

# IT adoption and spatial agglomeration: a model of cumulative adoption and growth in a small open economy<sup>1</sup>

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*Abstract.* This paper deals with the growth potential the Information Technologies (IT) offer to backward regions within an integrated market like the European one. I first present some evidences supporting the idea of strong interregional inequalities in the distribution of IT- investments and induced-productivity gains in Europe. Those evidences suggest that economic geography is an important component of the incentives to invest in IT producer sectors and/or to adopt IT in user sectors. I then applied the theory of circular causation proposed by Ciccone and Matsuyama (1996, 1999) to model a small open (regional) economy which imports differentiated IT-inputs within an imperfect competition market structure. Within this framework, the importance of fixed adoption costs and the existence of pecuniary externalities due to demand complementarities among the providers of IT inputs is highlighted. These key features of knowledge-based production processes are what allow for spatial agglomeration in IT investments despite the very low level of variable transport costs characterizing trade flows in IT-goods and services. The initial industrial and knowledge bases of the regional economy are also emphasized as key determinants of the likelihood of economic catching-up based on intensive IT adoption. Finally, alternative expectation schemes (optimistic versus pessimistic) and alternative market structures (monopolistic competition versus vertically integrated monopoly) may also play their part in providing an explanation for the non (automatic) diffusion of ITs towards peripheral regions.

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<sup>1</sup> This work is related to a previous paper, in French, by Bellone and Maupertuis (2003).

## INTRODUCTION

The revolution of Information Technologies (IT) has strongly contributed to the revival of American growth since the beginning of the 90's but has not induced a similar and uniform increase in the growth performances of European countries. On the contrary, recent evidence on the location of IT producer-sectors and on the dispersion of IT-investments in user-sectors shows that IT-induced-productivity gains are not equally distributed among all the European regions. These facts support the idea that economic geography matters in determining IT investment rates. However, considering that IT are generic technologies and mostly embodied in immaterial goods, it is far from obvious why investments in those technologies and induced-productivity gains should concentrate only in some locations.

To explain this paradox, technology-based explanations have been advanced in the literature on (at least) three different grounds. First, the production of IT's involves industries –for instance, the computer industry- which share the characteristics of highly concentrated industries (strong increasing returns to scale at the firm level, specific factors with low interregional mobility). Second, the adoption of IT requires infrastructures that can be unequally distributed on the European Territory. Third, the efficient use of IT requires complementary investments in human or non-human capitals that can be more or less abundant in different regions.

In this paper, we choose to pursue another avenue in emphasising coordination failures rather than purely technological determinants. Our starting point is that strong micro-economic unbalances characterise IT adoption processes: increasing returns due to fixed adoption costs and pecuniary externalities due to demand complementarities<sup>2</sup> among the providers of different IT goods and services. Such features have been emphasised in the microeconomic on innovation [Katz M.L., Shapiro C. (1985); Arthur B. (1990); Shapiro C., Varian H.R., (1999)] but are scarcely evoked in the literature oriented toward macroeconomic issues. Our aim is to show that coordination failures at the macro level -pecifically, the emergence of low-growth traps- can emerge as a consequence of such microeconomic unbalances.

The paper develops a small open economy framework to analyse the difficulties of coordinating the incentives of adopting IT intermediate goods and services in a local economy which does not dispose initially from a large range of those goods. Analytically, our model applies the circular causation theory of Ciccone and Matsuyama (1996) further extended in Ciccone and Matsuyama<sup>3</sup> (1999). This theory is well suited to investigate the macroeconomic implications of non-convexities arising because of demand complementarities between individual inputs.

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<sup>2</sup> Our emphasis on strategic rather than technological complementarities does not mean that the latter are not important in IT adoption processes. On the contrary, evidence supports the idea that IT investments are complementary to others types of investments.

<sup>3</sup> CM afterwards.

More specifically, CM put the emphasis on structural changes that involve an increase in the roundaboutness of production processes. This kind of changes is key to industrialisation processes. For instance, when a primitive form of agriculture is replaced by a modern technology, the latter relies on tractors, planes, and many supporting services which, when used together, make agribusiness operational. In this case, the passage from a pre-industrial to an industrial technology is associated with an increasing degree of task specialisation and a greater indirectness in the production process.

In the paper, it is argued that the change from industrial to post-industrial (i.e. information and communication) technologies is of the same nature: the adoption of IT allows the adopting firms to replace direct labour by a large range of sophisticated intermediate goods (computers, terminals, software, printers, etc ...). Moreover, adoption of external communication and EDI tools allow the adopting firms to rely for auxiliary activities on an ever larger set of specialized producers services (as financial services, legal services, information system management, advertising, accounting, insurance, personal training, management consultancy, etc...)<sup>4</sup>.

This key feature –i.e. the increase in the roundaboutness of production- is what give birth to a circularity between the choice of technology by consumer goods producers and the variety of intermediate IT goods and services available in the local economy. The issue of interest, in the paper, is to determine under which (plausible) conditions such circularity is strong enough that an economy that inherits a narrow range of IT inputs may be trapped into a low growth path.

