–	–	-0.040 (1.27)
trend	–	0.001 (3.30**)	–	–	(3.30**) (3.08***)	–
see	0.071	0.069	0.067	0.034	0.031	0.033
n-k	277	276	272	53	52	48

*significant at 10% level; **significant at 5% level; *** significant at 1% level; in brackets t- student values; trend – time effect coefficient.(n-k) – degrees of freedom.

Table 4 presents the results of the estimation of model A with constant, trend and individual constants for the smaller sample, with annual data and data at 5-year intervals, using OLS. Considering the results with annual data, the best model is model A with constant. In fact all the coefficients are significant and have the sign predicted by theory. Nonetheless the values of g

11 The results of the estimation of this model for the larger sample do not change significantly either qualitatively or quantitatively so we have refrained from including them here. These results are available from the authors upon request.

and c are very small. The other two models behave very badly. In fact, g and c are never significantly different from zero in these models. As for the results with 5-year data, these models should be disregarded: g and c are never significantly different from zero.

Table 5 – Seven countries (Nelson and Phelps, 1996, equation)

Fixed effects model	TPF annual growth rate	TFP 5-year growth rate
g	0.016 (5.19***)	0.016 (5.11***)
c	0.004 (1.69*)	0.003 (1.15)
see	0.067	0.032
n-k	310	47

*significant at 10% level; **significant at 5% level; *** significant at 1% level; in brackets t- student values; trend – time effect coefficient.(n-k) – degrees of freedom.

Table 5 presents the results of the estimation of model A for the smaller sample assuming fixed effects. The best result is obtained with annual data. In fact, all the coefficients are significant at the 1% level and at the 10% level. Notice that the value of g has increased compared with the estimation with OLS – the value of g is higher than c, whose value is very small. With 5-year data c is no longer significantly different from zero. The results are very sensitive to the frequency of the data.

Table 6 – Seven countries (Nelson and Phelps, 1996, equation)

Random effects model	TPF annual growth rate	TFP 5-year growth rate	TFP 5-year growth rate
constant	-0.064 (3.48***)	-0.066 (3.47***)	–
g	0.014 (5.59***)	0.013 (4.89***)	0.006 (3.45***)
c	0.006 (2.67***)	0.005 (1.75)	0.006 (2.14**)
see	0.066	0.031	0.033
n-k	317	53	54

*significant at 10% level; **significant at 5% level; *** significant at 1% level; in brackets t- student values; trend – time effect coefficient. (n-k) – degrees of freedom.

Table 6 presents the results of the estimation of model A for the smaller sample, now assuming random effects. With annual data, all the coefficients are significantly different from zero at the 1% level and the same is true for the model without constant using 5-year data. The value of coefficient c is higher in both models compared with those obtained with the fixed effects model and for the last model g is no longer higher than c.

To sum up, the evidence presented in this section confirms the importance of human capital as a determinant of technological progress, based on the results of the tests of the Nelson and Phelps (1966) linear specification. A somewhat surprising result comes from the fact that the influence of human capital is felt mainly through innovation and not imitation activities. This is, however, in accordance with the results of the tests of the Benhabib and Spiegel (2002) hypothesis that did not allow us to confirm that the TFP growth rate follows a logistic function, i.e. the human capital in our sample is already higher than the threshold necessary for it to exert its influence over the technological progress growth rate. The low impact of human capital on imitation activities, however, leads us to explore in the next section the hypothesis that human capital is more important for TFP growth through embodied technology diffusion than through disembodied technology diffusion, previously represented by the TFP gap to the technological leader.

3. Human capital and channels of technology diffusion

In this section we propose to analyse a little further the role of human capital in the process of technological diffusion, focusing on the complementarity between human capital and foreign direct investment (FDI) as determinants of the technological progress growth rate, on the one hand, and on the importance of human capital as a facilitator of the diffusion of information and communication technologies (ICT). Technology diffuses through many channels, two of which have been extensively studied in the empirical literature, international trade and Foreign Direct Investment (FDI)[12]. Data availability for our seven developing Mediterranean countries made us restrict our analysis the study of the complementarity between human capital and technology transfers through FDI. We also analysed the role of human capital as a facilitator of ICT diffusion, since this plays a major role in productivity growth[13]. The diffusion of these new technologies can thus contribute to the acceleration of technology diffusion in Mediterranean countries. In both cases we took Borensztein, Gregorio and Lee (1998) and Lee (2001) as the basic framework for our estimations.

3.1. The complementarity between human capital and FDI in the process of technological diffusion

The purpose of this section is to empirically examine the complementarity between human capital and FDI in the process of technology diffusion in our sample of Mediterranean countries. FDI is one of the channels[14] through which the technology from the leader is transferred to the followers. However, the host economy needs a sufficient level of human capital in order to apply the technology of the leader, i.e. the stock of human capital of the follower country limits its absorptive capability for the technology incorporated in FDI.

We test this complementarity hypothesis in a panel data framework between 1970 and 1998 following Borensztein, Gregorio and Lee (1998) and Lee (2001) and their basic formulation:

$$D(TFP)_{it} = \alpha_0 + \alpha_1 GTFP_{it-1} + \alpha_2 TYR_{it-1} + \alpha_3 FDI_{it} + \alpha_4 FDI_{it} \times SHYR_{it} + \eta_i + \varepsilon_{it} \qquad (5)$$

where $D(TFP)_{it}$ is the log difference of the TFP level as defined in the previous section, $GTFP_{it-1}$ is the initial gap in the technology level in relation to the USA computed as $\log(\frac{TPF_{USAt-1}}{TPF_{it-1}})$, TYR_{it-1} is the initial stock of human capital measured as the average years of total schooling in the population aged 15 and over, $SHYR_{it}$ is the average years of secondary and higher education in the population aged 15 and over, FDI_{it} is the net FDI flows as a ratio to GDP, η_i represents country-specific effects, and ϵ_{it} is the error term with the usual properties.

