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Technology diffusion, services, and endogenous growth in Europe. Is the Lisbon Strategy still alive?

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Abstract

We explore the role of business services in knowledge accumulation and growth and the determinants of knowledge diffusion including the role of distance. A continuous time model is estimated on several European countries, Japan, and the US. Policy simulations illustrate the benefits for EU growth of the deepening of the single market, the reduction of regulatory barriers, and the accumulation of technology and human capital. Our results support the basic insights of the Lisbon Agenda. Economic growth in Europe is enhanced to the extent that: trade in services increases, technology accumulation and diffusion increase, regulation becomes both less intensive and more uniform across countries, and human capital accumulation increases in all countries.

Keywords: Economic integration, manufacturing and services, diffusion processes,

JEL Classification: F150, O140, O330.

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1. Introduction

In this paper, we present and estimate a continuous time model of endogenous growth, business services and technology diffusion. We explore the role of business services in knowledge accumulation and growth and we study the determinants of knowledge diffusion including the role of distance as it evolves over time. The model is estimated on several European countries, Japan, and the US. We then discuss the results of policy simulations to illustrate the benefits for EU growth of the deepening of the single market, the reduction of regulatory barriers, and the accumulation of technology and human capital. Our results lend support to the basic insights of the Lisbon Agenda as further emphasized in the Kok Report (2004). In our model economic growth in Europe is enhanced to the extent that: trade in services increases, technology accumulation and diffusion increase and become less expensive over time (economic distance decreases also as a consequence of integration), regulation becomes both less intensive and more uniform across countries, and human capital accumulation increases in all countries (a possible result of integrating national education systems).

The paper is organised as follows. Section 2 presents the model including a three country version to clarify the mechanism of technology accumulation and diffusion. Section 3 presents the estimation results. Section 4 discusses policy implications, simulation results and section 5 presents concluding remarks.

2. The Model

2.1 Conceptual framework

Over the last decade, moving from the seminal contributions by Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992), economists have increasingly looked into the issue of integrating the accumulation of technology into growth models. While the literature on technology and growth is well developed, few studies have investigated the role of business services in affecting growth through the diffusion of technology as well as technology spillovers through trade in services. We develop and estimate a model which contributes to filling this gap. Our model is articulated enough to take into account a number of channels through which the interaction between technology accumulation, services, and innovation diffusion take place in the context of EU integration. This also allows to draw a number of policy implications for the European growth strategy.

The structure of the model is as follows. Output growth is a function of (exogenous) labor and capital accumulation as well as of endogenous accumulation of technology and business services. Business services, including communication, financial services and insurance, both domestically produced and imported, grow with output and with technology reflecting the idea that the share of "advanced" services in the economy increases with technology accumulation. The role of business services in technologically driven growth is a novel feature. Indeed the literature has so far devoted little attention to the tertiary sector as driver of technology accumulation while empirical analyses have almost entirely focused on the interaction between technology accumulation and growth of the manufacturing sector.

We also take into account the role of the composition of the manufacturing sector for producing and importing business services. This can be interpreted both as the direct stimulus coming from a higher level of intermediate demand and as the result of knowledge flows associated with forward linkages or "spillovers". Moreover, technological change leads to a "splintering" process, by which services (in particular, business services) spring from the increased technical and social division of labor within production, engendering a strong interdependence between manufacturing and service activities (Francois, 1990; Diaz Fuentes, 1998).

Technology grows with output, services and, through diffusion, with foreign technology, also given the contribution of exogenous variables (human capital in both receiving and sender countries). To measure technology, we consider patent citations as a "direct measure" of innovation output. However we also consider total spending on Information and Communication Technologies as an "indirect measure" of innovation. As is well known traditional technological variables, such as R&D expenditures and patents do not capture entirely innovation in business services. In fact, although manufacturing sectors spend more on R&D and generate more patents than service sectors, if technological innovation is understood as affecting marketing, training and other activities, many services are more technology intensive than generally considered (Tomlinson, 2001). At the same time the diffusion of knowledge-intensive service industries is deeply affected by the parallel diffusion and implementation of the new information and communication technology systems (Antonelli, 1998). The intangible and information-based nature of services gives the generation and use of ICTs a central role in innovation activities and performance that cannot be captured entirely by patents (Evangelista, 2000).

The role of ICTs as "enabling technologies" is also at the basis of the "reverse product cycle" model proposed by Barras (1986) to describe the dynamics of the innovation process in services. In this view, in the first stages of the reverse product cycle, services use ICT to enhance back-office efficiency. Subsequently, learning leads to process and product innovations. Finally, the industrial sector begins to use information technologies as they increase information-intensive activities. Information and communication technologies also allow for the increased transportability of service activities by making it possible for services to be produced in one place and consumed simultaneously in another (Soete, 1987; Miozzo and Soete, 1999) thus making provision of services independent from proximity to the final user.

The role of diffusion requires some further explanation as we introduce the space dimension[1]. Domestic technology grows also to the extent that it can absorb technology produced in other regions or countries and in our model productivity growth results from innovation in different countries which is measured by patent citations in each country (a bilateral variable). In this respect our model follows Eaton and Kortum (1996).

[1] For an extensive discussion of this aspect see Peri (2004)

However, as Peri (2004) shows in his discussion of the theoretical and empirical literature the amount of foreign produced technology that can be used domestically is limited by two sets of factors: distance, which does not only carry a spatial dimension, and absorption capacity in the receiving country. We take both factors into account. As far as geographical factors are concerned we assume that the contribution of foreign technology to domestic technology accumulation grows as a negative function of distance from the countries from which flows of technology are acquired, while the impact of distance is allowed to vary over time to the extent that technological progress brings forward a reduction in the cost of technology diffusion. Bilateral citation flows, however, are not the only channel of innovation diffusion as technological accumulation also depends on imports of services.

Finally, we take into account the impact of regulation in the production and import of services, and hence on growth in two different ways. National regulation intensity depresses the production of services while uniform (and low) levels of regulation across countries favor production and import of services. Nicoletti and Scarpetta (2003) look at the impact of regulation on productivity and growth. We use their measure of product market regulation to investigate the impact of regulation on production and imports of business services. At the same time we can evaluate the positive impact on service growth of similar, and low, levels of regulation across countries. In fact services are an area where the European Commission is making large efforts to promote harmonization but is encountering several problems due to the densely regulated domestic services markets.

2.2 The model equations

The model includes the following differential equations. The dependent variable in each equation is the rate of growth of the variable so that each variable x grows at a rate *Dlogx* according to the difference between the actual (x) and the partial equilibrium value (x^d). D stands for the derivative with respect to time. The superscript d defines the partial equilibrium (desired) value of the endogenous variable as a function of endogenous and exogenous variables. Solutions for the steady state growth rates are presented in the Appendix. Endogenous variables include output

(Y), business services[2], both domestic and imported (Sh, Sm) and technology (T). α's, γ's and δ's are parameters to be estimated. In continuous time the speed of adjustment can be interpreted in terms of the mean time lag, as its reciprocal represents the time required for about the 63% of the difference between the observed and the desired variables to be eliminated (see Gandolfo 1981). The model is a panel, hence each equation refers to a number of countries. To better clarify this point and explain how we model technology diffusion a model with many countries is discussed in section 2.3.

Output

$$(1)\ \begin{cases} D\log Y = \alpha\left(\log Y^{d} - \log Y\right) \\ \log Y^{d} = \alpha_0 + \alpha_1 \log T + \alpha_{sh2}\log S_h + \alpha_{mh2}\log S_m + \alpha_3 \log K + \alpha_4 \log L \end{cases}$$

Services domestic

$$(2)\ \begin{cases} D\log S_h = \gamma_{sh}\left(\log S_h{}^{d} - \log S_h\right) \\ \log S_h{}^{d} = \gamma_{sh0} + \gamma_{sh1}\log Y + \gamma_{sh2}\log T + \gamma_{sh3}\log STR + \gamma_{sh4} loICT + \gamma_{sh5}\log REG \end{cases}$$

Services imported

$$(2')\ \begin{cases} D\log S_m = \gamma_{sm}\left(\log S_m{}^{d} - \log S_m\right) \\ \log S_m{}^{d} = \gamma_{sm0} + \gamma_{sm1}\log Y + \gamma_{sm2}\log T + \gamma_{sm3}\log STR + \gamma_{sm4}\log ICT + \gamma_{sm5}\log REG \end{cases}$$

Technology

$$(3)\ \begin{cases} D\log T = g\left(\log T^{d} - \log T\right) \\ \log T^{d} = f(\delta_j, HK, HKR, S_h, S_m, Y, dist) \end{cases}$$

As mentioned output growth is a function of (exogenous) labor (L) and capital (K) accumulation as a well as of endogenous accumulation of technology (T) and services both domestic and imported (Sh, Sm). The introduction of services in the production function (eq. 1), can be interpreted as the result of the decomposition of TFP in presence of spillovers generated by the interaction among sectors in the economy. This effect can be connected to the service sector as

[2] Business services include also Communication services and Finance and Insurance. These sectors have been chosen as qualitative studies have shown their relevance in the diffusion of technology (for a review see Guerrieri and Meliciani, 2003).

shown in Nadiri and Mun (2002), where the TFP decomposition is obtained from the correspondence between the cost function, the production function, and the inclusion among explanatory variables of the services-sector spillover-effects. Services can be treated as a production factor in the same way as intermediate goods. It follows that the model (1)- (3) can be seen as a way to endogenize the components of TFP and to take into account the feed back effects of output growth on the TFP components themselves.

Services, both domestic and imported, (eq. 2) grow with output and with technology reflecting the idea that they represent an important intermediate input and that the share of "advanced" services in the economy increases with technology accumulation. So services do not include traditional services. The relevance of technology in the production of services has been widely considered in literature (see e.g Zagler, 2003). Our innovation is that the link between services and technology is modelled and tested simultaneously with the relationship between technology and services. Services are also expressed as a function of the exogenous expenditure in information technology (*ICT*) and of the structure of the economy (*STR*) according to how the manufacturing sector is oriented towards the use of services in production. To this purpose we use the index developed in Guerrieri and Meliciani. (2003)[3]. Finally, as discussed in Nicoletti and Scarpetta (2003), we assume that higher levels of regulation (*REG*) have a negative impact on the production of services, both domestic and imported.

Technology (eq.3), grows with output, services and, through diffusion, with foreign technology, also given the contribution of human capital. Technology accumulation in each country depends both on domestic factors and on the diffusion of technology between countries. This, in turn, depends on the intensity of technology accumulation in other countries, on the impact of

[3] In particular, we take a vector measuring the use of FCB services on total value added for each manufacturing sector and, for each country, multiply it by total production in each manufacturing sector; this number is then divided by the country's total production:

$$SM_{ik} = \frac{\sum_j W_{kj} P_{ij}}{\sum_j \sum_k P_{ijk}}$$

i= country, j= manufacturing sector, k= service sector, P= production, W= weight given by the production of the service sector k used by the manufacturing sector j on the total production of the manufacturing sector j (taken from the I/O tables as an average across countries).

"distance" between countries, as well as on the ability of receiving countries to use imported technology. Human capital in the receiving country (*HKR*) measures the capacity of absorption of technology by the recipient country while human capital in the sending country *HK* measures the capacity of the latter to produce technology. We also assume that services operate as an attractor of technology in that the more developed is the service sector in the recipient country the larger is the demand for technology.

2.3 Explaining technology accumulation and diffusion. The model with many countries

The role of technology diffusion, and distance require some further explanation. Technology in country j grows as a negative function of geographical distance (*dist*) from country i from which technology is acquired. In addition we assume that the impact of distance decreases over time reflecting lower cost of transferring technology and information across space as technological progress increases productivity. However, as Peri (2004) notes, time could have a negative impact to the extent that the value of innovation in a patent decreases over time with obsolescence. As a technology variable we use patents citations. Flows of patents (*Pat*) measure the accumulation of the stock of technology. Bilateral flows of patents (Pat_{ij}) capture the diffusion of technology between two countries.

We now consider the case of n countries so as to clarify the characteristics of the process of technology accumulation and diffusion. The technology flow relations among countries give rise to a matrix whose value changes over time. In a n country case the matrix would look like the following where patent flows take place between different pairs of countries.

Origin\ Destination	**1**	**2**	**3**	**…**	**n**	**Total**
1	Pat_{11}	Pat_{12}	Pat_{13}	…	Pat_{1n}	$Pat_{1.}$
2	Pat_{21}	Pat_{22}	Pat_{23}	…	Pat_{2n}	$Pat_{2.}$
3	Pat_{31}	Pat_{32}	Pat_{33}	….	Pat_{2n}	$Pat_{3.}$
…	…	…	…	…	…	…
n	Pat_{n1}	Pat_{n2}	Pat_{n3}	..	Pat_{nn}	$Pat_{n.}$
Total	$Pat_{.1}$	$Pat_{.2}$	$Pat_{.3}$	…	Pat_{3n}	$Pat_{..}$

The stock of technology in each country evolves over time from t-1 to t as follows, given the initial condition of the stock of knowledge *T*. In the n countries case for each country j we will have:

(4) $T_t^j = T_{t-1}^j + Pat_{ij}$ with i=1,… n

Where the first subscript of *Pat* indicates the sender country and the second subscript the recipient country. In (4) the process starts at *t*-1 while Pat_{ii} indicates the domestic accumulation of patents and Pat_{ij} indicates the amount of technology produced in country i that is actually received by country j.

Technology accumulation in each country can be disaggregated in the following elements: technology accumulated domestically and the amount of technology accumulated in each of the other countries that is transferred to the recipient country through diffusion. In addition we consider transfer of technology generated in the "rest of the world", e.g. in the US. For each country we specify a domestic technology accumulation component (Pat_{ii}) and an imported technology component from each of the other countries considered (Pat_{ij}) including technology imported from the "rest of the world". The impact of technology diffusion depends on distance as well as on the sending and receiving countries' human capital. As mentioned, while distance affects diffusion negatively, the impact of distance decreases over time (*t*) if technological progress and/or integration decrease the costs of transferring technology. However, over time the value of technology decreases with obsolescence. So over time the impact of diffusion increases if the first effect prevails. We consider these two effects by separating the overall impact of distance into two components, a fixed component (coefficient *a*) and a time-varying component (coefficient *b*) while the coefficient β_1^{ij} captures the overall impact of technology transfer (net of the impact of human capital) which may include elements additional to "distance"[4]

In the n country case, we have n×(n+1) equations to describe technology accumulation, where the last (n+1) equations represent the technology transfer from the rest of the world to the n countries of interest. In the estimation analysis we consider as the rest of the world the US and Japan. In particular for each country j (with j=1,…n) we will have:

[4] Such as cultural or linguistic factors, as discussed in Peri (2004)

Technology

$$(5)\quad \begin{cases} D\log Pat_{ij} = \beta^{ij}\left(\log Pat_{ij}^{d} - \log Pat_{ij}\right) \\ \log Pat_{ij}^{d} = \beta_0^{ij} + \beta_1^{ij}(a\ +\ b\ t)dist_{ij} + \beta_2^{ij}\log HK_i + \beta_{3sh}^{ij}\log S_{hj} + \beta_{3sm}^{ij}\log S_{mj} \\ \qquad + \beta_4^{ij}\log Y_j + \beta_5^{ij}\log HKR_j \end{cases}$$

with i=1,… n

$$(6)\quad \begin{cases} D\log Pat_{USj} = \beta^{USj}\left(\log Pat_{USj}^{d} - \log Pat_{USj}\right) \\ \log Pat_{USj}^{d} = \beta_0^{USj} + \beta_1^{USj}(a\ +\ b\ t)dist_{USj} + \beta_2^{USj}\log HK_{US} + \beta_{3sh}^{USj}\log S_{hj} + \beta_{3m}^{US1}\log S_{mj} \\ \qquad + \beta_4^{USj}\log Y_j + \beta_5^{USj}\log HK_j \end{cases}$$

In each of the n countries the stock of technology is then given by

$$(7)\quad T_j = T_j^0 + \int_0^t (Pat_{1j} + Pat_{2j} + Pat_{3j} + ... + Pat_{nj} + Pat_{usj})dt$$

To summarize, for each country j, the following are the endogenous and exogenous variables

Endogenous

Y_j, Pat_{ij}, Pat_{USj},, T_j,, S_{hj}, S_{mj}

Exogenous

HK_i, HKR_j, STR_j, ICT_j, REG_j, $dist_{ij}$, L_j, t

with i, j =1,..n

The model is a set of non linear differential equations for each country. The degree of the system is one. Eqs (7) define the domestic stock of technology in each country as the cumulated flow of patents obtained both through production and diffusion. Note that such equations may be written in differential form:

$$DT_j = Pat_{1j} + Pat_{2j} + Pat_{3j} + ... + Pat_{nj} + Pat_{usj}$$

The non linearity of the system is introduced through these equations as Pat_{ij} and T_j are not necessarily expressed in logs. Country fixed effects are not shown for sake of simplicity but they are included in each equation of the model replacing, as usual, the constant term with as many constants as the number of countries.

Additional constraints have to be introduced on distance, expressed in kilometers:

(8) $dist_{jj} = 0$

(9) $dist_{ij} = dist_{ji}$

3. Estimation

The model is estimated as a dynamic continuous time panel through the ESCONAPANEL program developed by Cliff Wymer (2002). We consider nine European countries, the US and Japan. We use a panel data for 1988-1998 period. Due to limitations in data availability on services[5] we consider the following countries in Europe: Austria, Germany, Denmark, Finland, France, UK, Italy, Holland, Sweden. We consider US and Japan as representative of the "rest of the world". Data[6] on output (GDP), services, human capital and physical capital are taken from the OECD database. Data on ICT expenditures are taken from EUROSTAT. Data on the bilateral technology flows (Pat_{ij}) are taken from the US patent office and are represented by the citations in the patents between countries. A citation received from country *a* by country *b* indicates a transfer of technology from the latter to the former. Citations internal to one country are not treated as technology transfers. Citations may be backward or forward if referred respectively to inventions discovered in the past or, from the point of view of the cited (source) country, in the future. This is not irrelevant if one wants to evaluate the transfers of technology with a limited time series given the risk to neglect potential citations in the initial and final part of the series. To cope with this problem we follow the method indicated by Hall, Jaffe, and Trajtenberg (2001) where it is suggested to divide each citation by the average number of citations received by other patents in the same cohort (fixed approach)[7]. Data on regulation are from Nicoletti, Scarpetta, and Boylaud (2000) and refer to product market regulation. Data for the structure indicator are

[5] For some missing data -largely imported services- we adopt the *multiple imputation* method applied to the whole set of data taking into account the model specification. We thank Prof. G. Espa for helpful assistance and suggestions in this respect.