The circularity will be strong enough if and only if demand complementarities act at the local level. Of primary importance, then, is the degree of tradability of the specialized intermediate inputs. CM rely on the assumption that inputs are non tradable. While this assumption is reasonable when one has to deal with traditional intermediate goods and services, it is far less suited for dealing with regional trade in IT inputs. We then allow our local economy to rely on specialized inputs initially produced in other regions. At first sight, those opportunities weaken the strength of the input-output linkages that we want to emphasise as a potential source of localized cumulative causation. Looking more carefully to the empirics of IT trade flows, it appears however that IT firms face on average considerable entry barriers in local markets (see, Melchior and Oi (2002)).

Clearly, trade in IT-products is not frictionless: while IT firms face small traditional trade barriers such as tariffs of transport costs, many firms have to invest significant amount on establishing sale channels or adapting products to local markets. These transaction costs cannot than be adequately tackled relying on the “iceberg” transport costs commonly emphasised by the New Economic Geography (NEG) approach<sup>5</sup> [Krugman P., Fujita M., P., Venables A. (1999)]. Transaction costs in IT-goods and services are more fixed sunk costs rather than

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<sup>4</sup> Fujita and Hamaguchi (2001) use a similar argument to explain the increasing use of externally-provided intermediate goods and services by manufacturing firms.

<sup>5</sup> Quah D. (2000) advocate that this basic assumption of the NEG models make them inappropriate to deal with the reality of « ICT clusters”.

variable costs. Those sunk costs exist not only because of providers who need to dispose from local distribution channels but also because of users who support adoption costs including a large variety of connection, material and learning costs. Considered as a whole, those localised fixed costs will explain in our model why the decisions to invest in IT are subject to cumulative effects. The growth dynamics of the modelled economy will then be characterised by multiple equilibria demonstrating the possible occurrence both of virtuous circles, i.e. when the economy makes an intensive use of IT, and of vicious circle, i.e. when the economy is trapped in traditional production technologies.

## **I. THE CONTRIBUTION OF IT TO REGIONAL GROWTH: SOME STYLISTED FACTS ON EUROPE.**

Two main types of empirical works attempt to evaluate the impact of IT on productivity growth. On the one hand, studies based on aggregate and industrial data develop growth accounting frameworks to evaluate the contributions of the production and the diffusion of IT in different countries. On the other hand, studies based on firm-level data attempt to rely IT-Investments to the heterogeneity of individual firms' productivity records. We propose to survey both these literature and to emphasise their main implications as regards the regional growth issue.

### **1.1. Evidence from macro and industry-level databases.**

Aggregate or industry-based growth accounting exercises, available at the country-level, can help to apprehend regional disparities in the following sense : first, if European countries exhibit very dissimilar performances in terms of IT-induced growth, it is likely that regional disparities should be strong as well<sup>6</sup>; second, if specific patterns of IT production and adoption are revealed at the industry-level, this may help to explain why specialised regions exhibit dissimilar performances in terms of IT induced growth.

The first evaluations of the impact of IT on aggregate productivity indexes have been carried out on the US economy in which a sharp increase in the trend of labour productivity and total factor productivity (TFP) growth occurred in the middle of the 1990's<sup>7</sup>. A debate has emerged on the issue to know whether this increase of productivity growth rates was localized in the limited number of IT-producing sectors or whether it has been the result of the diffusion of IT throughout the whole economy. On this issue, some argue that the growth acceleration is mainly due to improved productivity growth in the IT-producing sectors<sup>8</sup> (Jorgenson and Stiroh, 2000) or, even more specifically, in the computer

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<sup>6</sup> Note that the reverse implication (i.e. inferring low regional disparities from the observation of similar performances at the country level) could be far more misleading as IT productivity gains can be equally concentrated in each of the countries.

<sup>7</sup> See Oliner and Sichel (2000) and the US Department of Commerce (2000).

<sup>8</sup> IT-producing sectors consists of IT hardware, radio, television and communication equipment, medical appliances and instruments for measurement (together IT industry), wholesale trade in machinery and equipment, telecommunication and computer services and renting of IT goods

industry [Gordon (2000)]. Other methods of evaluation challenge this view in emphasising the under-estimation bias of the above methodologies [see in particular, Oliner S.D., Sichel D.E. (2000) and Whelan (2002)].

All in all, this debate leads to defend the more general view that TPF productivity gains should not be equally distributed among sectors. At least, they should be higher in industries relying intensively on IT<sup>9</sup> compared to others industries. Baily and Laurence (2001) partly confirm this view. They rank the most dynamical sectors of the US in the late 90s period and report, respectively in the first and subsequent positions, wholesale trade, durable goods industries, finance, retail trade, and airline industry. They also point out that productivity records increased sharply in the sectors of business and personal services.