Technological growth depends positively on the initial technological gap between the leader and the follower country – the higher the initial gap, the higher the potential for the adoption and implementation of new technologies, i.e., the higher the TFP growth rate of the follower, so we expect a positive and significant α_1 – this is the usual technological catch-up assumption of

12 See Coe and Helpman (1995), Engelbrecht (1997), Frantzen (2000), Potterie and Lichtenberg (2001), Xu (2000). See also Keller (2004) for a review of the literature on technology diffusion.

13 See Schreyer (2000), Van Ark, Inklaar and McGuckin (2003), Cette, Mairesse and Kocoglu (2004).

14 Another channel of technology diffusion from the leader to the followers is imports of machinery and transport equipment. Unfortunately, we were not able to get access to data on imports of machinery and transport equipment from the OECD countries, the countries responsible for most of the world's R&D initiatives, for our sample of Mediterranean countries.

technology diffusion models such as the Nelson and Phelps (1966) and the Barro and Sala-i--Martin (1997) models discussed before. Human capital also positively influences TFP growth, since the adoption and implementation of new technologies requires at least basic levels of skills ($\alpha_2 > 0$). On the other hand, FDI is a fundamental channel through which less developed countries gain access to the advanced technologies of the developed countries, which means that α_3 should be positive. Finally, the hypothesis that the diffusion of technology through FDI is only effective if the host economy has the necessary absorptive capability in the form of human capital is tested through the interactive term *FDIxSHYR* – if its coefficient is positive and significant this means that the technology spillovers coming from FDI depend on the stock of human capital. Note that now only average years of secondary and tertiary education are considered, meaning that we assume that to benefit from the FDI originating in developed countries the Mediterranean countries need more than the basic skills provided by primary education.

The TFP and human capital data are the same as those used in the previous sections. The FDI data comes from the OECD publication "Geographical distribution of financial flows to aid recipients " (OECD, 2003) and measures the net flows of FDI received by the countries in our sample from OECD countries, responsible for most of the R&D initiatives in the world.

We estimated our relationship using four different estimation procedures – the pooled ordinary least squares (OLS), the within-groups estimator, the first-differenced generalized method of moments (GMM-DIF) proposed by Arellano and Bond (1991), and the system generalized method of moments (GMM-SYS) proposed by Arellano and Bover (1995) and Blundell and Bond (1998), each corresponding to different assumptions concerning the econometric properties of the relationship we were analysing.

The pooled OLS estimator delivers unbiased and consistent estimators if there are no country--specific effects in the relationship and if the regressors are strictly exogenous. On the contrary, in the presence of country-specific effects but still strictly exogenous regressors, the within-groups estimator delivers unbiased estimators since it controls the omitted variable bias. In the presence of country-specific effects and the violation of the assumption of strict exogeneity of the regressors, however, the OLS and the within-groups estimators are biased, since equation (5) can be written as a dynamic panel with the lagged dependent variable on the right hand side. In this situation at least one of the regressors, the lagged dependent variable, is correlated with the error term and so the OLS estimate of the coefficient on initial TFP is biased upwards, whilst the within-groups estimator is biased downwards (see Nickell, 1981 and Bond, Hoeffler and Temple, 2001). If the regressors are not strictly exogenous the results from these two procedures relative to the estimated coefficient on the initial technological gap will be different, providing a clue that OLS and within-groups are not adequate estimation procedures. Arellano and Bond (1991) propose the use of the first-differenced GMM estimator to overcome this problem. This procedure consists of first differencing the TFP equation to eliminate fixed effects and then using adequate past levels of the relevant variables as instruments. However, in the presence of weak instruments the GMM-DIF estimator is biased towards the within-groups estimator and the GMM--SYS estimator proposed by Arellano and Bover (1995) and Blundell and Bond (1998), which uses both the levels and the first differences of the regressors as instruments is an adequate estimation procedure. To check the consistency of the GMM estimators used we present the results of the Sargan test of over-identifying restrictions that tests for the null of overall validity of the instruments used and the results of a test of the hypothesis that the errors are serially uncorrelated proposed by Arellano and Bond (1991). The results of the tests support the use of these estimation procedures.

In table 7 we present the results of the estimation of the different equations using annual data and the four different estimation procedures previously mentioned. To control the possibility of business cycle effects on the TFP growth rate we also estimated the different equations, averaging the data over 5-year periods[15]. The results for these estimations are presented in table 8.