[6] See appendix for a more detailed description of data sources.

[7] Indeed other methods, named structural, are suggested. They refer to a specific function to be estimated that should fit with different distorting effects to be eliminated (such as pure time effect, field effect etc). This method, while more formally appealing in its specification, embeds some strong hypothesis in the definition of the function to be used. For this reason we adopt the *fixed approach*.

from Guerrieri and Meliciani (2003). Nominal data have been deflated and homogenized by means of the PPP OECD index.

FIML estimation results of the continuous time parameters are reported in table 1. Point estimates of parameters are all significant at least at the 95% level and carry the expected sign (which is always positive with the exception of the two regulatory variables and geographical distance). We omit results of single country fixed effects as these have turned out to be insignificant. However two country group variables –*beu* and *ceu* – that turned out to be significant- are reported in the results. The term 't-ratio' denotes the ratio of a parameter estimate to the estimate of its asymptotic standard error, and does not imply that this ratio follows a Student's t-distribution. This ratio has an asymptotic normal distribution and so in a sufficiently large sample it is significantly different from zero at the 5 per cent level if it lies outside the interval +/- 1.96 and significantly different from zero at the one per cent level if it lies outside the interval +/-2.58.

We comment the estimation results by looking at each equation at the time. Results for Eq. (1) show that output is positively correlated with the stock of technology, the stock of capital and labor as well as with domestic and imported services. Note that the elasticities of the two components of services with respect to output are very similar (their difference is not significantly different from zero).

Table 1.

Equation number	Explanatory variables	Point estimation	asymptotic s.e.	t
1 (output)	T	0.78009	0.01729	45.1
1	Sh	0.10397	0.00203	51.3
1	Sm	0.09405	0.00637	14.7
1	K	0.70025	0.01562	44.8
1	L	0.52626	0.00796	66.9
1	adj. speed	0.00322	0.00128	2.50
2(domestic services)	Y	0.50726	0.00463	60.1
2	T	0.35290	0.00463	76.1
2	beu	4.9995	0.00045	10917.8
2	Regulation	-0.30311	0.00478	63.3
2	Structure	0.48295	0.00885	54.5
2	ICT	0.18024	0.00776	23.2
2	adj. speed	0.00309	0.00037	8.2
2’(imported services)	Y	0.50915	0.00752	67.7
2’	T	0.52334	0.00985	53.1
2’	Ceu	2.08367	0.04997	41.7
2’	Regulation	-0.30546	0.00403	75.8
2’	Structure	0.48160	0.01120	42.9
2’	ICT	0.17389	0.01159	14.9
2’	adj. speed	0.00312	0.00058	5.31
4-6 (technology)	Sh	0.10423	0.00268	38.8
4-6	Sm	0.49110	0.00632	77.7
4-6	Y	0.36370	0.00822	44.2
4-6	HK sender c.	0.472371	0.01375	34.3
4-6	HK receiving c.	0.52622	0.01325	39.7
4-6	Overall impact	0.01530	0.00070	21.6
4-6	Distance	-0.01953	0.00028	67.4
4-6	Time	1.03504	0.02242	46.2
4-6	adj. speed	0.00725	0.00134	5.39
Log-likelihood value = 0.1586610E+04				
R2 = 0.701413				
F=296.2435				

Results for Eq. (2) and (3) can best be considered jointly as the two equations have the same structure and the estimated values for the corresponding parameters are also very similar. Both domestic and imported services are positively correlated with output and with technology accumulation. However, while the output elasticities are not significantly different from one another, technology accumulation does affect imported services more than domestic service production. This result highlights the importance of trade services integration in European technology accumulation and hence on growth, an outcome that is confirmed by further results below.

The impact of EU integration is confirmed by the estimation results of the parameters associated with *beu* and *ceu.* To assess the impact of national characteristics we introduced country dummies all of which turned out to be insignificant. We then tried with a number of country aggregations; parameters *beu* and *ceu* reflect the impact on service production and trade of a group of countries[8] that, in addition to unobservable characteristics, share the lowest intensity of regulation as measured by the OECD indicators. The positive and significant value of these parameters signals that higher service production and trade in this group of countries may be associated with the positive impact of low regulatory barriers as well as of regulatory harmonization in the EU but also to a relatively low level of other unobservable impediments to production and trade of services also possibly associated with a deeper level of integration.

The impact of national levels of regulation is captured by the parameters associated with REG in both equations. The estimated parameters are both significant and negative as well as not significantly different from one another. These results indicate that higher levels of regulation have a negative impact on production and trade of services. The structure of manufacturing and service sector specialization exerts a significant impact (also of similar magnitude) on both domestic and imported services, thus confirming the results obtained in Guerrieri and Meliciani (2003). ICT investment also has a positive and significant impact on both service variables. Both adjustment speeds are low and significant, however the adjustment speed for domestic services is lower than the output adjustment speed while the adjustment speed for imported services is higher suggesting that trade integration in the service sector proceed at a somewhat faster pace.

[8] The countries are Austria, Denmark, Germany, Netherlands, Sweden

Let us, finally, discuss the results of the technology equation (eq. 4). Technology accumulation in each country depends both on domestic accumulation factors and on the diffusion of technology between countries. This, in turn, depends on the intensity of technology accumulation in other countries, on the impact of “distance” between countries, as well as on the ability of receiving countries to use imported technology. Our results help clarify the contribution of each of these factors. Technology accumulation is positively correlated with output and with domestic services, although the estimated value of the elasticity of this latter variable is relatively low. The elasticity of technology with respect to imported services, on the contrary, is quite high. Taken together with the results discussed above our results point to a virtuous interaction between technology and trade in services

Human capital also exerts, as expected, an important effect on technology accumulation both in sender countries and in receiving countries, and the point estimates of the two elasticities are very similar. One important implication of this result is that human capital accumulation in any country affects technology accumulation for two reasons. First because it increases the domestic ability to use imported technology, second because it increases the domestic stock of technology that can be exported to other countries.

The impact of technology diffusion also depends on the distance factor. The overall positive impact of diffusion is negatively affected by distance, as expected, and positively effected by time confirming the idea (see e.g. Keller 2002) that distance should not be considered a geographical factor but an economic factor whose impact decreases over time thanks to a decrease in the cost of transferring technology and information across space. Finally, and not surprisingly, the adjustments speed is low while highly significant.

4. Policy implications

Over the last few years a number of empirical studies, also in the wake of the launching the and reassessment of the Lisbon strategy (see Rodrigues 2004, Kok 2004) have investigated the gains in terms of output that can be obtained in Europe by deregulation, liberalization, as well higher knowledge accumulation.

Guiso, et al (2004) have assessed the growth gains for EU countries that would be obtained if EU financial markets were to reach a degree of “optimal” integration, as represented by the US financial market benchmark. They also consider a “suboptimal” case were the benchmark is represented by a degree of EU financial integration matching that of UK, the Netherlands, and Sweden. The IMF has presented, in the September 2002 edition of the World Economic Outlook (WEO 2002), simulation results of the impact of product market liberalization and increased labor market flexibility on EU output levels. Bayoumi, Laxton and Pesenti (2003) have computed the output gains deriving from extensive deregulation in European product markets. The gains amount to as much as a 7% increase in GDP and a 3% productivity increase. The European Commission (2003) has carried out a number of policy simulations of the gains from the implementation of measures included in the Lisbon strategy. Interestingly this analysis shows that deregulation alone (i.e. bringing the level of EU product market regulation down to the US level) would not be enough to fill the gap with the US in terms of per capita GDP. To reach this target Europe would have to increase spending in R&D, education, and ICT. The combination of these measures could increase the potential growth rate by 0.5-0.75 per year over a period of 5 to 10 years.

The analysis we have developed in this paper in the previous paragraphs carries several policy implications along similar lines to the studies mentioned above and it provides support to the general ideas on which the Lisbon strategy has been set up. In our model growth is positively affected by technology accumulation and diffusion as well as by market and regulatory integration. In addition, business services play a fundamental role in the process. The idea that growth is enhanced through a virtuous circle of technology accumulation, services and integration is confirmed by our empirical analysis.

In this paragraph we further develop this idea by performing a number of policy simulation to identify the contribution to growth of several policy actions that can be thought as parts of the implementation of the Lisbon Agenda. Note that the policy actions we discuss are, with some exceptions, under the jurisdiction of national authorities. Partial exceptions relate to the decrease in diffusion costs (which may be thought of as partially determined by EU level networks). As Kok (2004) discusses the disappointing performance of the Lisbon Agenda can be largely explained by lack of action at the national level

We perform the following simulation exercises[9]: a) elimination of the impact of regulation on services; b) deeper integration in the market for services; c) doubling of ICT spending; d) halving of diffusion costs as represented by distance; e) increase of 5% in the level of human capital in both receiving and sending countries; f) a combination of c) and e); g) a combination of a), c), and d).

We report the results of the simulations carried out over a ten year period for the rates of growth of the four endogenous variables, namely output, domestic and imported services, and technology (see figures 1-4) as differences with respect to the baseline (i.e. where the model is simulated with parameters taking on the estimated values). All of the simulated policy measures have a positive impact on output but the effects vary both in size and in pattern over time.

A persistent and significant impact over output is obtained in cases b) deeper integration in the market for services, and d) halving of diffusion costs. In both cases the quantitative impact is similar with rate of growth of output being about 1% higher over the simulation period. Interestingly, the impact of deeper integration in the market for services and of halving the diffusion costs, are also slightly increasing over time. The impact of doubling of ICT investment is also positive but much lower than the previous two cases and slightly decreasing over time.

The elimination of the effect of regulation on services also produces a positive and persistent effect on the rate of growth of output but this effect is lower than in the case of deeper integration in the market for services. Two reasons account for the different size of the impact. First, the impact of deregulation on output is indirect, i.e. it affects output through the higher provision of services, both domestic and imported. Second, deeper integration in the market for services could to some extent be associated with a common regulatory environment, partially captured through parameters *beu* and *ceu*.

A higher level of human capital, both in the receiving or in the sending country, -cases e1 and e2- exerts an initially limited but increasing impact on output growth through the effect on technology accumulation. It is interesting to note that this effect is increasing but significantly higher when combined with a larger amount of ICT spending (case f).

9 Simulations with the non linear model have been carried out through Wymer's APREDIC program (Wymer 2002).

If we consider the impact on services we note that all measures determine a output higher rate of growth, with respect to baseline, of both domestic and imported services. The largest impact is obtained through deeper integration in service markets (case b). A significant impact is also obtained in cases a) and c), the elimination of the impact of regulation and the increase in ICT spending. A much smaller impact is obtained in cases d) and e), lower diffusion costs and higher human capital availability. This last result is not surprising as these two cases exert a stronger impact on technology accumulation than on services. Interestingly, in all cases considered the impact is stronger on imported rather than on domestic production of business services, suggesting that the policy actions we consider might increase integration and hence trade in services.

Finally, we consider the impact on technology. In all cases the level of the stock of technology is higher with respect to baseline when the stock of human capital both in sending and receiving countries is increased. This last effect sheds some additional light on the interaction between technology accumulation and growth. The ultimate driver of growth is technology accumulation and the latter is strongly supported by human capital accumulation. However, for such a mechanism to produce significant effects a rather lengthy transmission mechanism is needed so that it is fair to say that this is a long term process. In the medium term growth is more effectively supported through a stronger diffusion of existing technology and a stronger contribution of services to the process.

5. Conclusions

In conclusion, our results show that EU output growth can be significantly increased if the availability of business services and the accumulation of knowledge are enhanced. These results, in turn, can be obtained through an improved regulatory environment, through deeper integration in service markets, and a stronger impact of technology diffusion. Higher ICT investment and, especially, higher availability of human capital are instrumental to such a strategy. Our results show that this three pronged strategy –deregulation, deeper integration, and more effective technology diffusion- determines a virtuous circle of output growth, provision of services, and knowledge accumulation in line with the objectives of the Lisbon strategy. Our results also show that these strategies require different time horizons to be effective. In the long run growth is best supported through stronger technology accumulation, itself supported by larger availability of human capital. In the medium term a better regulatory environment, more ICT investment and a larger availability of business services can provide a stronger boost to growth.

Data sources

HK, HKR: "Main Science and Technology Indicators" 1999, 2001 (vol 1, 2)

L, K: Penn World Tables www:NBER.org

Sh: STAN database, OECD.org

Sm: OECD International trade in services database, OECD.org

Reg: G. Nicoletti, S. Scapretta and O. Boylaud(2000), Summary Indicators of Product Market Regulation with an Extension to Employment Protection Legislation, EC Department OECD, WP 226

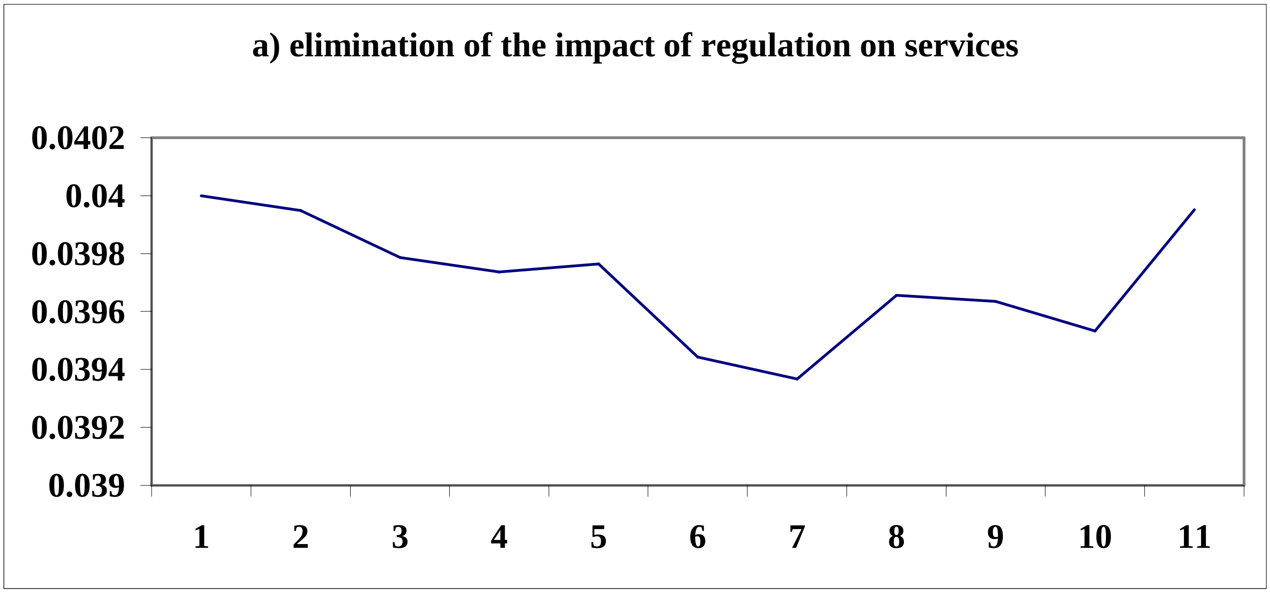
IT: OECD (2000), Information Technology Outlook. ICTs, E-commerce and the Information Economy, OECD, Paris