For Europe<sup>10</sup>, the first notable stylised fact consists in the low average growth performances of European countries compared to the US during the 90s. Van Ark (2002) evaluates the gap between the European Union and the US trends of GDP growth to 1 percentage point per year during the last decade. The second important fact is the increase in the dispersion of intra-European performances during the same period. Hence, while some Northern countries have matched or even surpassed the American performances, the below average performances of continental countries (France, Germany, Belgium) and of Southern countries (Italy, Spain) have contributed to place Europe far being the US.

The invoked causes of this diversity in growth performances across European countries are multifold, ranging from slow growth in investment, rigidities on labour, product and capital markets, sluggish demand and lack of technological progress [Ahn S., Hemmings P. (2000) ; Scarpetta S.A. and alii (2000) ; OCDE (2000)]. However, all the studies agree to attribute a significant role to the intra-European differences in IT investments [see, [Daveri F. (2002); Van Ark, (2002), Colecchia and Schreyer (2001), Oulton (2001)]. And indeed, those studies report that the contribution of IT to economic growth has been substantial in the United Kingdom and the Netherlands and rapidly increasing in Denmark, Norway, and Finland. It was instead less quantitatively relevant in France, Germany, Belgium, Sweden, and outright marginal in Spain and Italy.

In Europe, the main controversial issue turns now to be how much of the performance gap relative to the US economy is due to an «IT production gap» and how much is due to an IT diffusion gap». The former view finds some support in the Van Ark (2002) study which reports that the relative shares of IT-producing sectors compared to the US are significantly lower in almost all the European countries. The author points out that those differences are less pronounced in heavy IT-using sectors, specifically in IT using services<sup>11</sup>. In a

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(together IT services) (this classification is consistent with the OECD one).

<sup>9</sup> It is notable that IT-producing sectors are the industries that use the more intensively IT.

<sup>10</sup> Comparative analyses of the contribution of IT to the growth performances of European countries are more difficult to implement because of the heterogeneity of the data sources. Most of the existing literature rely on the OCDE databases. More recently, the GCDC databases compiled from national, European and OCDE sources have also been mobilized on this issue (see O'Mahony and B. van- Ark eds (2003)).

<sup>11</sup> The criteria used by van Ark (2002) to distinguish between heavy IT users and light users are IT intensity, i.e. the share of IT-investment in industry output, and the industry share in IT capital

similar perspective, evidence on the spatial repartition of IT investments reveals that IT-producing sectors are far more concentrated than IT-using sectors. More specifically, the location of IT-producing sectors seems to have followed a twofold dynamics. Globally, the main trend has been a re-enforcement of the initial advantage of the established Core European regions. Individually, a few « economic miracle »<sup>12</sup> have occurred with the emergence of very dynamic industrial poles in some peripheral regions. This has been, for instance, the case in Ireland and in some Finnish and Norwegian regions [Koski H., Rouvinen P., Ylä-Antilla, P. (2002)].

On the other side, some authors, like Daveri (2002), argue that the lags in the adoption and diffusion of IT are the main cause of the relative performance gap between the European countries and the US. In the same vein, Boyer (2001) argues that a specialisation in IT producing sectors is not a necessary condition to belong to the club of the fast growing European regions. He points out that the Scandinavian countries are better characterised by their common above average performances in IT adoption and diffusion rates than by their specialisations patterns in IT-producing sectors. Specifically, in all these countries, the diffusion of IT has been strongly favoured by the decrease in the price of telecommunications. Colecchia and Schreyer (2001), in a comparative analysis of nine OCDE countries including five European countries<sup>13</sup>, defend a similar view and conclude that IT diffusion and usage play a key role in shaping the European growth performance disparities. They also emphasize that IT diffusion is favoured by right framework conditions, not necessarily by the existence of a large IT producing sector.

## **2.2. Evidence from firm-level databases.**

The empirical works based on firm-level data add fruitful insights for several reasons.

First, micro-based data offer an interesting alternative to address the macroeconomic issue of the contribution of IT to aggregate productivity growth. Working in this direction, Crépon and Heckel (2001) use French firms data, aggregated by sectors, to evaluate the contribution of computers to aggregate growth over the period 1987-1998. Applying a traditional growth accounting framework, they estimate two types of contribution: first, the contribution of the accumulation of computer capital in all industries to apprehend a diffusion effect; second, the contribution of TFP gains observed in the IT-producing sectors.

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stock. According to this criteria, heavy users include some IT producing sectors. Specifically they are : printing and publishing, the chemical industry, electrical and electronic machinery and equipments, medical and measurement appliance (together IT using industries), wholesale trade, post and telecommunication, finance, renting of machinery, computer services, research and development and part of business services (accountants, architectural firms, legal offices, consultants and marketing agency) (together using services).

<sup>12</sup> In the sense of Lucas (1993).

<sup>13</sup> Finland, France, Germany, United Kingdom, and Italy.