15 For the last period, 1995-1998, we used 3-year averages.

Table 7 – Human capital and technology diffusion through FDI flows (annual data)

	Dependent variable: D(TFP) – Annual growth rate of TFP, 1970-1998											
	Pooled OLS			Within Groups			GMM-DIF[c]			GMM-SYS		
GTFP (t-1)	0.105 (4.86)**	0.106 (5.05)**	0.106 (5.12)**	0.171 (2.15)**	0.173 (2.26)**	0.175 (2.25)**	0.41 (7.59)**	0.179 (10.2)**	0.195 (9.20)**	0.181 (17.0)**	0.161 (25.8)**	0.18 (20.8)**
TYR (t-1)	0.0027 (4.18)**	0.0027 (4.31)**	0.0026 (4.13)**	0.004 (2.07)**	0.004 (2.24)**	0.004 (2.30)**	-0.01 (-0.952)	0.002 (0.802)	0.002 (0.665)	0.004 (3.72)**	0.004 (5.80)**	0.004 (5.60)**
FDI (t)		0.002 (2.66)**	0.0009 (0.549)		0.002 (1.63)*	0.0008 (0.247)**		0.001 (0.779)	-0.0024 (-0.448)		0.003 (1.42)	0.0012 (0.205)
*FDI*SHYR (t)*			0.0007 (1.21)			0.0007 (0.594)			0.002 (0.779)			0.0009 (0.393)
AR (2)[a]							0.72	0.792	0.824	0.761	0.770	0.782
Sargan Test[b]							0.029	0.921	1.000	0.000	0.000	0.000
Obs	203	203	203	203	203	203	189	189	189	196	196	196

Notes: values of the t-Student statistic in brackets. ** significant at the 5% level; * significant at the10% level.
Instruments used in GMM-DIF: lnTFPit-2, lnTYRit-3; lnFDIPit-2, lnFDI*SHYRSit-2, and lags up to the fourth lag.
Instruments used in GMM-SYS: same as for GMM-DIF and additionally instruments for the levels equations are ΔlnTFPit-1, ΔlnTYRPit-2; ΔlnFDIPit-1, ΔlnFDI*SHYRSit-1.
[a] p-values for the null hypothesis that the errors in the first-difference regression exhibit no second-order serial correlation. [b]p-values for the null hypothesis of overall validity of the instruments used. [c] Results for the one-step GMM estimator with standard errors robust to heteroskedasticity since the standard errors of the two-step GMM estimator can be seriously biased downwards.

Table 8 – Human capital and technology diffusion through FDI flows (5-year averages)

	Dependent variable: D(TFP) – Annual average growth rate of TFP, 1970-1998											
	Pooled OLS			Within Groups			GMM-DIF[c]			GMM-SYS		
GTFP (t-1)	0.067 (4.20)**	0.065 (4.34)**	0.065 (4.35)**	0.075 (3.11)**	0.094 (3.75)**	0.095 (3.42)**	0.499 (2.97)**	0.203 (4.84)**	0.201 (3.74)**	0.331 (6.53)**	0.146 (6.89)**	0.203 (5.40)**
TYR (t-1)	0.0017 (3.93)**	0.0017 (3.31)**	0.0017 (2.70)**	0.002 (2.25)**	0.002 (2.16)**	0.002 (1.81)**	-0.003 (-0.350)	-0.002 (-0.331)	0.003 (0.362)	0.009 (2.64)**	0.006 (1.77)*	0.006 (2.05)**
FDI (t)		0.0003 (0.320)	0.0005 (0.133)		-0.001 (0.631)	0.0003 (0.055)		-0.008 (-0.834)	-0.010 (-0.786)		-0.006 (-0.751)	-0.014 (-1.13)
*FDI*SHYR (t)*			-0.0009 (-0.059)			-0.001 (-0.519)			0.0019 (0.332)			0.005 (0.999)
AR (2)[a]							0.772	0.677	0.363	0.261	0.265	0.292
Sargan Test[b]							0.231	0.530	0.795	0.009	0.055	0.082
Obs	42	42	42	42	42	42	35	35	35	42	42	42

Notes: values of the t-Student statistic in brackets. ** significant at the 5% level; * significant at the10% level.
Instruments used in GMM-DIF: $\ln TFP_{it-2}$, $\ln TYR_{it-3}$; $\ln FDI_{Pit-2}$, $\ln FDI*SHYR_{Sit-2}$, and lags up to the fourth lag.
Instruments used in Sys-GMM: same as for GMM-DIF and additionally instruments for the levels equations are $\Delta \ln TFP_{it-1}$, $\Delta \ln TYR_{Pit-2}$; $\Delta \ln FDI_{Pit-1}$, $\Delta \ln FDI*SHYR_{Sit-1}$.
[a] p-values for the null hypothesis that the errors in the first-difference regression exhibit no second-order serial correlation. [b] p-values for the null hypothesis of overall validity of the instruments used. [c] Results for the one-step GMM estimator with standard errors robust to heteroskedasticity since the standard errors of the two-step GMM estimator can be seriously biased downwards.

As far as the results using annual data are concerned (Table 7), the technological catch-up hypothesis is confirmed for all the equations – the coefficient on the initial technological gap is always positive and significant, meaning that the initially more technologically backward countries were indeed the ones that exhibited faster TFP growth rates. The role of the initial level of human capital in the domestic innovation rate is also confirmed (except when we use the first-differenced GMM estimator) – its coefficient is always positive and significant. In the equation where FDI is included on its own its expected positive influence over the TFP growth is confirmed only when the pooled OLS and the within-groups estimators are used. In the case of the first-differenced GMM estimator the coefficient, although positive, is not significant and with the system GMM estimator it is positive but only significant at the 25% level. The hypothesis we are focusing on is that the technology originating in FDI flows is used effectively only if the host country has the necessary human capital, which means that in our full equation the coefficient in the interaction term between FDI and human capital should be positive and significant. From our results we see that this is not, however, the case – although the coefficient is always positive it is never significant. Furthermore, the coefficient on FDI alone always becomes non-significant and even negative when the GMM-DIF estimator is used. Our hypothesis of complementary between FDI flows and human capital is therefore not supported by this data for our seven Mediterranean countries.