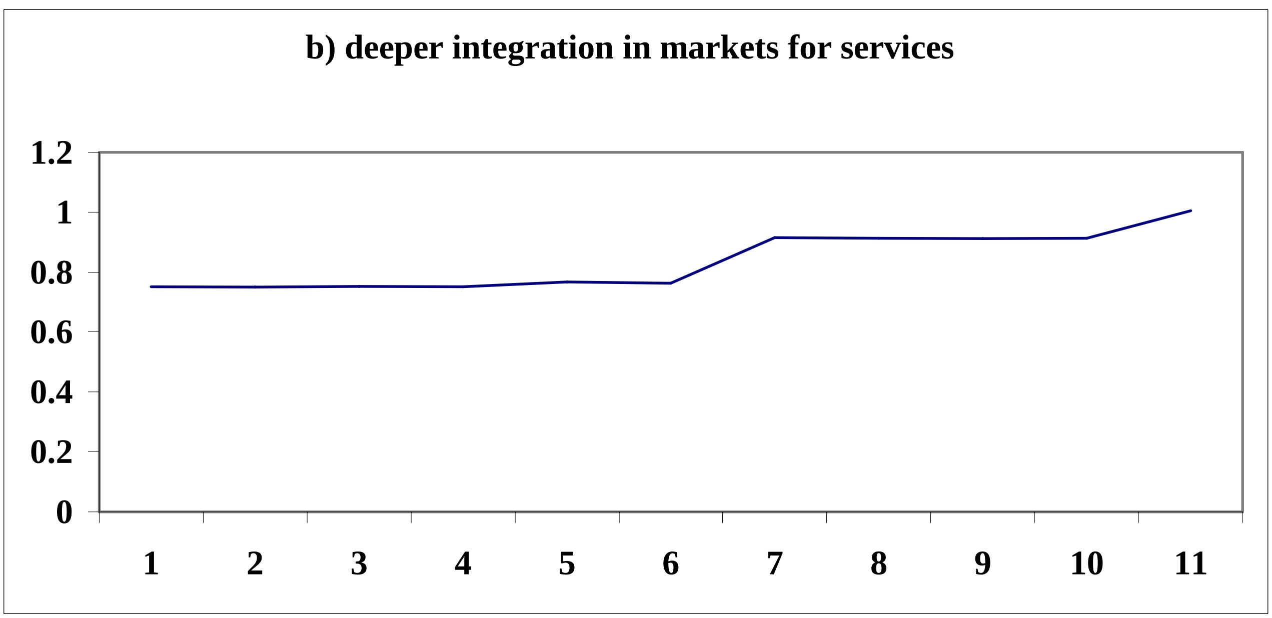
Dist: KM between capitals

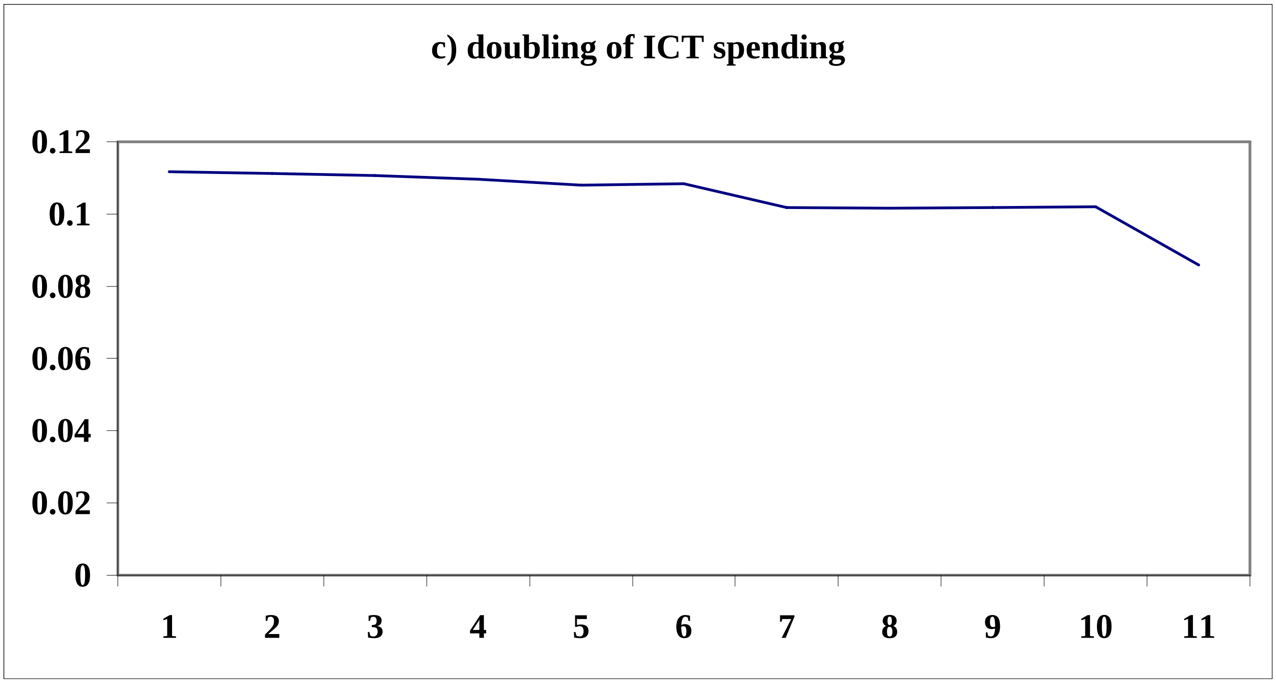
Pat: US patent office. NBER.org

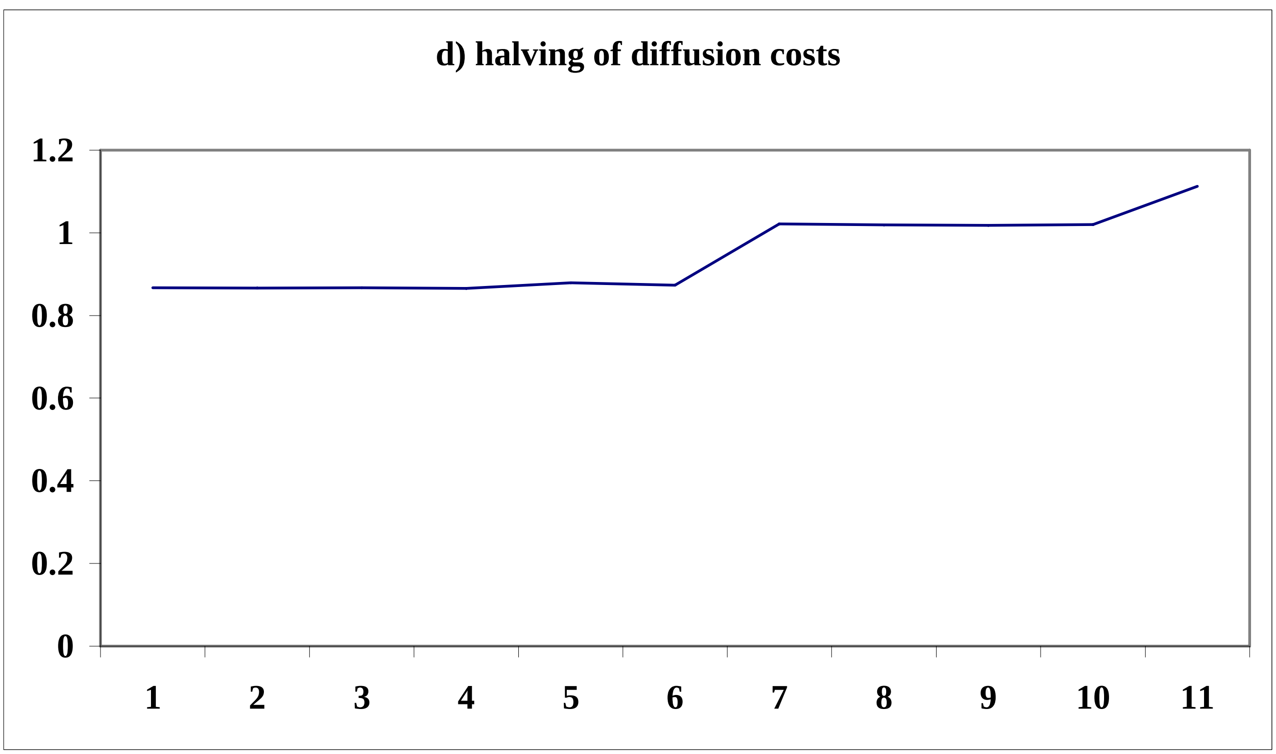
STR: P. Guerrieri and V. Meliciani (2004), “International competitiveness in producer services”, Paper prepared for the Conference: “What Do We Know About Innovation? A Conference in Honour of Keith Pavitt”, University of Sussex, 2004

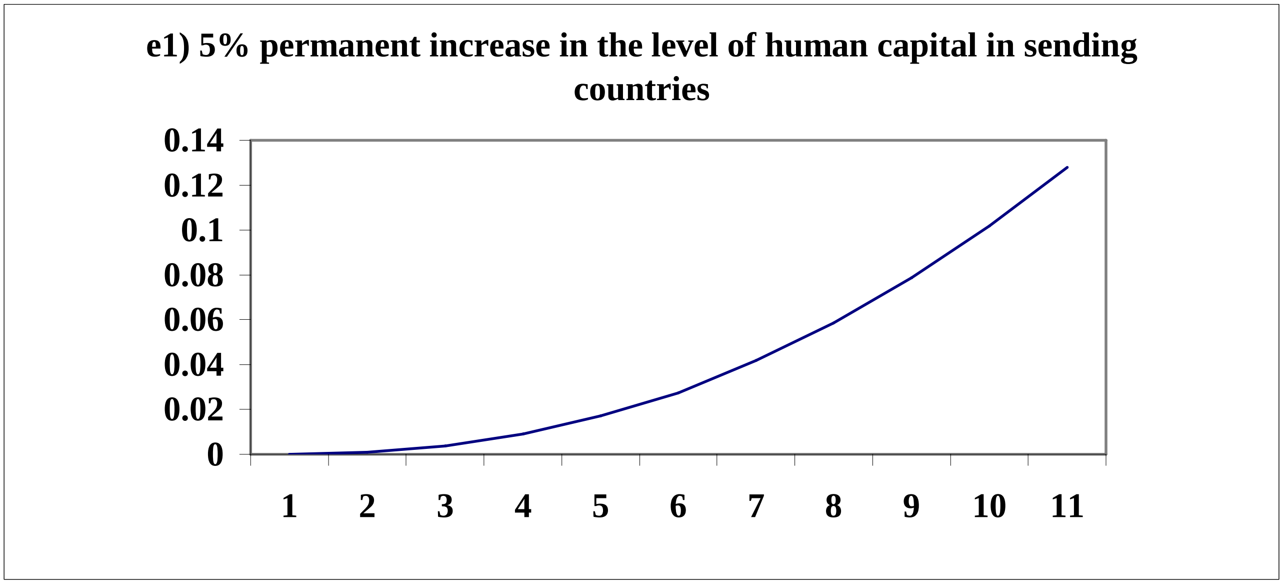
Figure 1. Output. Difference from baseline.

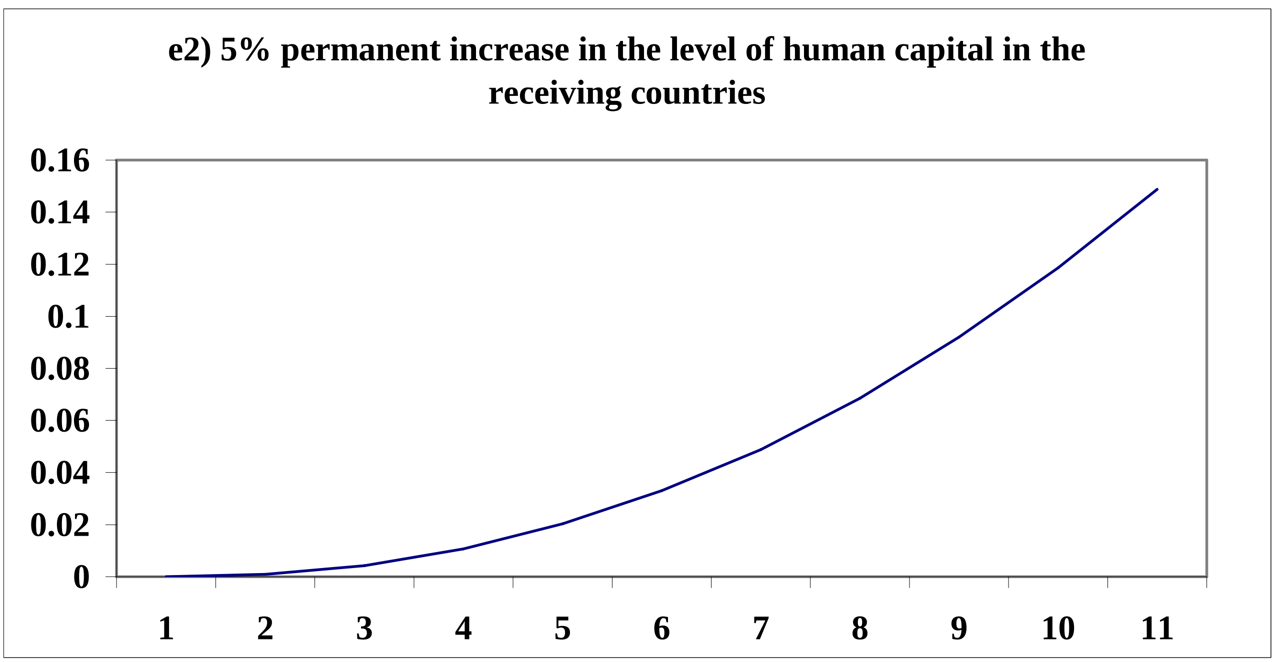


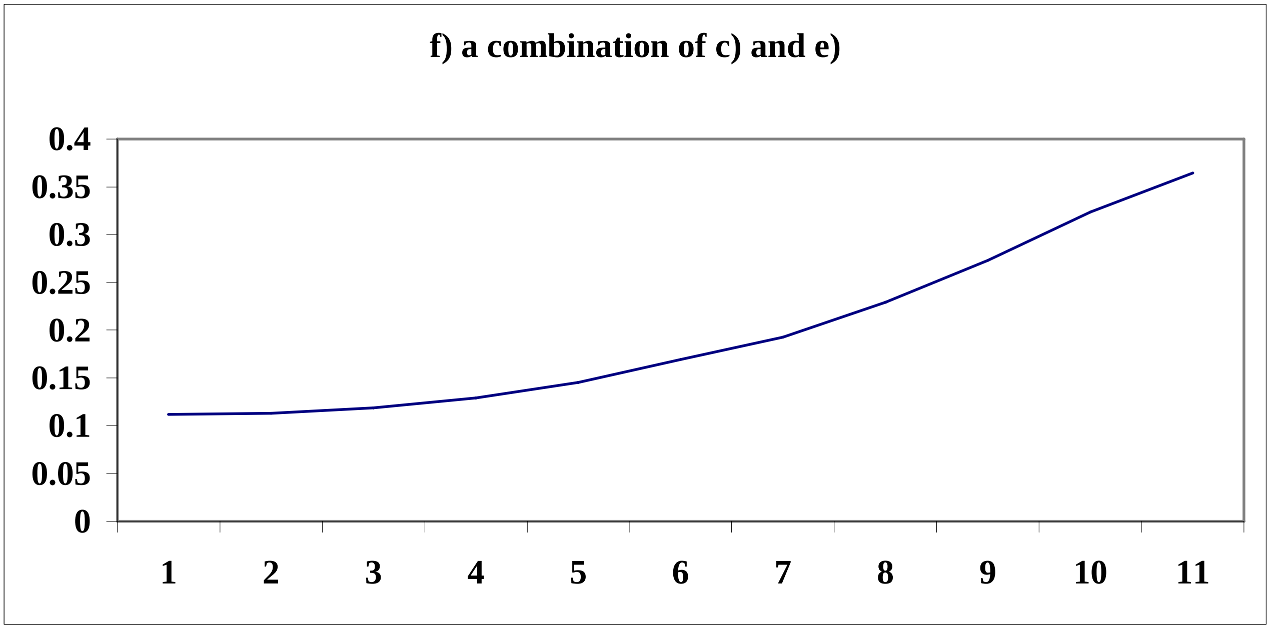



c) doubling of ICT spending
0.12
0.1
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11


d) halving of diffusion costs
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
10
11


e1) 5% permanent increase in the level of human capital in sending countries
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11


e2) 5% permanent increase in the level of human capital in the receiving countries
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11


f) a combination of c) and e)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
6
7
8
9
10
11