They find that the contribution of computer to economic growth is higher than the one usually reported in aggregate studies. For an average growth of 2,6 point par year on the considered period, they find a contribution of 0,3 point per year compared to 0.1 point per year in the Cette, Mairesse and Kocoglu (2000) study relying on French national accounts data<sup>14</sup>. Then, they show that almost an half of this contribution is due to diffusion effects, a result that confirm the idea that aggregate data may partly hide those effects. Finally, they confirm the existence of strong disparities in computer diffusion across IT-using sectors<sup>15</sup>. They find that 50% of the contribution of computer to growth is located in only 13 sectors (on a total of 90) which are the most heavily using sectors and which cumulate 25% of the total value added.

From this latter evidence, it is possible to infer that, because of sectoral composition effects, European regions, which are more specialised than European countries, should exhibit larger disparities in terms of IT contribution to growth. However, the issue to know whether such composition effects could exhaust or not the explanation of regional performances disparities cannot be settled with the Crepon and Heckel methodology<sup>16</sup>.

Micro-based data are also useful because they offer an opportunity to test directly the hypothesis according to which localisation variables are key determinants of the firms' decisions to adopt IT and of the firms' ability to realize the productivity gains potentially associated to these technologies. On this avenue, Karlsson C. (1995), and Fisher M.M. and Johanson B. (1994), emphasise the influence of the population density on the propensity of IT adoption by American firms. Karlsson (1995) shows that this influence is stronger, the more complex is the domain of application in which the firms use the IT. In others terms, the localisation bias in favours of large cities is stronger for innovative firms.

On French data, Galliano and Roux (2003) test directly the impact of geographical factors on the firms' decision to adopt IT. Their work assumption is twofold. First, it is supposed that urban concentration increases the probability to adopt IT. Second, it is supposed that a high concentration of services linked to IT reinforce that probability. The main limits of their study are that IT adoption is only measured by internet and intranet and that the firms' productivity is not evaluated. A positive point however is that they control for the sectoral belonging of the firm and for firm-specific effects with size. Their results are that geographical factors have a significant impact in both the dimension mentioned above.

Finally, Atzeni and Carboni (2004) work on two sub-samples of Northern and Southern Italian firms. They confirm that there is a large asymmetry in the IT adoption behaviours and the productivity performances between these two sub-samples. Unsurprisingly, Northern firms exhibit higher IT investment rates and

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<sup>14</sup> The gap is explained by the fact that the information available in firms' accounting allows tracing more appropriately IT investments.

<sup>15</sup> Defined as all sectors excluding producing sectors.

<sup>16</sup> The only way to do would be to produce an econometric test controlling regional performances by their specialisation patterns. One is confronted with the problem of building a growth accounting framework at the regional level in Europe.

higher TFP performances than Southern firms. More interesting is the fact that the dispersion of Southern firms performances is higher than the one of Northern firms. The authors point out that this higher dispersion can be explained by both localisation and firm-specific effects linked to human capital investment and catching-up opportunities. Their methodology does not however allow discriminating between these two types of effects.

## 2. A MODEL OF IT ADOPTION IN A SMALL OPEN LOCAL ECONOMY

The empirical materials surveyed above show that sectoral composition effects may not exhaust the explanation of regional disparities in IT diffusion and adoption rates. Theoretically, it is not however clear why local cumulative adoption dynamics should occur. We propose then to consider micro-economic specificities characterizing productive processes based on this kind of technologies. These specificities are, first, the presence of important fixed costs going on with the local supply of these inputs and, second, the necessity to rely on more indirect production processes in order to exploit the productivity gains associated to the use of various differentiated IT goods and services.

The analytical framework is that of a small open economy. IT are supposed generic technologies in the sense that they affect positively TFP in all final goods productive sectors. We then simplify the model in considering only one (homogenous) final good sector. IT intermediates inputs are freely tradable. Nonetheless local supply of these goods induces *start-up* costs supported by the local suppliers and *adoption* costs supported by the new users of the goods.

*Start up* costs exist because despite their immaterial character, local supply of informational goods needs usually physical relays on the region<sup>17</sup>. They can be very different according to the economic activity (informatics, internet providers, audiovisual...) as they depend variably of the high specificity of the processed information, of the level of infrastructure costs and of human capital costs<sup>18</sup>. *Adoption* costs are also complex in their structure since they cover both material investments and learning. They are supported by users. However, suppliers of the goods may want to support part of these costs if they want the new technologies to diffuse (for example they could offer physical materials and machines for using the immaterial good they sold or they can propose a learning training to their customers). In the following model, both costs are ultimately supported by final users considering that specialized suppliers can mark up positively their marginal production cost<sup>19</sup>.

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<sup>17</sup> Even if these necessary « relays » are not corresponding to physical enterprises, the firm want wants to sell this kind of goods in a particular locality will have to support a fixed cost of transaction (for instance for installing locally specialized consulting in order to assess local customers needs in IT).

<sup>18</sup> Indeed, the productive value of IT goods and services lies is their high specificity related to differentiated needs of firms. But this acute adaption to firms specific needs involves a fixed cost necessary to use efficiently the intermediate good or service in the production process.