Turning now to the results using 5-year averages, nothing much changes. The coefficients on the initial technological gap and human capital are still always positive and significant (except for the human capital coefficients using GMM-DIF), the coefficient on FDI when introduced on its own is never significant and it is only positive when using the pooled OLS estimator. Finally when the full equation is estimated the coefficient on FDI remains non-significant and the same happens with the coefficient on the interaction term.

To sum up, we can say that human capital on its own influences the growth rate of technological progress in our seven Mediterranean countries, due to its influence on the rate of domestic innovation but the evidence does not confirm its role in determining the TFP growth rate as a determinant of the absorptive capability of the technology embodied in FDI. Maybe a better measure for the spillovers of technology from the technological leaders to the followers would be imports of machinery and transport equipment which, unfortunately, we could not gain access to for our sample.

3.2. Human capital as a facilitator of the diffusion of IC technologies

It is widely accepted that Information and Communication technologies (ICTs) play a major role in technological progress nowadays and hence the diffusion of these new technologies contributes towards accelerating technological diffusion in our sample of Mediterranean countries. However, these new technologies require more than basic skills to be fully implemented, i.e., human capital levels are a major determinant of the absorptive capability of ICTs in the Mediterranean countries. In order to test this hypothesis we estimated the relationship between human capital and a set of ICT indicators in a panel data framework using the following equations, (6) and (7):

$$ICT_{it} = b_0 + b_1 logRGDP_{it} + b_2 TYR_{it} + \mu_i + \nu_{it} \qquad (6)$$

$$ICT_{it} = c_0 + c_1 logRGDP_{it} + c_2 PYR_{it} + c_3 SYR_{it} + c_4 HYR_{it} + \mu_i + \nu_{it} \qquad (7)$$

where ICT_{it} is an ICT indicator, measured alternatively as main telephone lines, number of personal computers, internet hosts, daily newspapers, and number of TV sets, all per 1,000 people[16] and $logRGDP_{it}$ is the natural logarithm of real GDP per capita from the PWT Mark 6.1 and proxies for the constraint that national financial resources represent on the investments necessary for building ICT infrastructures. In equation (6) we consider the influence of TYR_{it}, the average years of total schooling for the population aged 15 and over that proxies for the skills necessary for the implementation of ICTs. In equation (7) we consider the influence of the different levels of schooling separately, since basic literacy skills may not be sufficient to fully benefit from the ICTs and thus there might be separate effects for each level of schooling in the evolution of the different ICT indicators. PYR_{it} is the average number of years of primary education for the population aged 15 and over; SYR_{it} is average number of years of secondary education for the population aged 15 and over; and HYR_{it} is the average number of years of higher education for the population aged 15 and over. μ_i is a country-specific effect and v_{it} is the error term with the usual properties.

We present the results of the estimation of the different equations in tables 9 and 10. In the first table we ignored the presence of country-specific effects in determining the evolution of ICTs, i.e. we estimated our different equations using the pooled OLS estimator. In the second table we considered that there might have been country-specific effects governing the evolution of ICTs, so we present the results of the estimation of the different equations using the within-groups estimator.

Table 9 – Human capital and ICT diffusion (Pooled OLS)

Dependent variable	log(RGDP per capita)	TYR	PYR	SYR	HYR	$\bar{R}^2$	Obs.
Telephone lines	139.939	24.6327				0.798	172
	(2.89)**	(2.72)**					
	185.333		-92.3	53.16	745.6	0.888	172
	(5.68)**		(-4.6)**	(2.51)**	(7.80)**		
Personal computer	26.3	17.7				0.81	32
	(2.42)**	(3.58)**					
	51.9		-17.65	-25.38	272.72	0.886	32
	(1.77)**		(-0.482)	(-1.79)*	(1.36)		
Internet hosts	3.22	12.04				0.519	35
	(0.365)	(2.62)**					
	28.06		-23.18	-27.69	259.43	0.701	35
	(0.917)		(-0.554)	(-1.99)**	(1.16)		
Daily papers	66.52	16.63				0.700	63
	(2.04)**	(1.37)					
	79.40		9.34	-87.62	293.4	0.905	63
	(1.94)**		(0.266)	(-4.65)**	(1.40)		
TV sets	75.20	11.36				0.643	172
	(1.84)**	(1.20)					
	69.30		29.61	-46.91	62.38	0.703	172
	(1.79)**		(1.45)	(-1.91)**	(0.497)		

Notes: values of the t-Student statistic in brackets. ** significant at the 5% level. * significant at the10% level.

The results using the pooled OLS estimator show that real GDP and average years of schooling explain most of the development in ICTs in the Mediterranean countries with $\bar{R}^2$ higher than 50%. The availability of financial resources is an important determinant in the development of ICTs,

16 Except for the number of internet hosts, which are measured per 10,000 people. The period of coverage varies according to data availability – 1975-1998 for main telephone lines, daily newspapers and the number of TV sets, 1990-1998 for the number of personal computers, and 1994-1998 for internet hosts.

except in the case of internet hosts where only human capital is significant. As for human capital, the results confirm that the average years of total schooling influences the establishment of phone lines, personal computers and internet hosts. All variables are significant at the 5% level, while the diffusion of daily newspapers and TV sets does not depend on the years of schooling of the population – human capital is only significant at the 25% level. When we examine the influence of the different levels of schooling the results are somewhat awkward – the average years of primary education do not, in general, influence the development of any of the ICT indicators and even show a negative influence as far as phone lines are concerned; the average years of secondary education show a negative influence on all ICT indicators (negative and significant coefficients) except for the phone lines, where the influence is positive and significant as expected and, finally, the average years of higher education show a positive influence on all ICT indicators as expected, but this is only significant in the case of phone lines.