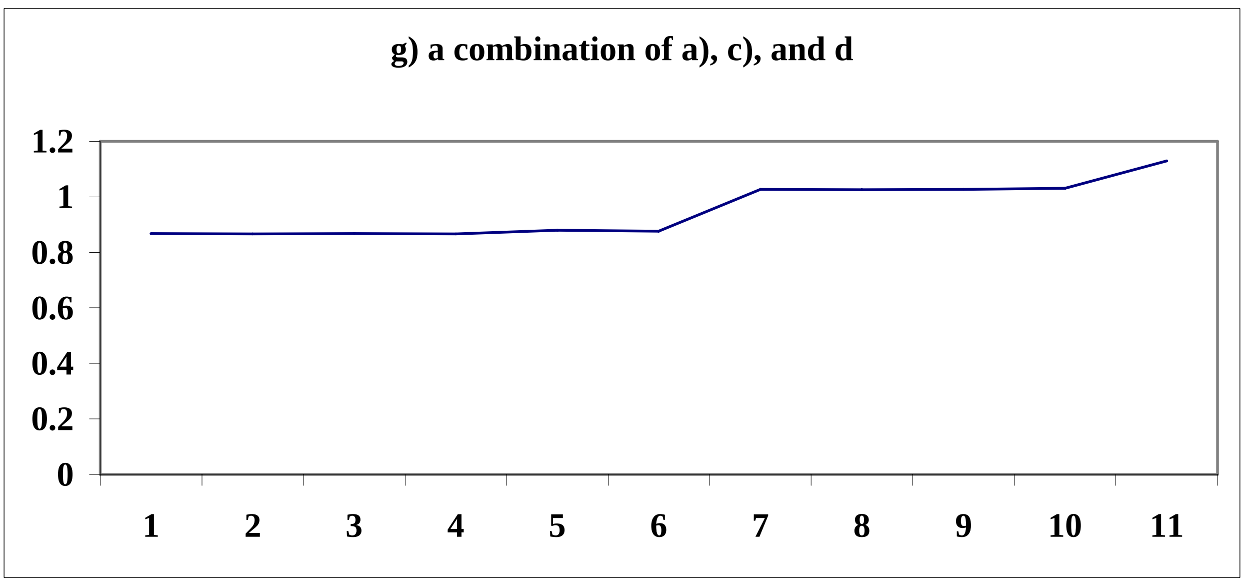
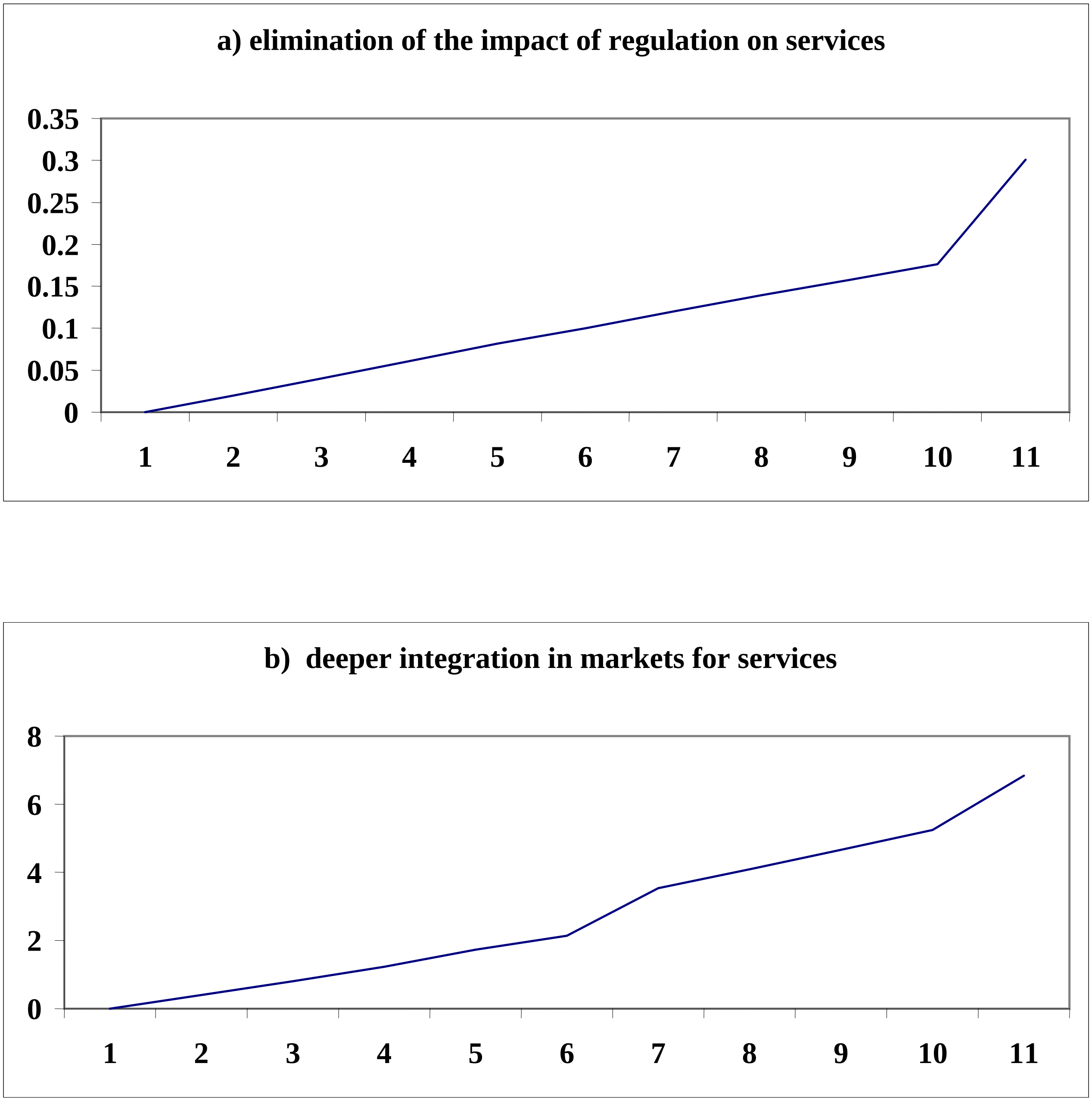
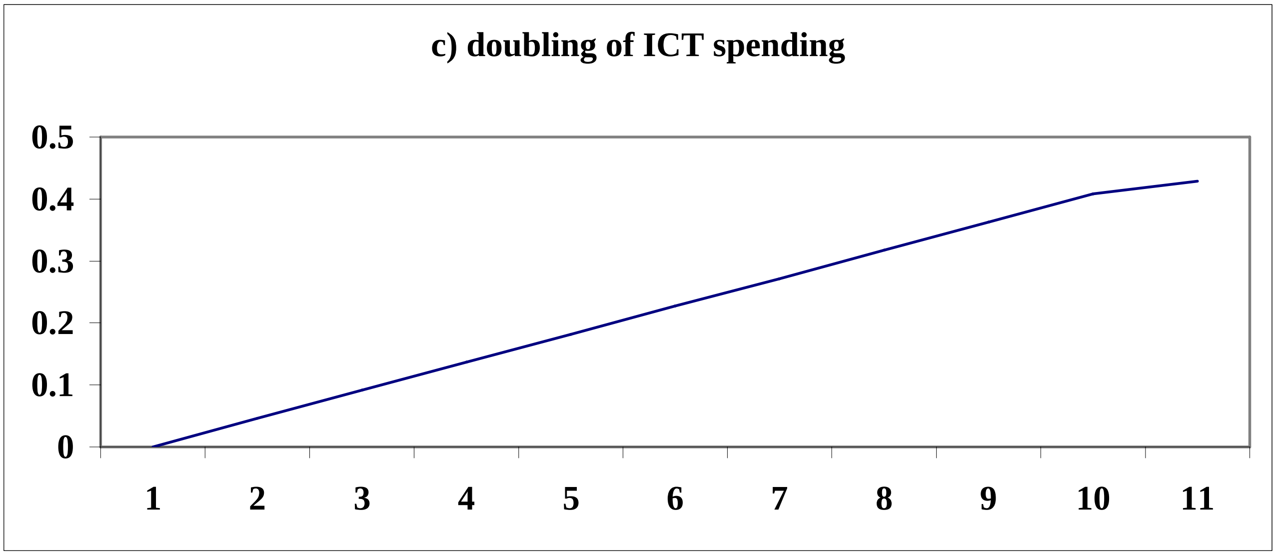
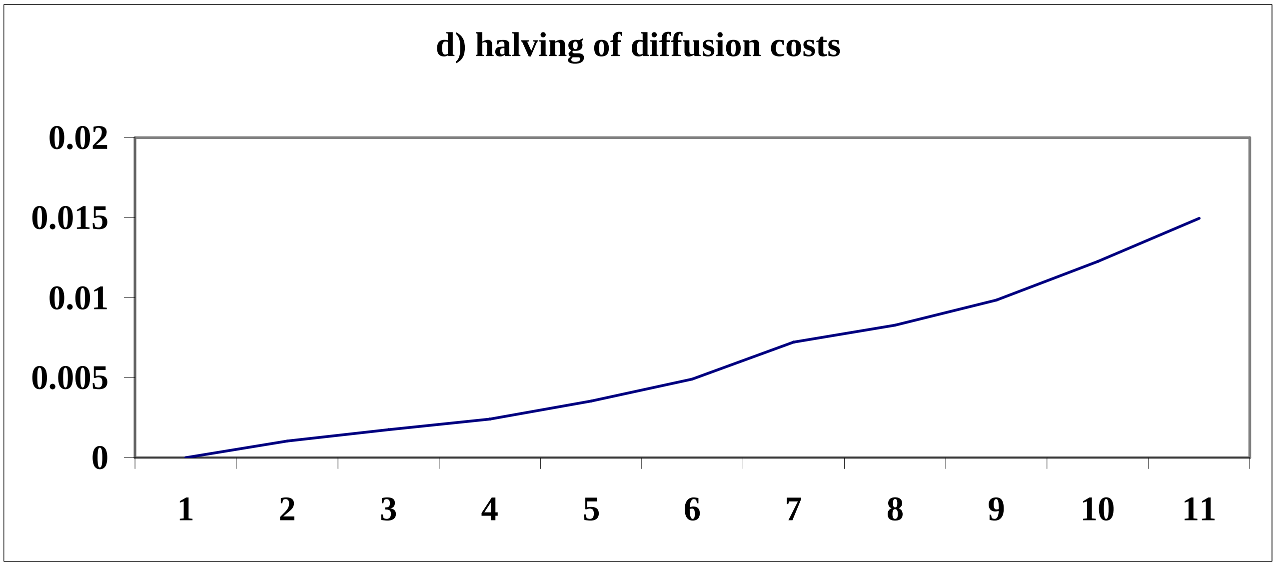
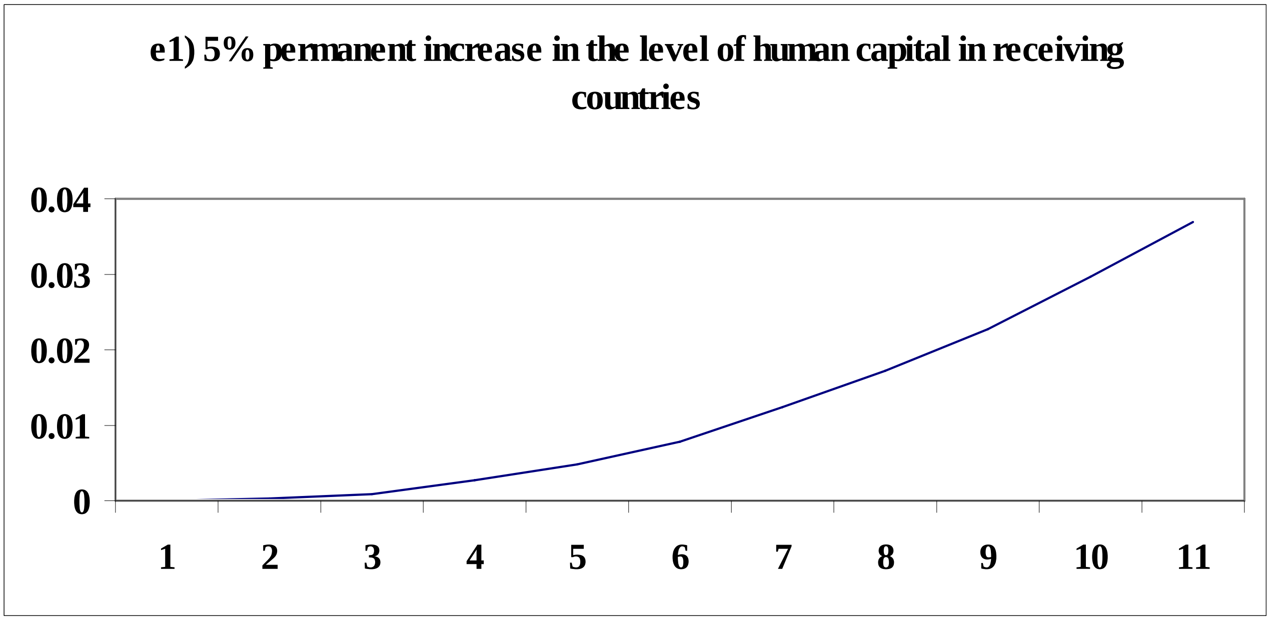

g) a combination of a), c), and d
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
10
11

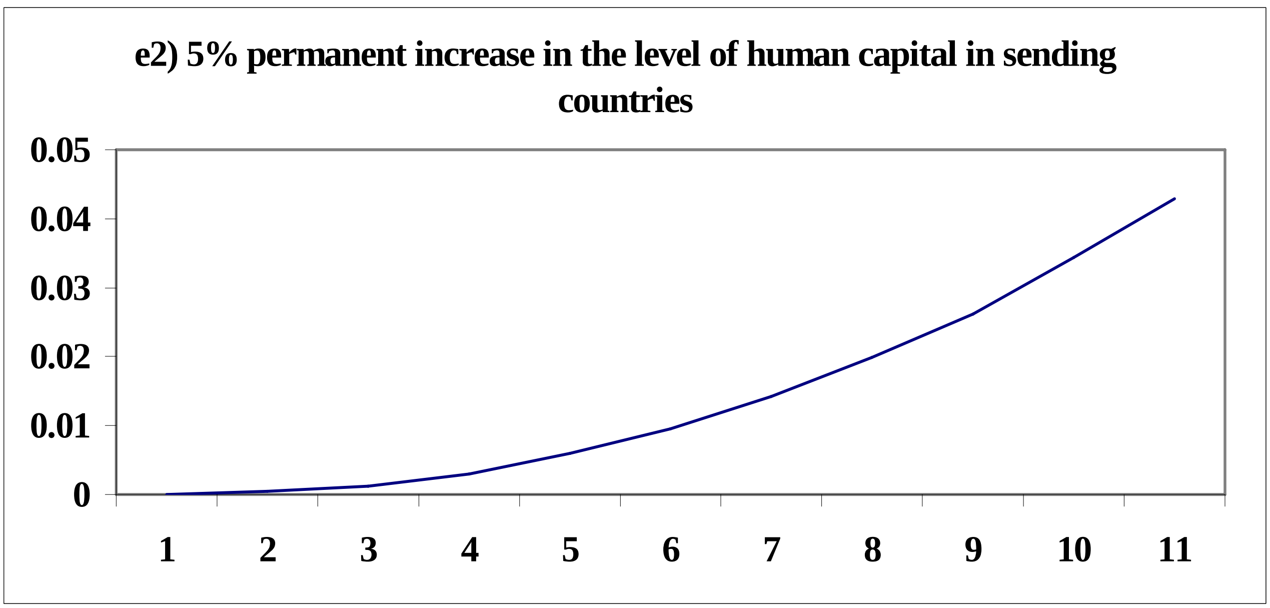
Figure 2. Domestic services. Differences from baseline.

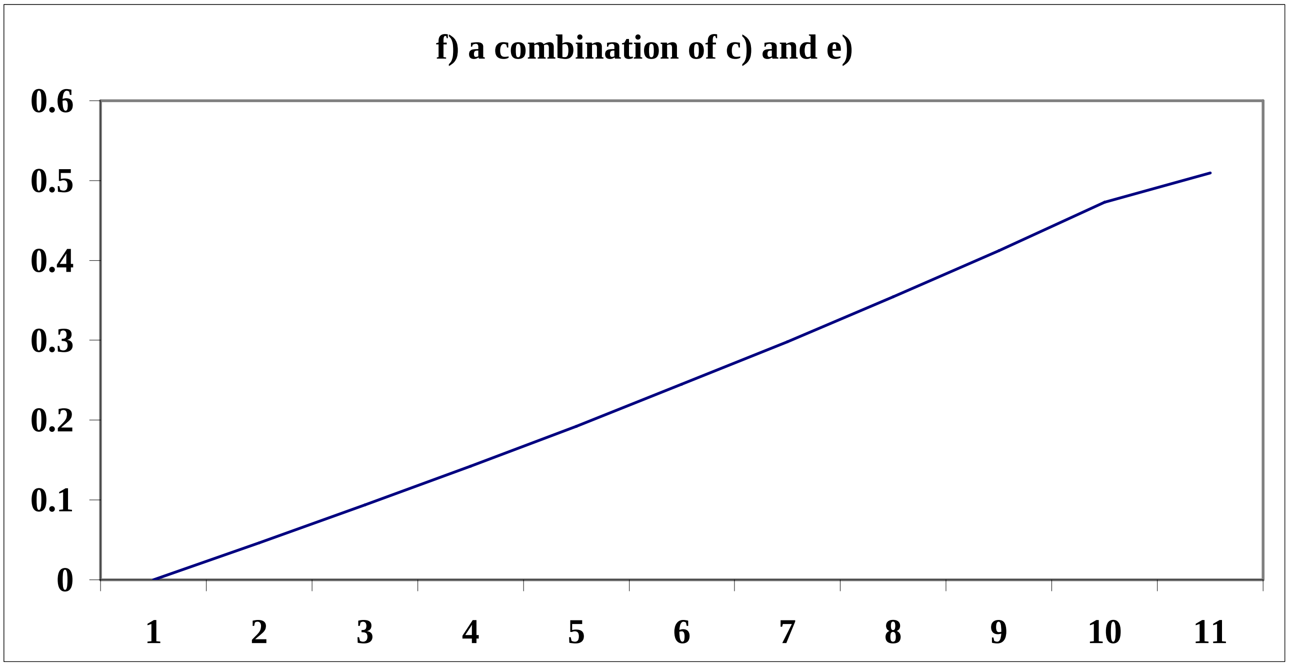



c) doubling of ICT spending
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11


d) halving of diffusion costs
0.02
0.015
0.01
0.005
0
1
2
3
4
5
6
7
8
9
10
11


e1) 5% permanent increase in the level of human capital in receiving countries
0.04
0.03
0.02
0.01
0
1
2
3
4
5
6
7
8
9
10
11


e2) 5% permanent increase in the level of human capital in sending countries
0.05
0.04
0.03
0.02
0.01
0
1
2
3
4
5
6
7
8
9
10
11


f) a combination of c) and e)
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11