<sup>19</sup> Monopolistic structures which prevail on internet services market at the regional level strengthen this hypothesis. The analysis of the structure of these costs could be an interesting extension of the present work. This could highlighth the interaction between market structures and



Considered as a whole, *start-up* and *adoption* costs represent a fixed cost the level of which can vary according to various determinants (quality of infrastructures, connexion costs, learning capabilities...). These determinants are sectors specific and firms specific but also spatially determined. For instance, the level of the fixed cost may differ whether the input or the productive service is produced locally or whether it is simply furnished locally (and produced abroad). This doesn't mean however that the input is systematically more costly when it is locally produced. As showed by Fujita M. And Hamaguchi N. (2001) adoption costs (particularly learning costs) are reduced for the users when close (geographical) contacts are possible between them and the producers. Since the actual levels of these fixed costs are difficult to assess, we prefer to not differentiate them as regards the location origin of the provided input<sup>20</sup>.

Once admitted the existence of the fixed costs in the local supply of the specialized input we can say how they are central for explaining the existence of a no-growth trap. In fact these local *start up* costs and *adoption* costs weigh up the investment decisions because of pecuniary externalities associated to them. Indeed, inputs suppliers are confronted to dynamic increasing returns. Precisely, from an individual supplier point of view the incentive to support the previous described costs depends on anticipations relative to market size. If the anticipated demand is high, news entrants are more numerous and then the range of specialized inputs will be larger. Then, entry in a market of a new IT supplier produces positive externalities in the sense that profits induced by this entry are not totally appropriated by those that have supported the fixed costs. Indeed, local furniture of new IT inputs makes producers of final goods to adopt more roundabout production processes (i.e. to use more intensively IT relatively to labour). Then global demand for all specialized inputs will grow. Other producers of intermediate goods will benefice from this increased demand and their own individual profits will expand.

It is important to highlight that these complementarities between specialized inputs is strategic rather than technological. It is the vertical complementarities between final goods sector and intermediate goods sector that are enhancing profitability of investments. In this framework, the dynamic of the economy is characterized by multiple equilibria with the occurrence of virtuous and vicious growth circles.

## 2.1. The analytical framework

The modelled economy is a Small Open *local* Economy (SO/E) endowed with a fixed amount of labour (L) and producing competitively homogenous final consumption-goods from those labour and from an endogenous variety of IT-intermediate-inputs.

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growth dynamics.

<sup>20</sup> From a formal point of view, this simplifying hypothesis also has a tractable implication: the symmetry between inputs in their productive contribution to the final good sector can be preserved.

*The final consumption-goods sector.* The consumption-goods technology is given most generally by  $C = F(m_C^i : i \geq 0, L_C)$  where  $L^C$  denotes the quantity of labor and  $m_i^C$  the quantity of intermediate input  $I$  employed in the production of consumption goods<sup>21</sup>. We assume that the consumption-goods technology can be rewritten as

$$C = F(M_C, L_C) \quad (1)$$

where  $F(\cdot)$  is a linear homogenous concave, and twice continuously differentiable function, and

$$M_C = \left[ \int_0^n (m_C^i)^\beta di \right]^{1/\beta} \quad \text{with } 0 < \beta < 1 \quad (2)$$

where  $[0, n]$  is the continuum of differentiated IT input available at any moment in time in the local economy. Note that the range  $n$  depends both on time and on geographical space. Indeed, over time this range can be increased in a given locality by allocating a fixed amount of resources to local start-up operations<sup>22</sup>. We refer to  $M_C$  as IT-intermediate-input composites.

This specification implies weak separability between differentiated inputs and labor. The assumption  $\beta > 0$  ensures that no single input is essential for producing IT-intermediate-inputs composites<sup>23</sup>. All differentiated input enters symmetrically into the intermediate-input composite, and the elasticity of substitution between any pair of inputs in the production of intermediate-input composites is constant and equal to  $\sigma = 1/1 - \beta$ .

Specification (2), widely used in the new growth and new economic geography literature, has been first introduced by Dixit and Stiglitz (1977) and Ethier (1982) to formalize the following idea: the larger the specialisation of tasks in upstream sector, the stronger the productive contribution of intermediate inputs in the downstream one. In other words, total factor productivity increase with the variety of intermediate inputs available. And indeed, with an elasticity of substitution upper than one, the price index of intermediate-input composites, decreases with the number of intermediate goods offered in the economy. Moreover this effect is stronger, the weaker the elasticity  $\sigma$ . To see this, let us assume that all inputs are charged at a common price (this will be true at the equilibrium). Then, the cost of the IT-intensive-input composite can be written as

$$P_M = \left[ \int_0^n [p_m(i)]^{1-\sigma} di \right]^{1/(1-\sigma)} = n^{1/(1-\sigma)} p_m \quad (3)$$

<sup>21</sup> All endogenous variables depend on time but time subscripts are generally omitted, i.e. unless confusion is caused by doing so.