Table 10 – Human capital and ICT diffusion (Within Groups)

Dependent variable	log(RGDP per capita)	TYR	PYR	SYR	HYR	$\bar{R}^2$	Obs.
Telephone lines	409.4 (3.94)**	-19.14 (-0.951)				0.674	172
	278.37 (2.66)**		-47.4 (-0.614)	-47.01 (-0.357)	717.76 (5.22)**	0.766	172
Personal computer	200.8 (2.11)**	7.8 (0.279)				0.273	32
	44.74 (0.432)**		-362.3 (-1.9)**	428.3 (1.44)	565.65 (0.852)	0.551	32
Internet hosts	108.9 (2.14)**	7.72 (0.314)				0.114	35
	-72.29 (-0.552)		-292.6 (-1.7)*	250.9 (0.926)	1047.6 (1.56)*	0.53	35
Daily papers	66.59 (1.58)*	-14.75 (-1.48)				0.128	63
	32.45 (0.843)**		-12.34 (-0.347)	-126.85 (-2.12)**	503.59 (5.29)**	0.592	63
TV sets	55.58 (1.07)	26.04 (1.96)**				0.530	172
	75.59 (3.25)**		120.8 (1.83)*	-163.17 (-1.57)*	218.42 (1.30)	0.62	172

Notes: *values of the t-Student statistic in brackets. * significant at the 5% level; ** significant at the10% level.*

Considering that there might be country-specific effects in the development of ICTs we used the within-groups estimator, as previously mentioned, to estimate the different relationships. The fit of the equations is not as good as before, especially when the different levels of schooling are included in the regressions, although there are some small $\bar{R}^2$ such as in the case of personal computers, internet hosts and daily newspapers when the average years of total schooling is considered. Again, the availability of financial resources is an important determinant in the development of ICTs, except in the case of internet hosts and daily newspapers when the different levels of schooling are considered, and in the case of TV sets taking into account the average years of total schooling. As for human capital, the results do not confirm that the average years of total schooling influences the implementation of ICTs, with the exception of the diffusion of TV sets – where human capital is significant at the 10% level. When we examine the influence of the different levels of schooling the results are mixed – the average years of primary education only shows a positive and significant influence in the case of TV sets, the influence over personal computers and internet hosts is negative and significant, whilst the remaining influences are not significant; the average years of secondary education shows negative and significant coefficients in the case of daily newspapers and TV sets, while all the other influences are non significant; finally, the average years of higher education show a positive influence over all ICTs indicators as expected but this is only significant in the case of phone lines, daily newspapers and TV sets.

From the tests carried out in this section we can say without doubt that to fully benefit from the diffusion of ICTs that have been responsible for the acceleration of technological progress in recent years, the Mediterranean countries need the financial resources to build the necessary infrastructures and the human capital that enables people to work with these new technologies. The role of the different levels of schooling is not so clear, although one would expect that the diffusion of some ICTs like personal computers and Internet hosts require more than just the basic literacy skills provided by primary education. Some of the results that point to the negative and significant influence of primary and secondary education on the development of ICTs are puzzling.

4. Technological shocks and human capital shocks

In order to confirm or reject one of the main theses at stake in our paper, the role of human capital as a facilitator of technological progress, we have tried to apply a different econometric methodology from those used in the previous sections that would enable us to conduct our empirical research without imposing any *a priori* about exogeneity/endogeneity or substituability/complementary in production technology. The VAR methodology is the one that best suits this purpose. In addition, VAR methodology allows us to analyse the dynamics of the model resulting from different shocks (Sims (1980)). We used the Cholesky decomposition, Enders (1995) because we want to run shocks on each variable without imposing any other constraints upon the error structure of the VAR model. Nevertheless, we controlled the ordering of the variables. We think that the empirical analysis performed in this section is quite original[17] and appropriate to the study of dynamic transition paths.

4.1. The VAR model

In order to ascertain the influence of TFP growth rate shocks and human capital shocks on the economy we built a VAR model in the Sims (1980) tradition. It is a VAR model that applies to all seven economies in the smaller sample and has four variables: real GDP per capita, annual TFP growth rate, investment per capita and the stock of human capital, all expressed in logarithms.

The number of lags was chosen using the BIC criteria and the system stationarity condition: the number of lags for Algeria is two, for Cyprus five, for Egypt two, for Israel two, for Syria two, for Tunisia three and for Turkey two. The shocks simulated over the variables are unit shocks. In the case of the TFP growth rate, the impulses resulting from the shocks were accumulated so in all the figures we have plotted the level of TFP. The number of periods is twenty except for Cyprus, which is thirty, when a unit shock is simulated over TFP growth rate, in order to show that the model is stationary.