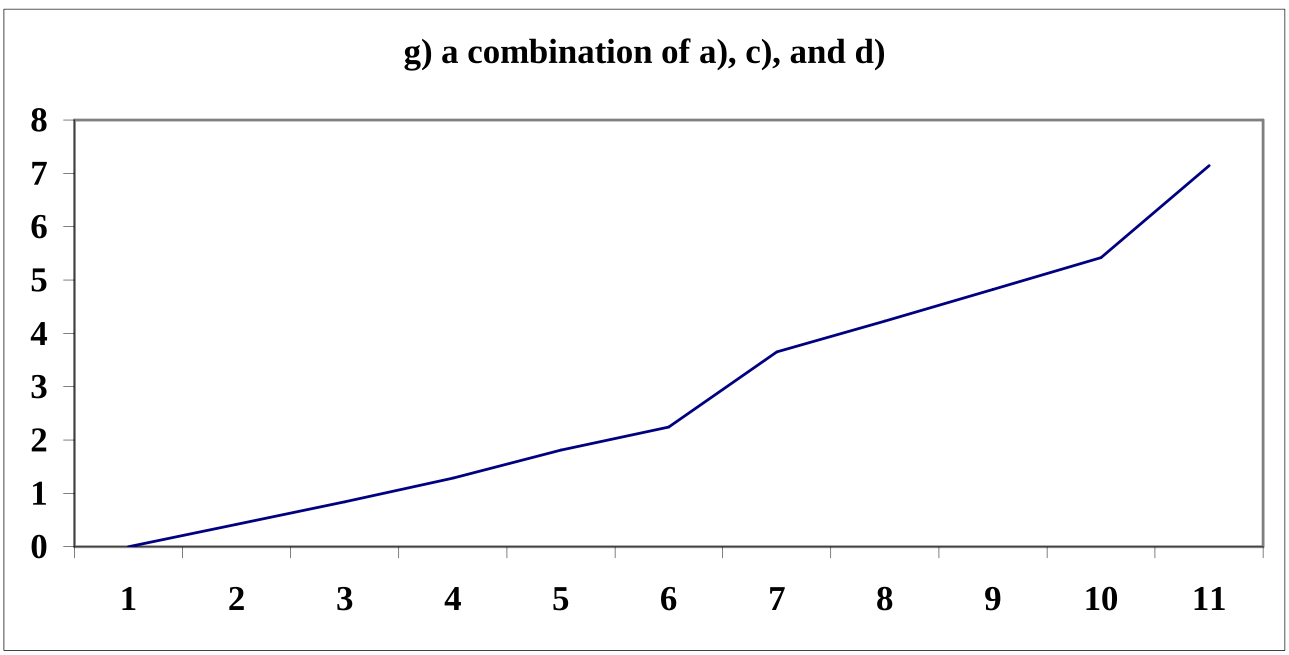
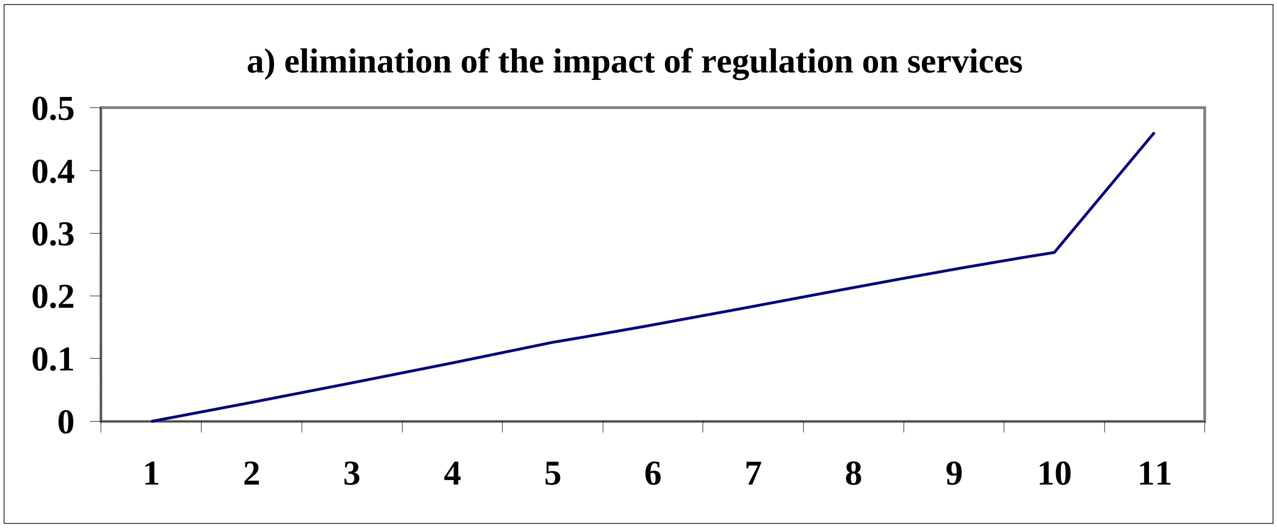
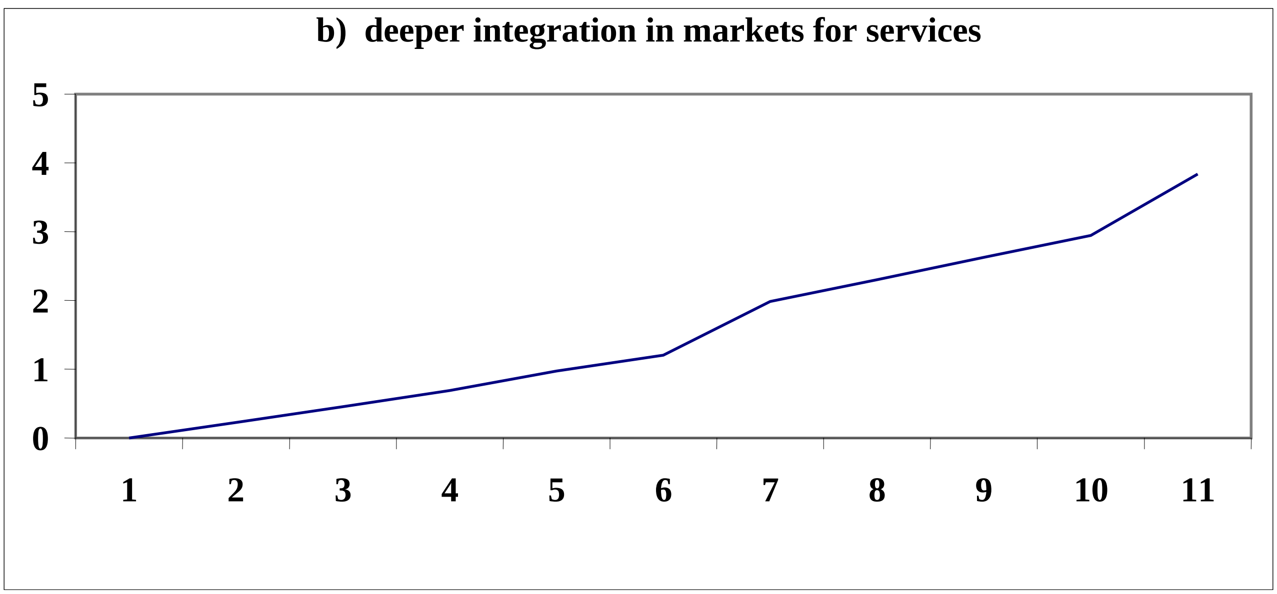
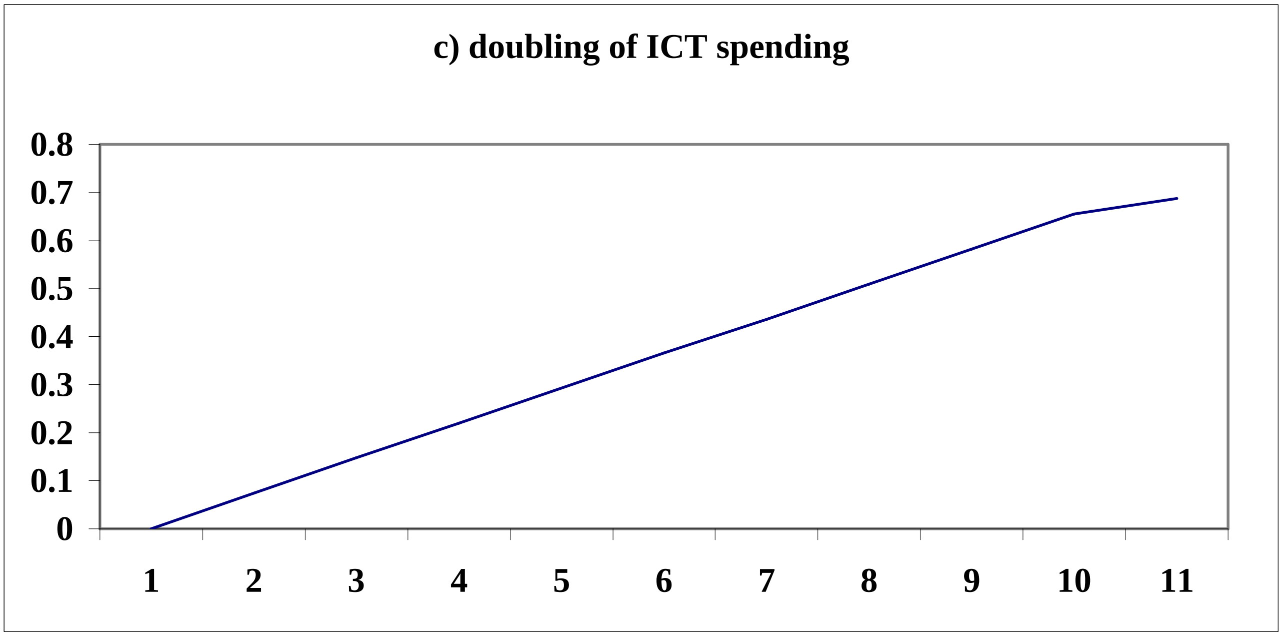
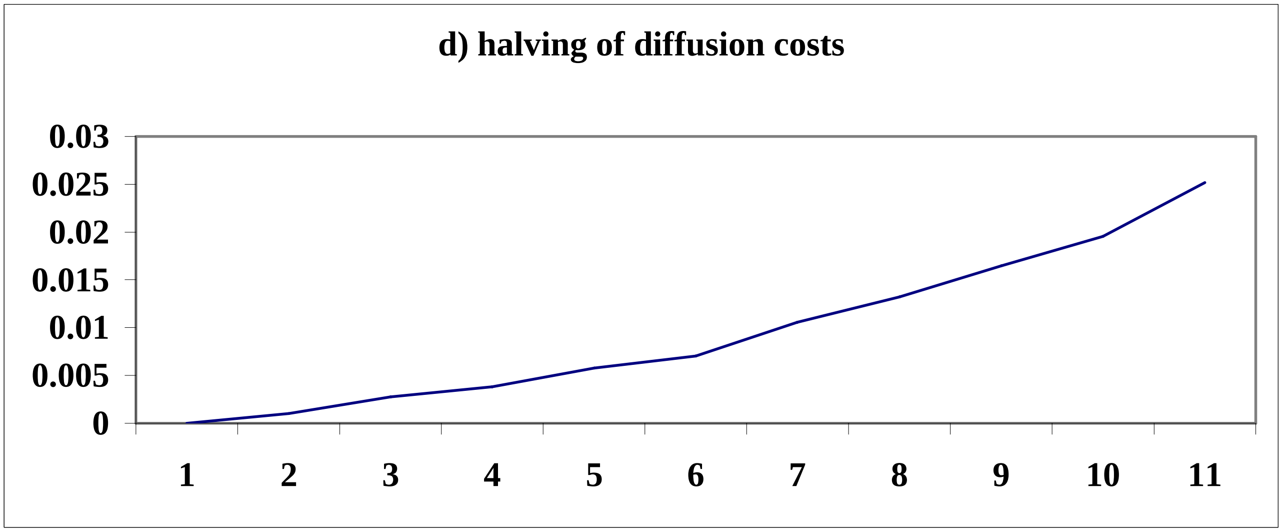

g) a combination of a), c), and d)
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11

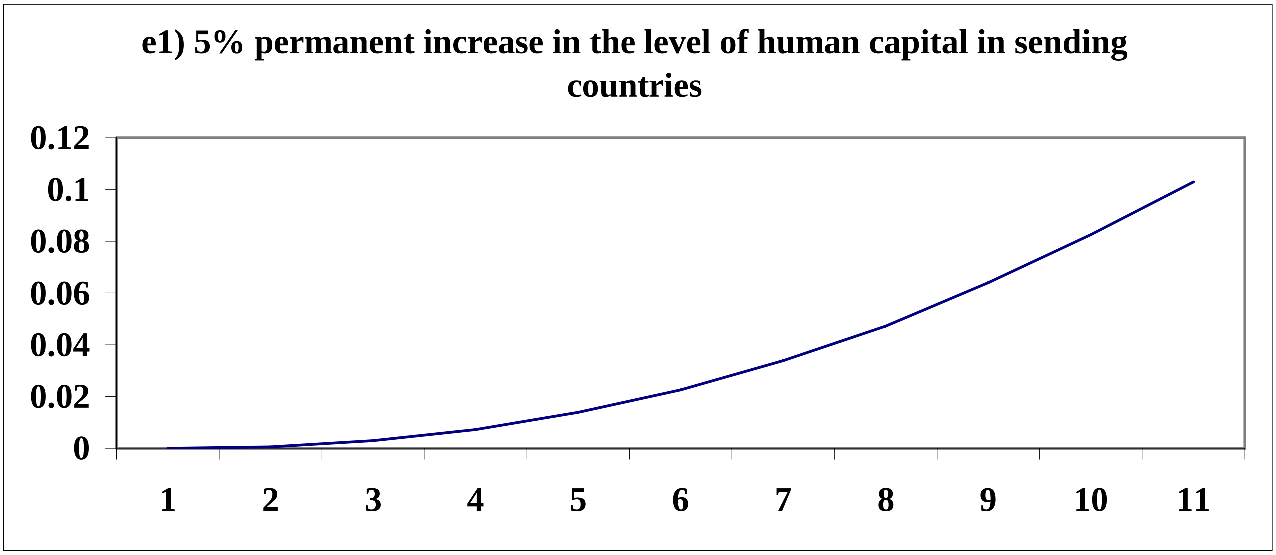
Figure 3. Imported services. Differences from baseline.

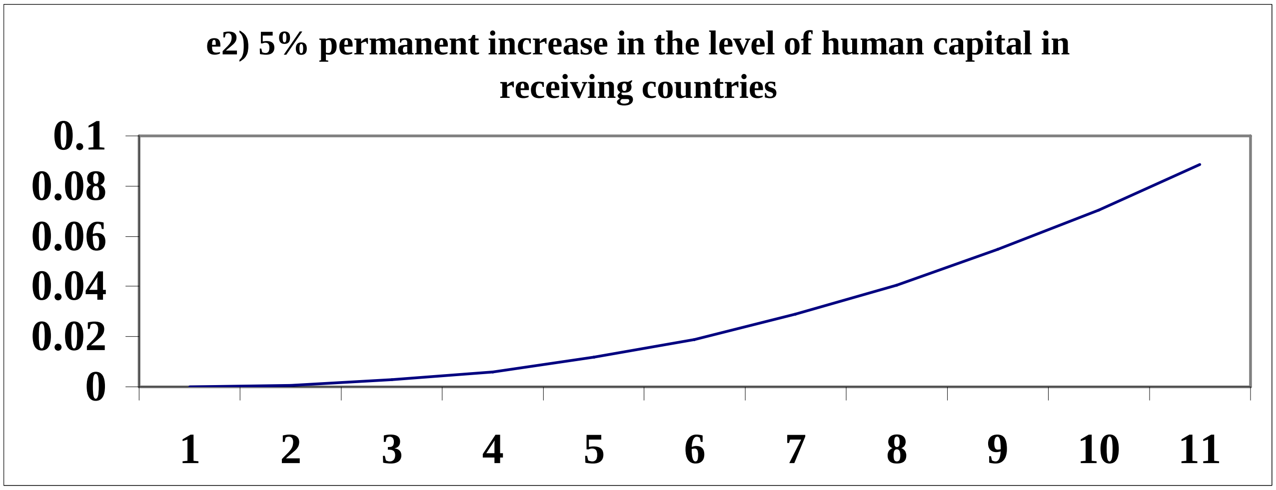


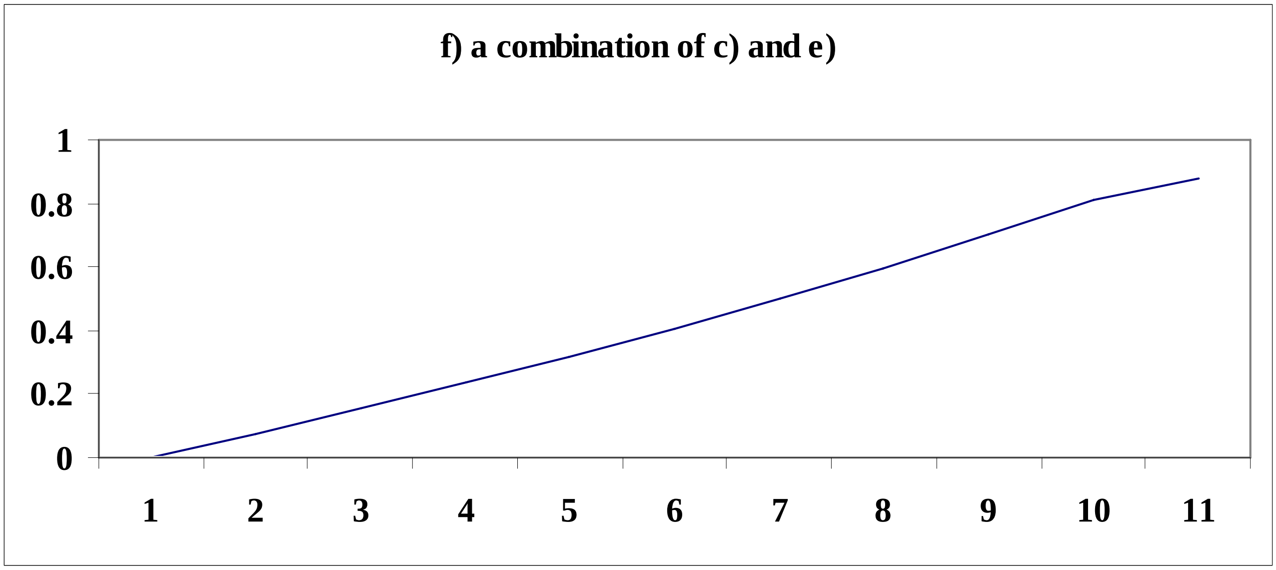



c) doubling of ICT spending
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11


d) halving of diffusion costs
0.03
0.025
0.02
0.015
0.01
0.005
0
1
2
3
4
5
6
7
8
9
10
11


e1) 5% permanent increase in the level of human capital in sending countries
0.12
0.1
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11


e2) 5% permanent increase in the level of human capital in receiving countries
0.1
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11


f) a combination of c) and e)
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
10
11