<sup>22</sup> It is implicitly assume that the space

<sup>23</sup> Recent studies have demonstrated the existence of strong technological complementarities between different inputs lied to IT. For instance in USA during the year 1998-99, one estimated that for one dollar spent in materials, firms had to support 2,3 dollars of technical consulting and maintenance services. In the present paper, those complementarities are not taken into account not only to simplify the purpose but also to show that problems of economic coordination are as important as technological complementarities.

Specification (2) does not however imply that the production processes becomes more roundabout when the range of intermediate inputs increase. In order to reproduce this second key feature of IT based production processes, we need to constraint further specification (1).

Let assume that the consumption-goods technology combines L and Mc with the following specification

$$C = F(M_C, L_C) = [M_C^{\beta'} + L_C^{\beta'}]^{1/\beta'} \quad \text{with } 0 < \beta' < 1 \quad (4)$$

It implies that the elasticity of substitution between Mc and Lc,  $\varepsilon$ , is greater than 1. This, in turn implies that the relative share of intermediate inputs used in technology (1) increases more than proportionally when the relative price of intermediate-input composites decrease<sup>24</sup>. In other words, Mc and Lc are strongly substitutable<sup>25</sup>. That means that when the price of Mc decrease, the share of the value added by the upstream industries relative to the value added by the downstream industries increases. In other words, the intensive use of IT intermediate goods in a modernization process increases the roundaboutness of production processes. This evolution makes the quantity of labour directly used in the final-goods industry to decrease and, reciprocally, the quantity of labour used by the intermediate-goods industry to increase<sup>26</sup>.

Formally, this implies a positive relationship between, n, the range of IT-goods locally available and the relative share of intermediate inputs in the global output. This is because the larger the range of intermediate goods supplied in the economy, the weaker the relative cost of the intermediate input composite, i.e.  $P_M/w$ .

If we note  $\alpha_t$  the relative share of intermediate inputs in the global output, we have:

$$\alpha_t = \alpha(n_t^{1/1-\sigma} p_m / w) \equiv A(n_t) \quad \text{with } A'(\cdot) > 0 \quad (5)$$

This property is what explains the possible occurrence of a circularity between the choice of technology made by the local producers of the final consumption-goods, and the incentives to supply locally new IT-goods and services in upstream industries. In order to understand this mechanism, let's consider the decisions taken by the suppliers of IT-intermediate-inputs.

*The IT intermediate-goods sectors.* Each supplier of IT intermediate-inputs faces an increasing returns technology in the sense that he can supply the local economy only if he accept to uncover some local fixed costs besides other variable costs.

<sup>24</sup> For a more general specification see CM (1999).

<sup>25</sup> We have to underline that  $M_C$  does not correspond here to a capital stock but rather to a set of intermediate goods and services.

<sup>26</sup> Note that the underlying hypothesis is not the one of a strong substitutability between labour and capital (this assumption is not empirically verified) but that of a modification of the vertical structure of the production.

Moreover, we assume that this cost is the same whether the specialized input is produced locally or whether it is imported. We note  $F$  and  $a$  the amount of labour necessary to cover, respectively, the fixed costs and the variable costs for each specialized inputs.

Under the assumed monopolistic competition framework, each intermediary good is supplied by a unique firm which benefits from a monopoly power on its market niche. Then, each supplier sets the price applying a mark up on its marginal cost of production  $w_i a$ . Normalizing<sup>27</sup> units such that  $a = \beta$ , this price can be written

$$p_m(i) = p_m = \frac{aw}{\beta} = w \quad (6)$$

The instantaneous profit of the IT-input supplier is given by

$$\pi = (p_m - aw) m(i) = \frac{p_m m(i)}{\sigma} = \frac{\alpha Y}{\sigma n}$$

which can be re-written taking into account (6), as

$$\pi_t = \frac{A(n_t) Y_t}{\sigma n_t} \quad (7)$$

Equation (7) highlights the double effect of an increase in  $n$ , the range of IT inputs locally available or, in other words, the double impact of the entry of a new supplier of IT-intermediate-inputs on the profit of the incumbents. In the one side, this new entry means more competition which reduces the profit by variety, being given the level of expenses devoted to these production factors. In the other side, this new entry affects positively the global level of expenses devoted to IT-intermediate-inputs as the share of product devoted to this kind of expenses increases relatively to the one devoted to labour. This second effect increases the profit by variety.

The net impact of an increase of the range of IT inputs on the profit per variety is then ambiguous. When revenue effects are stronger than substitution effects, specialized inputs become strategic complements. In this case, pecuniary externalities appear in the production of IT goods and services. In order to understand the consequences of this, the equilibrium conditions must be defined.