Equation (8) below presents the VAR model used in the analysis:

17 The VAR methodology applied to growth empirics is quite recent. See for instance Gali (1999), Kalaitzidakis and Korniotis (2000), Ding (2000), and Kane (2001).

$$
\begin{aligned}
y_t &= const_1 + \sum_{i=1}^{k}\alpha_{1i}y_{t-1} + \sum_{i=1}^{k}\alpha_{2i}h_{t-1} + \sum_{i=1}^{k}\alpha_{3i}inv_{t-1} + \sum_{i=1}^{k}\alpha_{4i}g_{TPF(t-1)} + \varepsilon_{1t} \\
g_{TPF(t)} &= const_4 + \sum_{i=1}^{k}\gamma_{1i}y_{t-1} + \sum_{i=1}^{k}\gamma_{2i}h_{t-1} + \sum_{i=1}^{k}\gamma_{3i}inv_{t-1} + \sum_{i=1}^{k}\gamma_{4i}g_{TPF(t-1)} + \varepsilon_{2t} \\
inv_t &= const_3 + \sum_{i=1}^{k}\delta_{1i}y_{t-1} + \sum_{i=1}^{k}\delta_{2i}h_{t-1} + \sum_{i=1}^{k}\delta_{3i}inv_{t-1} + \sum_{i=1}^{k}\delta_{4i}g_{TPF(t-1)} + \varepsilon_{3t} \\
h_t &= const_2 + \sum_{i=1}^{k}\beta_{1i}y_{t-1} + \sum_{i=1}^{k}\beta_{2i}h_{t-1} + \sum_{i=1}^{k}\beta_{3i}inv_{t-1} + \sum_{i=1}^{k}\beta_{4i}g_{TPF(t-1)} + \varepsilon_{4t}
\end{aligned}
\tag{8}
$$

4.2 Shocks Simulation

In the following we analyse briefly the main effects of the three types of shocks under consideration on the seven Mediterranean economies[18]. Table 11 contains a summary of the different types of shocks and their respective impact on the TFP level, investment, human capital and GDP.

Table 11 – Summary table of the impact of the different shocks

SHOCK \ IMPACT	TPF level	Investment	Human capital	GDP
TPF growth rate	Positive and permanent	Initially strong but temporary	Positive and permanent	Positive and permanent
Human capital	Positive and permanent	Initially strong but temporary	Positive and permanent	Positive and permanent
Investment	Positive and permanent	Temporary	Positive and permanent	Positive and permanent

As far as technological shocks are concerned, there is complementarity between technology, physical capital and human capital in the absorption of this shock (see figure C. 1) in all countries except Turkey (see figure C. 2). The same conclusion applies to human capital shocks (see figure C. 3), except for Algeria (see figure C. 4) and Israel (see figure C. 5), which exhibit substitutability between physical capital and human capital in the first four and twelve years, respectively. As for investment shocks, there is complementarity between TFP, physical capital and human capital (see figure C. 6) in the absorption of this shock in all countries except Egypt (see figure C. 7) and Israel (see figure C. 8), which show substitutability between physical investment and human capital.

From the analysis above, we can conclude that the existence of factor complementary between TFP, physical capital and human capital in the absorption of any of the three types of shocks considered, for almost all the seven developing Mediterranean countries, is in accordance with the main results from the previous sections that confirm human capital as a facilitator of technological progress.

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18 Syria is a representative country when faced with each of the three types of shocks considered. In the Appendix we include the figures with the response of the different variables to the shocks for Syria, as well as figures for the countries that do not follow the standard responses. Figures for the remaining countries are available from the authors upon request.

5. Concluding remarks

This paper presents evidence on the importance of human capital in technological change in a sample of seven developing Mediterranean countries using the empirical methodologies proposed by Benhabib and Spiegel (1994) and Benhabib and Spiegel (2002), both derived from the Nelson and Phelps (1966) endogenous growth model on the importance of human capital for technological diffusion. Additionally, we tested the importance of human capital in benefiting from the technology embodied in FDI and its role in speeding up the diffusion of ICTs. We also analysed the importance of technological shocks in explaining TFP growth and the importance of human capital in the absorption of these shocks.

The Benhabib and Spiegel (2002) non-linear specification for TFP has the interesting feature of accommodating both the hypothesis of technological convergence and the hypothesis of convergence clubs. The results of the estimation of this specification in a panel data framework using NLLS were, however, very weak. These results led us to conclude that this type of specification does not capture the influence of human capital as a facilitator of technological diffusion. Neither the logistic nor exponential paths for technological diffusion seem to apply to our samples. One possible explanation is the fact that for the smaller sample the level of human capital as a facilitator of technological diffusion is not constrained by a threshold, which would probably happen if we worked with a larger sample as the authors did, including the poorest countries in the world.

Due to the results above, we estimated the Benhabib and Spiegel (1994) linear formulation that we designated the Nelson and Phelps (1966) methodology to avoid confusion. This linear specification assumes an exponential diffusion path, i.e. convergence of the follower to the technological leader. The results were good, especially for the fixed effects and random effects models with annual data. Nonetheless, although the importance of human capital is confirmed by our estimations, its influence is very low when taking into account the value of the estimated coefficient for the technology diffusion term. To conclude, we could say that the Nelson and Phelps (1966) specification seems to capture the process of technological diffusion in our seven countries but the importance of human capital as a facilitator of technological imitation, though confirmed, is small.

The low impact of human capital on imitation activities led us to explore the hypothesis that human capital is more important for TFP growth through embodied technology diffusion than through disembodied technology diffusion. As in Borensztein, Gregorio and Lee (1998) and Lee (2001), we focused on FDI as the major channel of embodied technological diffusion which is only effective if the host country has the necessary human capital available. Although the results from our analysis support the technological catch-up hypothesis and the importance of initial human capital stocks for the TFP growth rate, due to its influence on the domestic innovation rate we were not able to confirm the existence of a complementarity between FDI and human capital. This may be due to the proxy used for the channel of technological diffusion – this analysis should be checked against an alternative channel such as imports of machinery and transport equipment. We also analysed the role of human capital in the diffusion of a particular kind of technology, ICTs, identified as a major source of technological progress in the world today. We considered both the aggregate influence of human capital, which revealed itself to be significant, and also the influence exerted by the human capital acquired through different levels of schooling. In this last case, the results support higher education as a main determinant of the diffusion of ICTs, a result in accordance with the idea that the diffusion of this kind of technology needs more than basic levels of literacy.