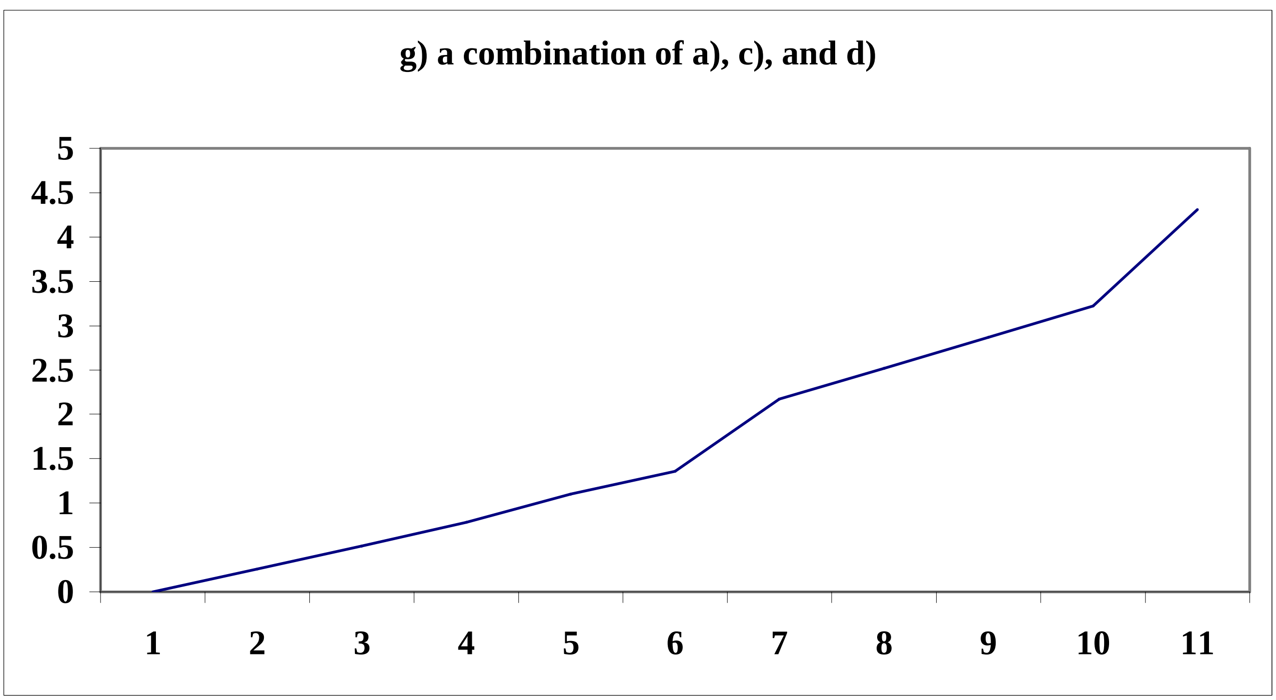
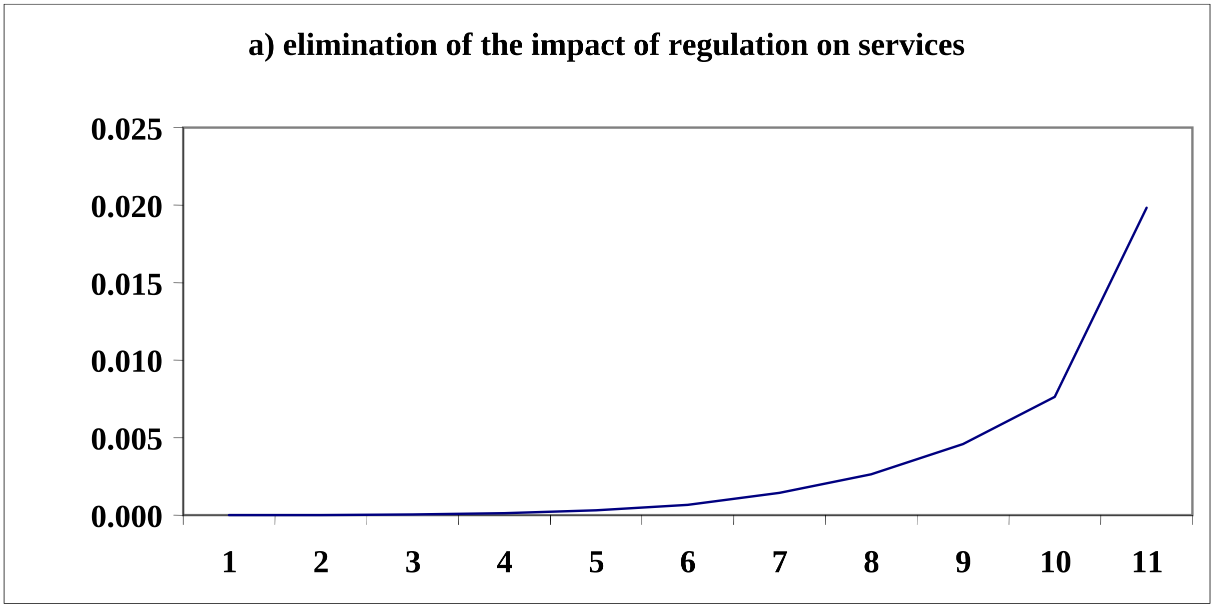
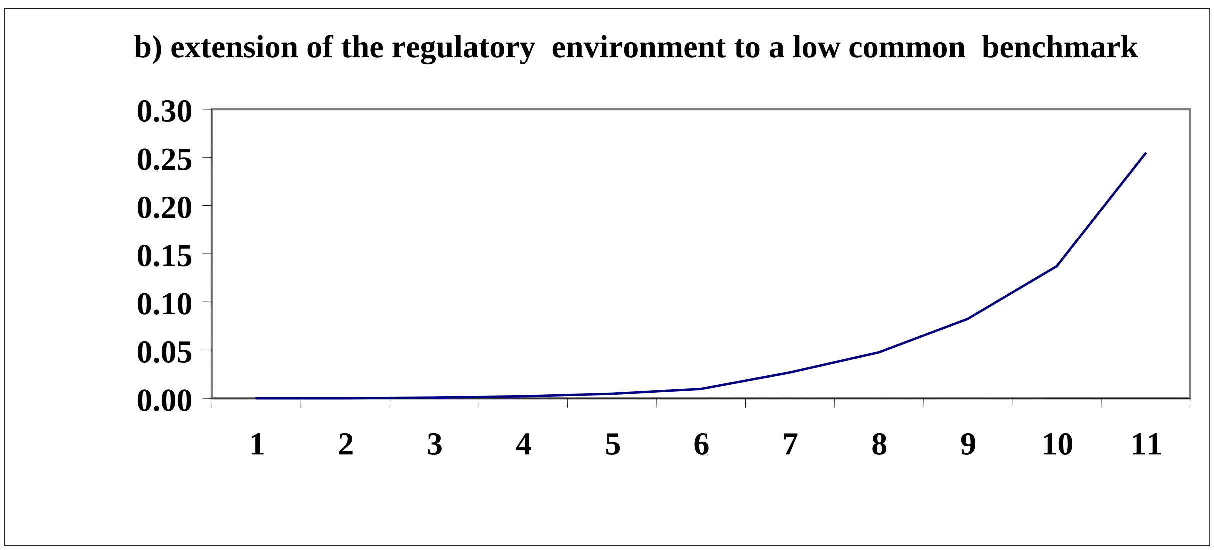
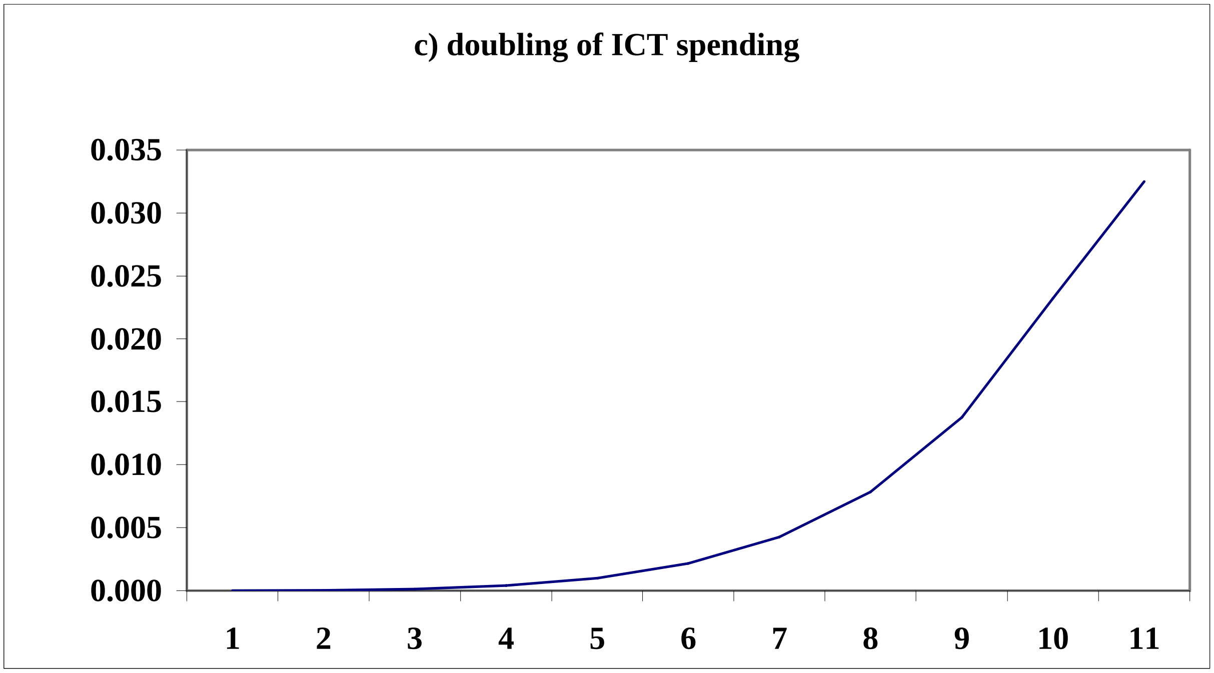
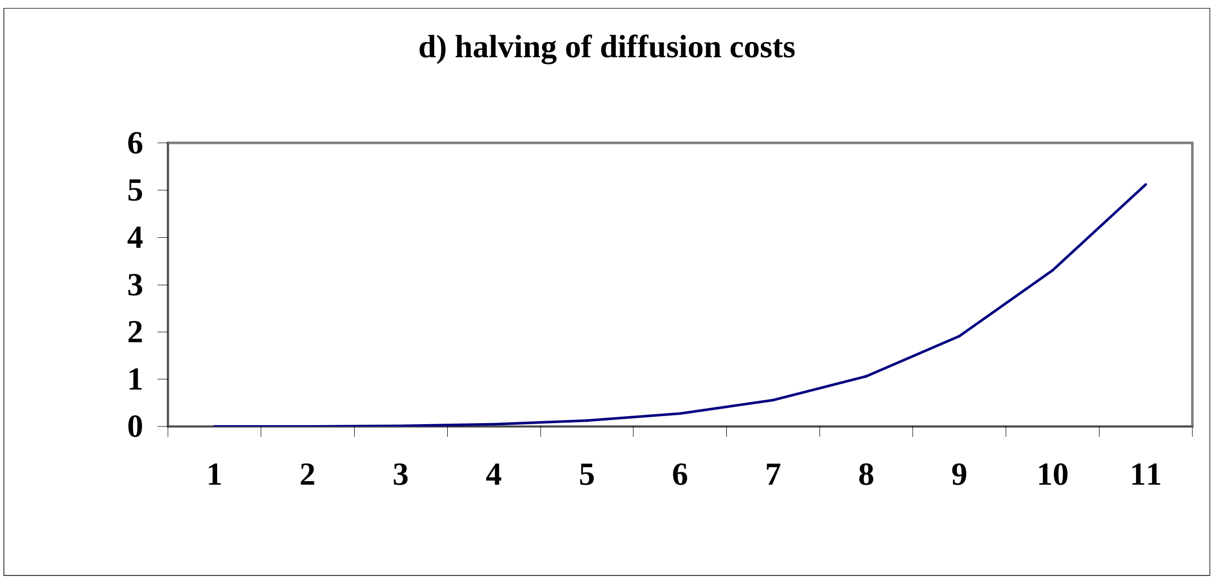

g) a combination of a), c), and d)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11

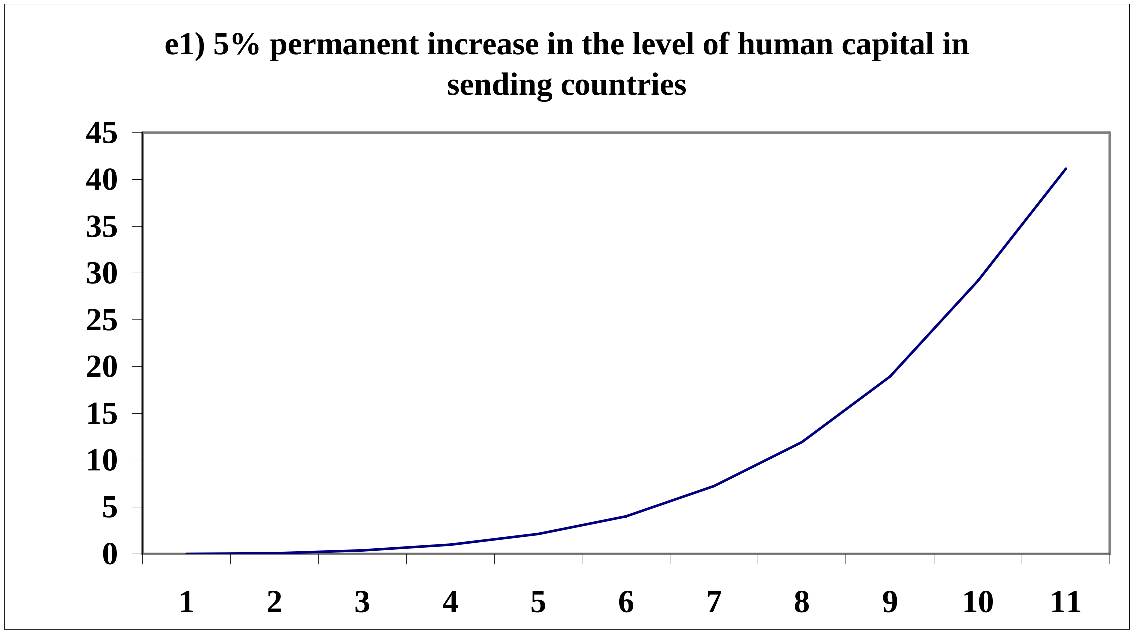
Figure 4. Technology. Differences from baseline.

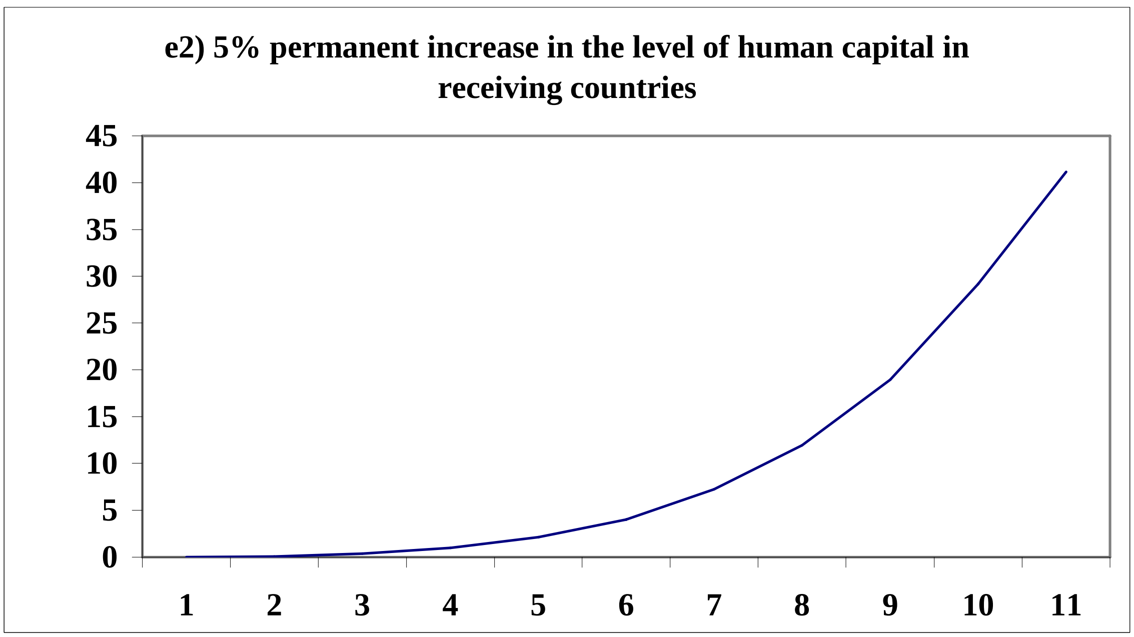


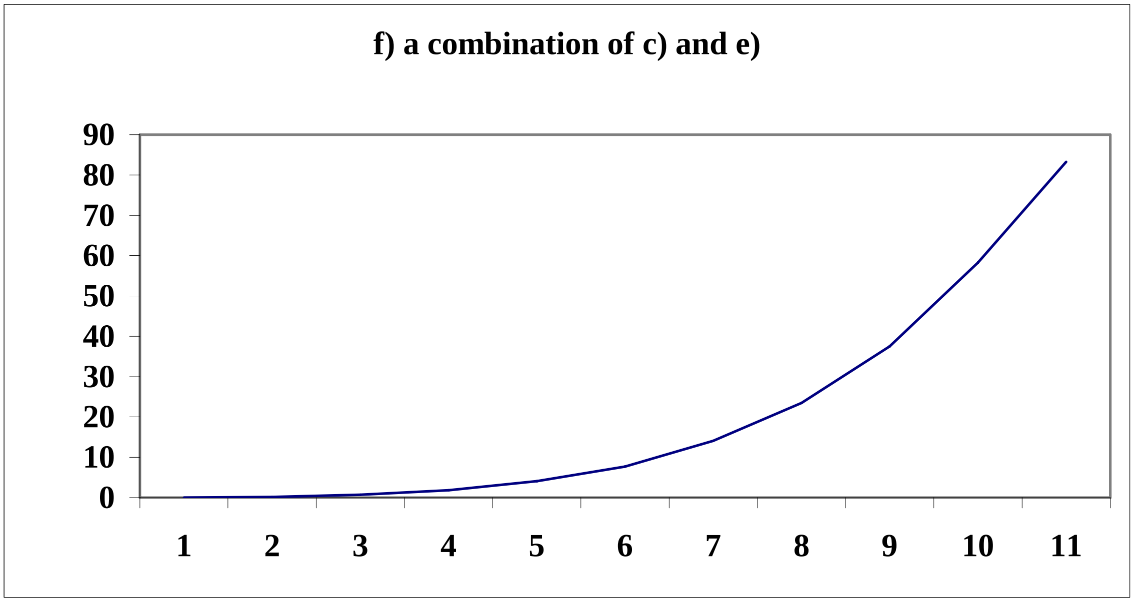


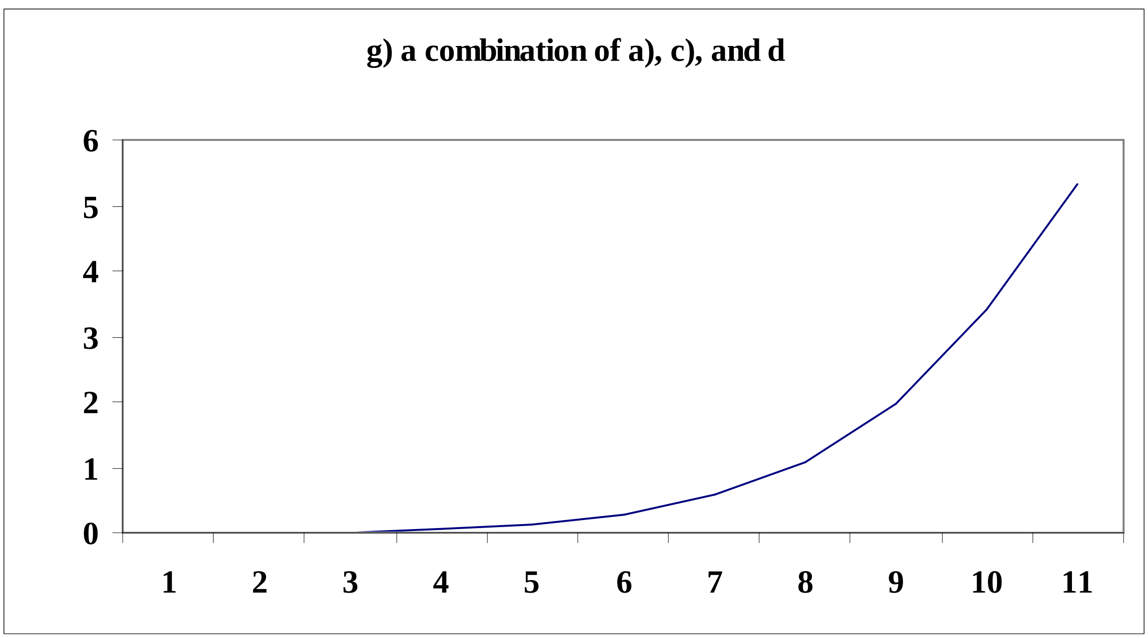

c) doubling of ICT spending
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1
2
3
4
5
6
7
8
9
10
11


d) halving of diffusion costs
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11


e1) 5% permanent increase in the level of human capital in sending countries
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11


e2) 5% permanent increase in the level of human capital in receiving countries
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11


f) a combination of c) and e)
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11


g) a combination of a), c), and d
6
5
4
3
2
1
0
1
2
3
4
5
6
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10
11

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Appendix. Steady state and stability

Steady state solution

The search for the steady state solution is conducted by means of the undetermined coefficients method through the definition of the expressions for the exogenous variables and the solution for the endogenous ones. The functional form we try is exponential. ρ and μ indicate, respectively, the steady state rates of growth for exogenous and endogenous variables. Starred variables identify the initial conditions.