The free entry condition in the monopolistic sector is sketched as follows : if we wrote  $w_i F$  the fixed cost (defined in terms of wage) necessary for entry in the intermediate good sector, and with  $v_t$  the present value of this new entrant, free entry condition can be written as :

$$w_t F \geq v_t, \dot{n}_t \geq 0 \text{ where strict equality holds if } \dot{n}_t > 0 \quad (8)$$

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<sup>27</sup> This normalization is usually used in monopolistic competition model (cf. [Fujita M., Krugman P. and Venable A. (1999)]. It does not imply a loss of generality in the equilibrium conditions even if it could be troublesome when implementing static comparative analysis (cf. [Neary P., (2001)].

The entry will be effective only if the no arbitrage condition between financial market and goods markets is respected such that  $v_t$  is equal to the present discounted value of profits

$$v_t \equiv \int_t^{\infty} e^{-(\tau-t)} \pi_{\tau} d\tau.$$

From which we obtain

$$\pi_t + \dot{v}_t = \dot{r}_t v_t \quad (9)$$

The last equilibrium condition concerns the allocation of labour resource between sectors. Indeed labour supply in the economy must be equal to the sum of labour needed to produce final goods, labour used for the production of intermediate goods and to cover *start-up* costs faced by news entrants in the IT sector.

$$L = L_{BF} + L_{BI} \quad (10)$$

$$\text{with } L_{BFt} = \frac{(1-\alpha)}{w_t} Y_t \text{ and } L_{BI} = n_t am(i) + F\dot{n}_t = (1 - \frac{1}{\sigma})\alpha_t (\frac{Y_t}{w_t}) + F\dot{n}_t.$$

It comes that the productivity increase is given by

$$F\dot{n}_t = L - (1 - \frac{A(n_t)}{\sigma}) \frac{Y_t}{F(n_t^{1/(\sigma-1)} A(n_t), 1 - A(n_t))} \quad (11)$$

Then the extension of the production process - i.e. the division of labour in the economy – and the increase of related productivity gains can only be obtained through a re-allocation from the final good sector towards the IT inputs one<sup>28</sup>.

## 2.2. The evolution of the economy and the occurrence of no-growth traps

Growth opportunities for the small open economy are bounded in the long run by the market size<sup>29</sup>. Then in the presence of a constant fixed cost, the size of the local market (the labour force is fixed to L) limits the number of viable competitors on a monopolistic competition market. Consequently there will be a time when the productivity gains involved by a new entry will not be sufficient to compensate the cost of this entry. The growth dynamic we model here is a transitory one. In other words, we will show that with some key parameters values our economy could be locked on a low equilibrium (i.e. with a reduced number of IT firms) or instead follow a transitory dynamic to reach a high equilibrium (i.e. an allocation characterised by an intensive use of IT and the enlargement of the related market). These different configurations can be described using the

<sup>28</sup> This supposes that it exists a perfect mobility of the workforce from downstream sectors to upstream ones. Without such a mobility, human resources and coordination failures on labour market could be additional constraints in the modernization of productive methods.

<sup>29</sup> It could be more realistic to impose a technological limit to the division of labour implied by the introduction of IT. We use this « unrealistic » formulations à la Dixit-Stiglitz for simplification. Remember that the aim here is to explain the lock-in which prevents to adopt technical change and not to explain the limits of growth induced by this technical change.

evolution of two key variables:  $n$  the number of varieties in the economy and  $V = v/Y$ , the value of an IT firm measured in utility.

Using (1), (7) and (9) the evolution of the value of an IT firm through time is given by :

$$\dot{V}_t = \rho V_t - \frac{A(n_t)}{\sigma n_t} \quad (12)$$

Simultaneously (8) and (10) authorize to write the evolution through time of the number of IT suppliers

$$\dot{n}_t = \max \left\{ \frac{L}{F} - \left(1 - \frac{A(n_t)}{\sigma}\right) \frac{1}{V_t}, 0 \right\} \quad (13)$$

with considering (1) and (12),

$$\lim_{t \rightarrow \infty} V_t n_t e^{-\rho t} = 0 \quad \text{when } t \text{ tends to the infinite} \quad (14).$$

There's an equilibrium with no more incentive to enter the IT sector ( $\dot{V} = 0$ ) and when the number of IT suppliers present in the economy is constant ( $\dot{n} = 0$ ). In this case we have using (12)

$$V = \frac{A(n)}{\rho \sigma n} \quad (AA)$$

and then using (13)

$$V = \frac{F}{L} \left(1 - \frac{A(n)}{\sigma}\right) \quad (BB)$$

These two last expressions give us the geometrical locus where the value of an IT firm is constant for a constant number of suppliers present on the market. It exists a number  $n^*$  of suppliers such that (AA) = (BB) that can be defined as follows :

$$\Omega(n^*) \equiv n^* \left( \frac{\sigma}{A(n^*)} - 1 \right) = \frac{L}{\rho F} \quad (15)$$

This result shows that the set of intermediate goods offered in the economy is a function of the market size, in other words the importance of the labour force. Then, the division of labour depends from the size of the market. Reciprocally the lengthening of the production process induces the extent of the market.