Finally, from the analysis of the importance of technological shocks for technological diffusion using a VAR model we concluded that there was factor complementary between TFP, physical capital and human capital in the absorption of any of the three types of shocks considered for almost all of our seven Mediterranean economies, in accordance with the main results of sections 2 and 3, namely the influence of human capital as a facilitator of technical progress. Note, however, that in section 4 we did not control its double role, in the innovation and imitation processes.

These results have to be considered with some care since: a) they are sensitive to the method used to compute the physical capital stock series and the TFP levels and growth rates i.e. TFP was computed based on a Cobb-Douglas aggregate production function that was imposed and not estimated; b) for these countries the usual concerns about data reliability apply, especially as far as human capital data is concerned; and c) other channels of technological diffusion should be considered, such as imports of machinery and transport equipment. These are tasks for future research on technological diffusion in this specific sample of countries.

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Appendix

A. The physical capital stock series

We followed the Klenow and Rodriguez-Clare (1997) methodology to compute the series of physical capital stock.

The initial stock of physical capital was estimated according to the formula,

$$\text{(A.1)} \quad \left(\frac{K}{Y}\right)_{it_0} = \frac{\left(\frac{I}{Y}\right)_i}{\gamma_i + \delta_i + \eta_i}$$

where $\left(\frac{I}{Y}\right)_i$ represents the average investment rate of country i over period 1960-2000; γ_i represents the GDP per capita average growth rate of country i over period 1960-2000; andδ_i is the depreciation rate, equal to 0.03 by assumption.

Equation (A.1) can be written as,

$$\text{(A.2)} \quad K_{it_0} = \left[\frac{\left(\frac{I}{Y}\right)_i}{\gamma_i + \delta_i + \eta_i}\right]\left(\frac{Y}{POP}\right)_{it_0} POP_{it_0}$$

To apply the perpetual inventory method we considered t_0=1959. Under this assumption equation (A.2) becomes,

$$\text{(A.3)} \quad K_{i1969} = \left[\frac{\left(\frac{I}{Y}\right)_i}{\gamma_i + \delta_i + \eta_i}\right]\left(\frac{Y}{POP}\right)_{i1960}\left(\frac{1}{1+r_{y1960}}\right) POP_{i1960}\left(\frac{1}{1+r_{POP1960}}\right)$$

where $r_{pop1960}$ represents the average growth rate of the population of country (i) over 1960-2000 and r_{y1960} represents the average growth rate of real GDP per capita of country i over 1960-2000.

Real investment of country (i) at time (t), I_{it}, is computed using the formula,

$$\text{(A.4)} \quad I_{it} = \left(\frac{I}{Y}\right)_{it}\left(\frac{Y}{POP}\right)_{it} POP_{it}$$

Finally, the physical capital stock series is computed using the perpetual inventory method, according to the formula,

$$\text{(A.\%)} \quad K_{it} = \sum_{j=0}^{t}(1-\delta)^{t-j} I_{ij} + (1-\delta)^t K_{1959}$$

B. Panel unit root tests of the TFP growth rate series

Conventional panel data econometric estimation procedures can only be applied if the TFP growth rate series is stationary. We have used the IPS (Im, Pesaran and Shin) and the LL (Levin and Lin) panel unit root tests to check whether the TFP growth rate series is stationarity. The LL unit root test assumes heterogeneity of the coefficient on the lagged variable. As we can see from the results in table B1, for all tests we can reject the presence of a unit root, so we applied classical econometric methods to estimate the Benhabib and Spiegel (2002) and the Nelson and Phelps (1966) equations.

Table 1 – Unit-Root Panel Tests for the TFP Growth Rate Series

TFP Growth rate	7 Countries Sample	13 Countries Sample
	t_δ	t_δ
LL_1	22.33 (0.0)	31.31 (0.0)
LL_2	32.63 (0.0)	47.19 (0.0)
LL_3	48.49 (0.0)	74.51 (0.0)
	$\bar{Z}$	$\bar{Z}$
ADF without trend	-12.25 (0.0)	-14.61 (0.0)
ADF with trend	-11.81 (0.0)	-13.78 (0.0)

Note: In square brackets we have the level of probability; ADF $\bar{Z}$ test is the test proposed by Im, Pesaran and Shin (2003) and t_δ test corresponds to the equations in Levin and Lin (1993) for the null of unit root. LL_1: $\Delta Y_{it} = \delta_i Y_{it-1} + e_{it}$; LL_2: $\Delta Y_{it} = \alpha_i + \delta_i Y_{it-1} + e_{it}$; LL_3: $\Delta Y_{it} = \alpha_{0i} + \alpha_{1i} T + \delta_i Y_{it-1} + e_{it}$.