Clearly the steady state solution depends on the constraints we impose on coefficients. As there are several possibilities regarding constraints, also dependent on economic-policy experiments we will carry out later, it seems reasonable at this stage to solve the steady state solution for the more general unconstrained case.

The steady state solution will be characterised by the equality of r.o.g.'s of flows and of the stock of technology in order to ensure the constancy of all rates of growth in the steady state.

Another possibility is -other than consider solely the technology stock- the possibility to reach the steady state only in the, let's say, "very long term" -i.e. in the limit as time tends to infinity.

Alternatively different r.o.g.'s for variables for patents are admitted and the stock of steady state of technology will grow at a pace given by the highest rate of growth of the flows involved. In the limit this will be the relevant one. As an example, consider the following decomposition of the stock of knowledge with T_0 being the initial level:

$$T_t = T_0 + A_t + B_t + C_t$$

$$A_t = Ae^{at}, B_t = Be^{bt}, C_t = Ce^{ct}$$

$$\frac{\dot{T}}{T} = \frac{T_0}{T} + \frac{aAe^{at} + bBe^{bt} + cCe^{ct}}{Ae^{at} + Be^{bt} + Ce^{ct}} = \frac{T_0}{T} + aw_a + bw_b + cw_c$$

where w_i is the share of the i$^{\text{th}}$ patent flow component

If a is the dominant r.o.g. in the limit the result will be

$$w_a \to 1, w_b \to 0, w_c \to 0, \frac{T_0}{T} \to 0$$

and so $\frac{\dot{T}}{T} \to a$.

i.e. the rate of growth of the technology stock will be determined by the highest among the rates of growth of the patent flows and only the fastest growing patent component will, in the limit determine the accumulation of technology. This might not be the rate of growth of domestic patents. Hence the role of distance as representing the capacity to attract innovations is crucial in order to allow for technology accumulation to take place through diffusion, even if the domestic production of technology is negligible.

In the non-limit solution, on the contrary, all variables grow at the same rate. To this case we now turn.

Initial levels of technology are equal to $T_i^* = \frac{Pat_{.i}^*}{\mu_{pati}}$ in order to allow μ_{pati} to be the r.o.g, as can be derived by integrating eqs. (23)-(25).

The list of exogenous and endogenous variables for the application of the undetermined coefficient method (see Gandolfo 1981, 1997) is the following:

Exogenous*:*

(30) $HK_1 = HK_1^0 e^{\rho_{HK_1} t}$

(31) $HK_2 = HK_2^0 e^{\rho_{HK_2} t}$

(32) $HK_3 = HK_3^0 e^{\rho_{HK_3} t}$

(30’) $HKR_1 = HKR_1^0 e^{\rho_{HKR_1} t}$

(31’) $HKR_2 = HKR_2^0 e^{\rho_{HKR_2} t}$

(32’) $HKR_3 = HKR_3^0 e^{\rho_{HKR_3} t}$

(33) $L_1 = L_1^0 e^{\rho_{L_1} t}$

(34) $L_2 = L_2^0 e^{\rho_{L_2} t}$

(35) $L_3 = L_3^0 e^{\rho_{L_3} t}$

(36) $STR_1 = STR_1$

(37) $STR_2 = STR_2$

(38) $STR_3 = STR_3$

(39) $ICT_1 = ICT_1^0 e^{\rho_{ICT_1} t}$

(40) $ICT_2 = ICT_2^0 e^{\rho_{ICT_2} t}$

(41) $ICT_3 = ICT_3^0 e^{\rho_{ICT_3} t}$

Endogenous:

(42) $Y_1 = Y_1^* e^{\mu_{Y_1} t}$

(43) $Y_2 = Y_2^* e^{\mu_{Y_2} t}$

(44) $Y_3 = Y_3^* e^{\mu_{Y_3} t}$

(45) $S_{h1} = S_{h1}^* e^{\mu_{Sh1} t}$

(46) $S_{h2} = S_{h2}^* e^{\mu_{Sh2} t}$

(47) $S_{h3} = S_{h3}^* e^{\mu_{Sh3} t}$

(45') $S_{m1} = S_{m1}^* e^{\mu_{Sm1} t}$

(46') $S_{m2} = S_{m2}^* e^{\mu_{Sm2} t}$

(47') $S_{m3} = S_{m3}^* e^{\mu_{Sm3} t}$

(48) $Pat_{11} = Pat_{11}^* e^{\mu_{Pat_1} t}$

(49) $Pat_{21} = Pat_{21}^* e^{\mu_{Pat_1} t}$

(50) $Pat_{31} = Pat_{31}^* e^{\mu_{Pat_1} t}$

(51) $Pat_{US1} = Pat_{US1}^* e^{\mu_{Pat_1} t}$

(52) $Pat_{12} = Pat_{12}^* e^{\mu_{Pat_2} t}$

(53) $Pat_{22} = Pat_{22}^* e^{\mu_{Pat_2} t}$

(54) $Pat_{32} = Pat_{32}^* e^{\mu_{Pat_2} t}$

(55) $Pat_{US2} = Pat_{US2}^* e^{\mu_{Pat_2} t}$

$$(56)\ Pat_{13} = Pat_{13}^{*} e^{\mu_{Pat_3} t}$$

$$(57)\ Pat_{23} = Pat_{23}^{*} e^{\mu_{Pat_3} t}$$

$$(58)\ Pat_{33} = Pat_{33}^{*} e^{\mu_{Pat_3} t}$$

$$(59)\ Pat_{US3} = Pat_{US3}^{*} e^{\mu_{Pat_3} t}$$

$$(60)\ T_1 = T_1^{*} + \int_0^t (Pat_{11} + Pat_{21} + Pat_{31} + Pat_{US1})dt = \frac{Pat_{.1}^{*}}{\mu_{pat_1}} e^{\mu_{Pat_1} t}$$

$$(61)\ T_2 = T_2^{*} + \int_0^t (Pat_{12} + Pat_{22} + Pat_{32} + Pat_{US2})dt = \frac{Pat_{.2}^{*}}{\mu_{pat_2}} e^{\mu_{Pat_2} t}$$

$$(62)\ T_3 = T_3^{*} + \int_0^t (Pat_{13} + Pat_{23} + Pat_{33} + Pat_{US3})dt = \frac{Pat_{.3}^{*}}{\mu_{pat_3}} e^{\mu_{Pat_3} t}$$

$$(63)\ Pat_{11}^{*} + Pat_{21}^{*} + Pat_{31}^{*} + Pat_{US1}^{*} = Pat_{.1}^{*}$$

$$(64)\ Pat_{12}^{*} + Pat_{22}^{*} + Pat_{32}^{*} + Pat_{US2}^{*} = Pat_{.2}^{*}$$

$$(65)\ Pat_{13}^{*} + Pat_{23}^{*} + Pat_{33}^{*} + Pat_{US3}^{*} = Pat_{.3}^{*}$$

$$(66)\ T_1^{*} = \frac{Pat_{.1}^{*}}{\mu_{pat_1}}$$

$$(67)\ T_2^{*} = \frac{Pat_{.2}^{*}}{\mu_{pat_2}}$$

$$(68)\ T_3^{*} = \frac{Pat_{.3}^{*}}{\mu_{pat_3}}$$

We now solve the system for the rates of growth and initial levels for the endogenous variables. We consider only the solution for country 1 which can be easily replicated for the remaining countries.

The following system, based on the undetermined coefficient method, is derived by imposing the condition that the steady state model, (5)-(25), is identically satisfied in each moment of time i.e, the constant terms and time coefficients are constrained to be zero in each equation:

Output
(69)
$$\alpha^1\alpha_0^1+\alpha^1\alpha_1^1\log T_1^*+\alpha^1\alpha_{2h}^1\log S_{sh1}^*+\alpha^1\alpha_{2m}^1\log S_{sm1}^*+\alpha^1\alpha_3^1\log K_1^*+\alpha^1\alpha_4^1\log L_1^*+\alpha^1\log Y_1^*-\mu_{y1}=0$$

(70) $\alpha^1\alpha_1^1\mu_{p1}+\alpha^1\alpha_{2h}^1\mu_{Sh1}+\alpha^1\alpha_{2m}^1\mu_{Sm1}+\alpha^1\alpha_3^1\rho_{K1}+\alpha^1\alpha_4^1\rho_{L1}-\alpha^1\mu_{Y1}=0$

Domestic Services
(71)
$$\gamma^{sh1}\gamma_0^{sh1}+\gamma^{sh1}\gamma_1^{sh1}\log Y_1^*+\gamma^{sh1}\gamma_2^{sh1}\log T_1^*+\gamma^{sh1}\gamma_3^{sh1}\log STR_1+\gamma^{sh1}\gamma_4^{sh1}\log ICT_1^*-\gamma^{sh1}\log S_{h1}^*-\mu_{Sh1}=0$$

(72) $\gamma^{sh1}\gamma_1^{sh1}\mu_{Y1}+\gamma^{sh1}\gamma_2^{sh1}\mu_{p1}+\gamma^{sh1}\gamma_4^{sh1}\rho_{ICT1}-\gamma^1\mu_{Sh1}=0$

Imported Services
(71')
$$\gamma^{sm1}\gamma_0^{sm1}+\gamma^{sm1}\gamma_1^{sm1}\log Y_1^*+\gamma^{sm1}\gamma_2^{sm1}\log T_1^*+\gamma^{sm1}\gamma_3^{sm1}\log STR_1+\gamma^{sm1}\gamma_4^{sm1}\log ICT_1^*-\gamma^{sm1}\log S_{m1}^*-\mu_{Sm1}=0$$

(72') $\gamma^{sm1}\gamma_1^{sm1}\mu_{Y1}+\gamma^{sm1}\gamma_2^{sm1}\mu_{p1}+\gamma^{sm1}\gamma_4^{sm1}\rho_{ICT1}-\gamma^1\mu_{Sm1}=0$

Patents
From country 1

(73)
$$\begin{aligned}&\beta^{11}\beta_0^{11}+\beta^{11}\beta_1^{11}adist_{11}+\beta^{11}\beta_2^{11}\log HK_1^*+\beta^{11}\beta_{3h}^{11}\log S_{h1}^*+\beta^{11}\beta_{3m}^{11}\log S_{h1}^*+\beta^{11}\beta_4^{11}\log Y_1^*\\&+\beta^{11}\beta_5^{11}\log HKR_1^*-\beta^{11}\log Pat_{11}^*-\mu_{p1}=0\end{aligned}$$

(74) $\beta^{11}\beta_1^{11}bdist_{11}+\beta^{11}\beta_2^{11}\rho_{HK1}+\beta^{11}\beta_{3m}^{11}\mu_{Sh1}+\beta^{11}\beta_{3m}^{11}\mu_{Sm1}+\beta^{11}\beta_4^{11}\mu_{y1}++\beta^{11}\beta_4^{11}\rho_{HKR1}-\beta^{11}\mu_{p1}=0$

From country 2

(75)
$$\begin{aligned}&\beta^{21}\beta_0^{21}+\beta^{21}\beta_1^{21}adist_{21}+\beta^{21}\beta_2^{21}\log HK_2^*+\beta^{21}\beta_{3h}^{21}\log S_{h1}^*+\beta^{21}\beta_{3m}^{21}\log S_{m1}^*\\&+\beta^{21}\beta_4^{21}\log Y_1^*+\beta^{21}\beta_5^{21}\log HKR_1^*-\beta^{21}\log Pat_{21}^*-\mu_{p1}=0\end{aligned}$$

(76) $\beta^{21}\beta_1^{21}bdist_{21}+\beta^{21}\beta_2^{21}\rho_{HK2}+\beta^{21}\beta_{3h}^{21}\mu_{Sh1}+\beta^{21}\beta_{3m}^{21}\mu_{Sm1}+\beta^{21}\beta_4^{21}\mu_{y1}+\beta^{21}\beta_5^{21}\rho_{HKR1}-\beta^{21}\mu_{p1}=0$

From country 3

(77)
$$\begin{aligned}&\beta^{31}\beta_0^{31}+\beta^{31}\beta_1^{31}adist_{31}+\beta^{31}\beta_2^{31}\log HK_3^*+\beta^{31}\beta_{3h}^{31}\log S_{h1}^*+\beta^{31}\beta_{3m}^{31}\log S_{m1}^*\\&+\beta^{31}\beta_4^{31}\log Y_1^*+\beta^{31}\beta_5^{31}\log HKR_1^*-\beta^{31}\log Pat_{31}^*-\mu_{p1}=0\end{aligned}$$

(78) $\beta^{31}\beta_1^{31}bdist_{31}+\beta^{31}\beta_2^{31}\rho_{HK3}+\beta^{31}\beta_{3h}^{31}\mu_{Sh1}+\beta^{31}\beta_{3m}^{31}\mu_{Sm1}+\beta^{31}\beta_4^{31}\mu_{y1}+\beta^{31}\beta_5^{31}\rho_{HKR1}-\beta^{11}\mu_{p1}=0$

From the rest of the world (U.S.).

(79)
$$\begin{aligned}&\beta^{US1}\beta_0^{US1}+\beta^{US1}\beta_1^{US1}adist_{US1}+\beta^{US1}\beta_2^{US1}\log HK_{US}^{*}+\beta^{US1}\beta_{3h}^{US1}\log S_{h1}^{*}+\beta^{US1}\beta_{3m}^{US1}\log S_{m1}^{*}\\&+\beta^{US1}\beta_4^{US1}\log Y_1^{*}+\beta^{US1}\beta_5^{US1}\log HKR_1^{*}-\beta^{US1}\log Pat_{US1}^{*}-\mu_{p1}=0\end{aligned}$$

(80)
$$\beta^{US1}\beta_1^{US1}bdist_{US1}+\beta^{US1}\beta_2^{11}\rho_{HKUS}+\beta^{US1}\beta_{3h}^{US1}\mu_{Sh1}+\beta^{US1}\beta_{3m}^{US1}\mu_{Sm1}+\beta^{US1}\beta_4^{US1}\mu_{y1}+\beta^{US1}\beta_5^{US1}\rho_{HKR1}-\beta^{US1}\mu_{p1}=0$$

Calculations for the solution of system (69)-(80) are lengthy and tedious. Here, we report the results with the specification that the above system is composed of two blocks of equations, one of which is independent of the initial levels. From this block steady state rates of growth are derived and this solution is used to solve for initial levels.

Solutions for steady state rates of growth:

(81)
$$\begin{aligned}\mu_{y1}=&\left\{1-\left[\left(\alpha_1^1+\alpha_{2sh}^1\gamma_1^{1sh}+\alpha_{2sm}^1\gamma_1^{1sm}\right)\left(1-\beta_{3sh}^{i1}\gamma_{2sh}^1-\beta_{3sm}^{i1}\gamma_{2sm}^1\right)^{-1}\left(\beta_4^{i1}+\beta_{3sh}^{i1}\gamma_{1sh}^1+\beta_{3sm}^{i1}\gamma_{1sm}^1\right)-(\alpha_{2sh}^1+\alpha_{2sm}^1)\beta_1^1\right]\right\}^{-1}\\&\times\left\{\begin{array}{l}\alpha_3^1\rho_{K1}+\alpha_4^1\rho_{L1}+\alpha_{2Sh}\gamma_{4sh}^1\rho_{ICT}+\alpha_{2Sm}\gamma_{4sm}^1\rho_{ICT}+\left(\alpha_1^1+(\alpha_{2sh}^1+\alpha_{2sm}^1)\beta_1^1\right)\left(1-\beta_{3sh}^{i1}\gamma_{2sh}^1-\beta_{3sm}^{i1}\gamma_{2sm}^1\right)^{-1}\\\left(\beta_1^{i1}bdist_1+\beta_2^{i1}\rho_{HK}+\beta_5^{i1}\rho_{HKR}+\beta_{3Sh}^{i1}\gamma_{4sh}^1\rho_{ICT}+\beta_{3Sm}^{i1}\gamma_{4sm}^1\rho_{ICT}\right)\end{array}\right\}\end{aligned}$$

(82) $\mu_{Sh1}=\gamma_{1Sh}^1\mu_{y1}+\gamma_{4Sh}^1\rho_{ICT1}+\gamma_{2Sh}^1\mu_{p1}$

(82') $\mu_{Sm1}=\gamma_{1Sm}^1\mu_{y1}+\gamma_{4Sm}^1\rho_{ICT1}+\gamma_{2Sm}^1\mu_{p1}$

(83)
$$\begin{aligned}&\mu_{p1}=\left(1-\beta_{3sh}^{i1}\gamma_{2sh}^1-\beta_{3sm}^{i1}\gamma_{2sm}^1\right)^{-1}\\&\left[\beta_1^{i1}bdist_1+\beta_2^{i1}\rho_{HK}+\beta_5^{i1}\rho_{HKR1}+\beta_3^{i1}\gamma_{4Sh}^{i1}\rho_{ICT1}+\beta_3^{i1}\gamma_{4Sm}^{i1}\rho_{ICT1}+\mu_{y1}\left(\beta_4^{i1}+\beta_{3sh}^{i1}\gamma_{sh1}^1+\beta_{3sm}^{i1}\gamma_{sm1}^1\right)\right]\end{aligned}$$

where

$$dist_1=\frac{\sum_{i=1}^{n}dist_{i1}}{n},\ \rho_{HK}=\frac{\sum_{i=1}^{n}\rho_{HK\,i}}{n}$$

Solutions for initial levels:

(84) $$\log Y_1^* = \begin{bmatrix} \alpha_0^1 + \alpha_3^1 \log K_1^0 + \alpha_4^1 \log L_1^0 + \alpha_1^1 \log T_1^* + \\ + \alpha_{4sh}^1 \left(\gamma_0^{1sh} + \gamma_2^{1sh} \log T_1^* + \gamma_3^{1sh} STR + \gamma_4^{1sh} ICT * - \mu_{Sh1} / \gamma^{sh1}\right) + \\ \alpha_{sm4}^1 \left(\gamma_0^{1sm} + \gamma_2^{1sm} \log T_1^* + \gamma_3^{1sm} STR + \gamma_4^{1sm} ICT * - \mu_{mS1} / \gamma^{sm1}\right) - \mu_{y1} / \alpha^1 \end{bmatrix} \times \left[1 - \gamma_1^{sh1} \alpha^{1sh} \alpha_{4sh}^1 - \gamma_1^{sm1} \alpha^{1sm} \alpha_{4sm}^1\right]^{-1}$$

(85) $$\log S_{h1}^* = \gamma_0^{1sh} + \gamma_1^{1sh} \log Y_1^* + \gamma_2^{1sh} \log T_1^* + \gamma_3^{1sh} \log STR_1 + \gamma_4^{1sh} \log ICT_1^* - \mu_{Sh1} / \gamma^{1sh}$$

(85') $$\log S_{m1}^* = \gamma_0^{1sm} + \gamma_1^{1sm} \log Y_1^* + \gamma_2^{1sm} \log T_1^* + \gamma_3^{1sm} \log STR_1 + \gamma_4^{1sm} \log ICT_1^* - \mu_{Sm1} / \gamma^{1sm}$$

The solution for initial levels of patents is rather complex as it depends also on the initial level of technology which, in turn, depends on the aggregation of initial level of patents (eqs. (66)-(68)). A complication lies in the fact that we find a solution in logs of variables which depends on the sum of the variables themselves. However, although numerical solutions are always possible, we need a closed form solution to be used for economic analysis (an appealing application is comparative dynamics). To find this we need the sum of the patents flows:

(86) $$\begin{aligned} \log Pat_{i1}^* = {} & \beta_0^{i1} + \beta_1^{i1} adist_{i1} + \beta_2^{i1} \log HK_1^0 + \beta_5^{i1} \log HKR_1^0 \\ & + \left[\beta_{3sh}^{i1} \gamma_0^{1sh} + \beta_{3sh}^{i1} \gamma_1^{1sh} A + \beta_{3sh}^{i1} F \log T_1^* + \beta_{3sh}^{i1} \gamma_2^{1sh} \log T_1^* - \beta_{3sh}^{i1} \mu_{Ss1} / \gamma^{1sh}\right] \\ & + \left[\beta_{3sm}^{i1} \gamma_0^{1sm} + \beta_{3sm}^{i1} \gamma_1^{1sm} A + \beta_{3sm}^{i1} F \log T_1^* + \beta_{3sm}^{i1} \gamma_2^{1sm} \log T_1^* - \beta_{3sm}^{i1} \mu_{Sm1} / \gamma^{1sm}\right] \\ & \beta_4^{i1} F \log T_1^* + \beta_4^{i1} A - \mu_{p1} / \beta^{i1} \end{aligned}$$

$$A = \begin{bmatrix} \alpha_0^1 + \alpha_3^1 \log K_1^0 + \alpha_4^1 \log L_1^0 + \alpha_{4Sh}^1 \left(\gamma_0^{1sh} + \gamma_3^{1sh} STR + \gamma_4^{1sh} ICT * - \mu_{Sh1} / \gamma^{1sh}\right) + \\ \alpha_{4Sm}^1 \left(\gamma_0^{1sm} + \gamma_3^{1sm} STR + \gamma_4^{1sm} ICT * - \mu_{Sm1} / \gamma^{1sm}\right) - \mu_{y1} / \alpha^1 \end{bmatrix} \left[1 - \gamma_1^{1sh} \alpha^{1sh} \alpha_{sh4}^1 - \gamma_1^{1sm} \alpha^{1Sm} \alpha_{4sm}^1\right]^{-1}$$

$$F = \left(\alpha_1^1 + \alpha_{4sh}^1 \gamma^{1sh} \gamma_2^{1sh} + \alpha_{4sm}^1 \gamma^{1sm} \gamma_{2sm}^1\right)\left(1 - \gamma_1^{1sh} \alpha^{1sh} \alpha_{sh4}^1 - \gamma_1^{1sm} \alpha^{1Sm} \alpha_{4sm}^1\right)^{-1}$$

(87) $$Pat_{i1}^* = \exp \left\{ \begin{aligned} & \beta_0^{i1} + \beta_1^{i1} adist_{i1} + \beta_2^{i1} \log HK_1^0 + \beta_5^{i1} \log HKR_1^0 \\ & + \left[\beta_{3sh}^{i1} \gamma_0^{1sh} + \beta_{3sh}^{i1} \gamma_1^{1sh} A - \beta_{3sh}^{i1} \mu_{Ss1}\right] \\ & + \left[\beta_{3sm}^{i1} \gamma_0^{1sm} + \beta_{3sm}^{i1} \gamma_1^{1sm} A - \beta_{3sm}^{i1} \mu_{Sm1}\right] \\ & + \beta_4^{i1} A - \mu_{p1} / \beta^{i1} \end{aligned} \right\} \exp\left\{(\beta_{3sh}^{i1} F + \beta_{3sh}^{i1} \gamma_2^{1sh} + \beta_{3sm}^{i1} F + \beta_{3sm}^{i1} \gamma_2^{1sm} + \beta_4^{i1} F) \log T_1^*\right\}$$

$$\begin{aligned}C_{i1} = {} & \beta_0^{i1} + \beta_1^{i1} adist_{i1} + \beta_2^{i1} \log HK_1^0 + \beta_5^{i1} \log HKR_1^0 \\ & + \left[\beta_{3sh}^{i1}\gamma_0^{1sh} + \beta_{3sh}^{i1}\gamma_1^{1sh} A - \beta_{3sh}^{i1}\mu_{Ss1}\right] \\ & + \left[\beta_{3sm}^{i1}\gamma_0^{1sm} + \beta_{3sm}^{i1}\gamma_1^{1sm} A - \beta_{3sm}^{i1}\mu_{Sm1}\right] \\ & + \beta_4^{i1} A - \mu_{p1} / \beta^{i1}\end{aligned}$$

$$E_1 = (\beta_{3sh}^{i1} F + \beta_{3sh}^{i1}\gamma_2^{1sh} + \beta_{3sm}^{i1} F + \beta_{3sm}^{i1}\gamma_2^{1sm} + \beta_4^{i1} F)$$ [10]

(88) $$Pat_{i1}^* = e^{C_{i1}} \mu_{p1}^{-E_1} \left(Pat_{11}^* + Pat_{21}^* + Pat_{31}^* + Pat_{US1}^*\right)^{E_1}$$

$$Pat_{11}^* + Pat_{21}^* + Pat_{31}^* + Pat_{US1}^* = \sum_i e^{C_{i1}} \mu_{p1}^{-E_1} \left(Pat_{11}^* + Pat_{21}^* + Pat_{31}^* + Pat_{US1}^*\right)^{E_1}$$

$$0 = \log\left(\sum_i C_{i1}\right) - E_1 \log \mu_{p1} + (E_1 - 1)\log\left(Pat_{11}^* + Pat_{21}^* + Pat_{31}^* + Pat_{US1}^*\right)$$

$$\log\left(Pat_{11}^* + Pat_{21}^* + Pat_{31}^* + Pat_{US1}^*\right) = \left(E_1 - 1\right)^{-1} \log\left(\mu_{p1}^{-E_1} \sum_i C_{i1}\right)$$

(89) $$Pat_{11}^* + Pat_{21}^* + Pat_{31}^* + Pat_{US1}^* = \left(\mu_{p1}^{-E_1} \sum_i C_{i1}\right)^{(E_1 - 1)^{-1}}$$

Substituting (89) in (66) and finally in (86) completes the analysis of the steady state solutions.

Stability analysis

We are now ready to analyse of the dynamic properties of the model. This can be done by studying the equations of motion of the endogenous variables expressed in terms of the difference (x_k) between actual and steady state values. This will be done, as usual, for country 1.

(90) $$x_1 = \log \frac{Y_1}{Y_1^* e^{\mu_{Y1} t}}$$

(91) $$x_2 = \log \frac{S_{h1}}{S_{h1}^* e^{\mu_{Sh1} t}}$$

(92) $$x_3 = \log \frac{S_{m1}}{S_{m1}^* e^{\mu_{Sm1} t}}$$

[10] This term is constant for all *i* by virtue of the equality constraints imposed on coefficients.

(93) $x_8 = \log \dfrac{T_1}{T_1^* e^{\mu_{p1} t}}$

(94) $x_4 = \log \dfrac{Pat_{11}}{Pat_{11}^* e^{\mu_{p11} t}}$

(95) $x_5 = \log \dfrac{Pat_{21}}{Pat_{21}^* e^{\mu_{p21} t}}$

(96) $x_6 = \log \dfrac{Pat_{31}}{Pat_{31}^* e^{\mu_{p31} t}}$

(97) $x_7 = \log \dfrac{Pat_{US1}}{Pat_{US1}^* e^{\mu_{pUS1} t}}$

By substituting the steady state values in eqs. (5), (8), (8'), (11), (12), (13), (20) and (23) and subtracting them from the same equations expressed in terms of actual values we obtain

i =1, 2, 3, 4 where 4 stands for the U.S.

(98) $Dx_1 = -\alpha^1 x_1 + \alpha^1 \alpha_2^1 x_2 + \alpha^1 \alpha_{2sm}^1 x_3 + \alpha^1 \alpha_1^1 x_8$

(99) $Dx_2 = -\gamma^{sh1} x_2 + \gamma^{1sh} \gamma_{sh1}^1 x_1 + \gamma^{1sh} \gamma_{sh2}^1 x_8$

(100) $Dx_3 = -\gamma^{1sm} x_3 + \gamma^{1sm} \gamma_{1sm}^1 x_1 + \gamma^{1sm} \gamma_{2sm}^1 x_8$

(101)
$$\begin{aligned} Dx_8 = D\log T_1 - D\log T_1^* &= \frac{Pat_{11}}{T_1} + \frac{Pat_{21}}{T_1} + \frac{Pat_{31}}{T_1} + \frac{Pat_{US1}}{T_1} \\ &- \frac{Pat_{11}^* e^{\mu_{p1} t}}{T_1^*} + \frac{Pat_{21}^* e^{\mu_{p1} t}}{T_1^*} + \frac{Pat_{31}^* e^{\mu_{p1} t}}{T_1^*} + \frac{Pat_{US1}^* e^{\mu_{p1} t}}{T_1^*} \end{aligned}$$

by linearization around the steady state (that is possible in the case of autonomous systems as the conditions of the Poincarè-Liapunov-Perron theorem are automatically satisfied) we can write

(102) $e^{x_i - x_8} \dfrac{Pat_{i1}^*}{T_1^*} \mu_{p1} = \dfrac{Pat_{i1}}{T_1} \cong (1 + x_i - x_8) \dfrac{Pat_{i1}^*}{T_1^*} \mu_{p1}$

(103)
$$Dx_8 = \sum_i e^{x_{i+2}-x_8} \frac{Pat^*_{i1}}{T^*_1} \mu_{p1} - \sum_i \frac{Pat^*_{i1}}{T^*_1} \cong \sum_i (x_{i+2} - x_8) \frac{Pat^*_{i1}}{T^*_1} \mu_{p1} =$$
$$\sum_i x_{i+2} \frac{Pat^*_{i1}}{T^*_1} \mu_{p1} - x_8 \mu_{p1}$$

(104) $Dx_4 = \beta^{11}\beta^{11}_{3sh} x_2 + \beta^{11}\beta^{11}_{3sm} x_3 + \beta^{11}\beta^{11}_4 x_1 - \beta^{11} x_4$

(105) $Dx_5 = \beta^{21}\beta^{21}_{3sh} x_2 + \beta^{21}\beta^{21}_{3sm} x_3 + \beta^{21}\beta^{21}_4 x_1 - \beta^{21} x_5$

(106) $Dx_6 = \beta^{31}\beta^{31}_{3sh} x_2 + \beta^{31}\beta^{31}_{3sm} x_3 + \beta^{31}\beta^{31}_4 x_1 - \beta^{31} x_6$

(107) $Dx_7 = \beta^{41}\beta^{41}_{3sh} x_2 + \beta^{41}\beta^{41}_{3sm} x_3 + \beta^{41}\beta^{41}_4 x_1 - \beta^{61} x_7$

Equations (98)-(100) and (103)-(107) form the autonomous system of linear differential equations of degree one we use to study the dynamics of the model in the case in which steady state r.o.g.'s of patents flows are equal. The stability propriety of such a system may be studied by considering the characteristic equation of the following matrix and applying the Routh-Hurwitz necessary and sufficient conditions

(108)
$$\begin{vmatrix}
-\alpha^1 & \alpha^1\alpha^1_{sh2} & \alpha^1\alpha^1_{sm2} & \alpha^1\alpha^1_3 & 0 & 0 & 0 & 0 \\
\gamma^{sh1}\gamma^1_{sh1} & -\gamma^{1sh} & & \gamma^{sh1}\gamma^1_{2sh} & 0 & 0 & 0 & 0 \\
\gamma^{sm1}\gamma^1_{sm1} & -\gamma^{1sm} & & \gamma^{sm1}\gamma^1_{2sm} & 0 & 0 & 0 & 0 \\
0 & 0 & & 0 & \mu_{p1}\sum_i \frac{Pat^*_{11}}{Pat^*_{i1}} & \mu_{p1}\sum_i \frac{Pat^*_{21}}{Pat^*_{i1}} & \mu_{p1}\sum_i \frac{Pat^*_{31}}{Pat^*_{i1}} & \mu_{p1}\sum_i \frac{Pat^*_{US1}}{Pat^*_{i1}} \\
\beta^{11}\beta^{11}_4 & \beta^{11}\beta^{11}_{3sh} & \beta^{11}\beta^{11}_{3sm} & 0 & \beta^{11} & 0 & 0 & 0 \\
\beta^{21}\beta^{21}_4 & \beta^{21}\beta^{21}_{3sh} & \beta^{21}\beta^{21}_{3sm} & 0 & 0 & \beta^{21} & 0 & 0 \\
\beta^{31}\beta^{31}_4 & \beta^{31}\beta^{31}_{3sh} & \beta^{31}\beta^{31}_{3sm} & 0 & 0 & 0 & \beta^{31} & 0 \\
\beta^{US1}\beta^{US1}_4 & \beta^{US1}\beta^{US}_{3sh} & \beta^{US1}\beta^{US1}_{3sm} & 0 & 0 & 0 & 0 & \beta^{US1}
\end{vmatrix}$$

Such conditions are usually difficult to interpret from an economic point of view when the corresponding differential equation is of degree greater than three (here is seven). Hence the analysis is strictly linked to the numerical values of the parameters of the model. Specifically: a) some elasticities may be close to 1 or 0 thus simplifying the characteristic equation, b) we can check the system convergence through a numerical solution, c) the final solution depends on the constrains during estimation.

The long term solution, with different rates of growth for patents and a dominant one, is given by eqs. (99)-(101) and

$$(110)\ Dx_8 = D\log T_1 - D\log T_1^* \cong e^{x_4 - x_8}\mu_{p1} - \mu_{p1} \cong (x_4 - x_8)\mu_{p1}$$

$$(111)\ Dx_4 = \beta^{11}\beta_{3sh}^{11}x_2 + \beta^{11}\beta_{3sm}^{11}x_3 + \beta^{11}\beta_4^{11}x_1 - \beta^{11}x_4$$

Equation (110) is obtained having in mind that, in this case, μ_{p1} is the r.o.g. of Pat_{11} and is the maximum among those referred to country 1 patents flows. In this case all other terms ($\frac{Pat_{i1}^* e^{\mu_{pi}t}}{T_1^* e^{\mu_{p1}t}}\mu_{p1}$) present in eq. (104) disappear in the limit. For the same reason $\frac{Pat_{11}^*}{Pat_{.1}^*} \rightarrow 1$. The remaining patents equations can be used to identify the maximum r.o.g. This completes the stability analysis.

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