C. Graphical analysis of shocks

C.1 Technological shocks

Figure C.1 – Syria, Unit shock on dTFP

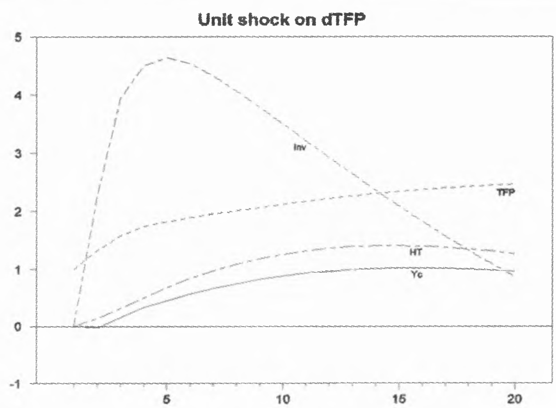
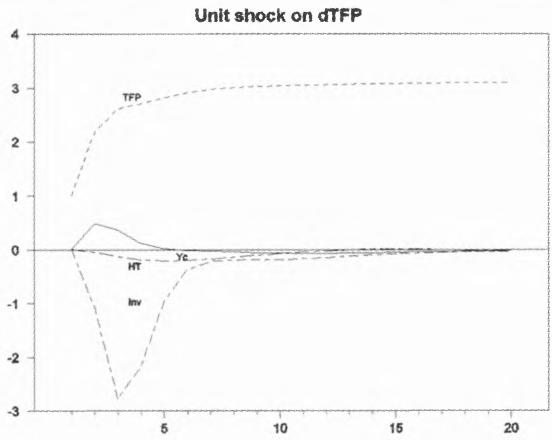


Figure C.2 – Turkey, Unit shock on dTFP



C.2. Human Capital shocks

Figure C.3 – Syria, Unit shock on HT

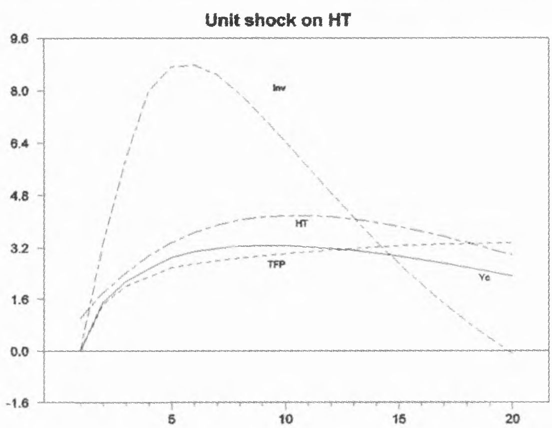


Figure C.4 – Algeria, Unit shock on HT

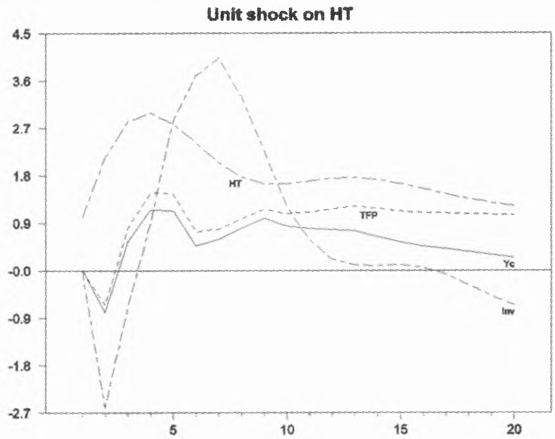
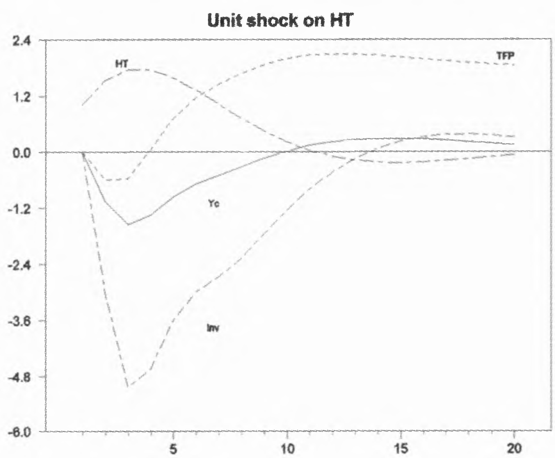


Figure C.5 – Israel, Unit shock on HT



C.3. Investment shock

Figure C.6 – Syria, Unit shock on Investment

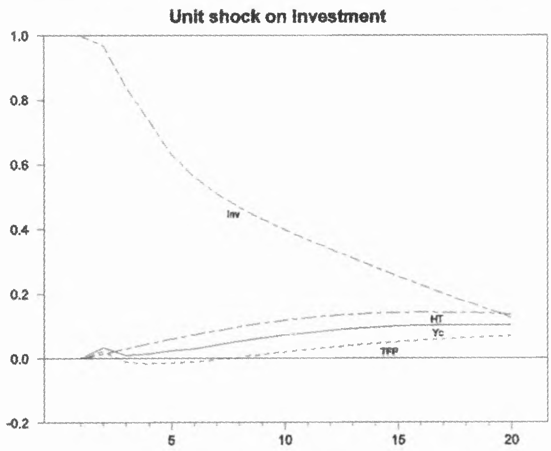


Figure C.7 – Egypt, Unit shock on Investment

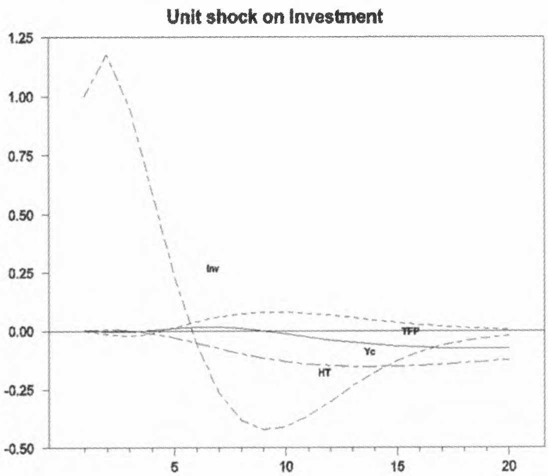


Figure C.8 – Israel, Unit shock on Investment