When the roundabout process is sufficiently important through the introduction of IT, this circularity implies a multiplicity of equilibria (i.e. the occurrence of a virtuous circle or reciprocally the persistence of a no-growth trap). Precisely, we can show that this multiplicity of equilibria appears as the condition  $\varepsilon > \sigma > 1$  strictly respected<sup>30</sup>.

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<sup>30</sup> For more details, see the demonstration made by CM (1996), p.43.

In this case as  $\alpha = A(n) = 1 + wL_{BF}/P_K$  and being given the definition of the elasticity  $\varepsilon$ <sup>31</sup>, the equilibrium condition can be written as

$$\frac{1}{A(n)} = 1 + n^{(\varepsilon-1)/(\sigma-1)} \quad \text{that is} \quad \frac{n}{A(n)} = n + n^{(\sigma-\varepsilon)/(\sigma-1)}$$

such that the value  $V$  ( given by 12) is maximal for a number of suppliers  $\bar{n}$  given by :

$$\bar{n} = \left[ \frac{(\varepsilon - \sigma)}{\sigma - 1} \right]^{(\sigma-1)/(\varepsilon-1)}$$

This number is a discriminating value for characterizing the nature of the goods and services. Indeed for  $n < \bar{n}$  intermediate goods are complements in the sense of Hicks-Allen, i.e. the demand for one good decreases when the price of other goods increases. When  $n > \bar{n}$ , intermediate goods are substitutes in the sense of Hicks-Allen, i.e. the demand of one good increases when the price of other goods increases<sup>32</sup>. It results that the evolution of a firm value when the number of intermediary goods increases in the economy can undertake different trajectories as these goods are strategic complements or not. Particularly even if fixed costs are low, the modernization of the production process could not be implemented. In order to describe these various dynamics we have to consider the different parameters which influence directly the probability of occurrence of each of them. These parameters are : the level of fixed costs, the number of IT inputs available in the economy (i.e. initial conditions) and finally the nature of the anticipations on the local supply of IT goods and services.

*The level of fixed costs: a necessary condition to reach growth trajectories.*

High fixed costs appear as an insuperable constraint for the economy. Indeed for high value of fixed costs, the entry of new suppliers is never profitable, even if the initial number of suppliers is as low as the investments could be strategic complements. Then in this case, each initial situation is a trivial equilibrium such that an economy that possesses only a narrow range of IT goods and services will not be incited to enlarge it. This result is explained by the fixed costs constraint that weights in terms of resources on a small economy (here a region). The underlying - and basic - idea is that an important fall in costs of access and of infrastructures is a necessary condition (even if an insufficient one) to reach a growth regime using intensively IT.

*Threshold effects in the development of IT goods and services.*

For intermediate fixed costs, the long term equilibrium that will prevail in the economy depends on the initial situation, i.e. of the number of intermediate goods and services present at the beginning. In this case, one can identify a low

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<sup>31</sup>  $\varepsilon (P/w) = - \frac{d \log(K/L_{BF})}{d \log(P/w)}$

<sup>32</sup> It is noteworthy that if  $1 < \varepsilon < \sigma$ , the geometrical locus described by  $V$  does not have a maximum. In this case the system has got a unique solution. An economy which has got initially a narrow set of intermediate goods will be a good candidate for start up new IT firms.

equilibrium (with  $n_1$  suppliers) and a high equilibrium (with  $n_2$  suppliers and  $n_1 < n_2$ ). If the economy has got a weak industrial basis (less than  $n_1$ <sup>33</sup>), final goods producers have no incentives to use IT. The demand of IT goods and services remains weak and there's no motivation to entry in this sector. The economy is trapped on traditional productive methods and productivity gains cannot emerge.

On the contrary for an initial number of suppliers upper to  $n_1$ , the IT inputs yet available in the economy, the incentives are sufficiently strong such that virtuous mechanisms of growth are putted in motion: producers of final goods are incited to adopt IT and producers of IT goods and services are incited to enter the market. The roundabout method of production of the final good extends the market size. The economy invests in IT and that procures productivity gains. The cumulative virtuous process plays until the competition in the IT sector reduces the incitation to enter this sector. The economy is then on a high equilibrium (for  $n_2$  suppliers) with the productive system strongly using IT.

*Anticipations and the need for coordination in the adoption of IT.*

If fixed costs are weak, two new effects appear: on the one hand, the high equilibrium is more easily reached even if the industrial basis is relatively narrow ( $n_1 < \tilde{n}$ ). On the other hand, it exists an interval of initial conditions for which the occurrence or the non-occurrence of the virtuous circle will be conditioned by the nature of the anticipations of agents.

For optimistic anticipations from IT furnishers, strategic complementarities are in motion even if the initial number of these furnishers is small. Precisely each IT furnisher anticipates that after the simultaneous entry of competitors, the enlargement of the scope of IT goods and services in the economy he contributes to will be sufficiently important to induce other incentives to enlarge this scope. With self-fulfilling prophecy the high equilibrium is reached, i.e. the positive feedback between entry and increase of the share of intermediate goods in the final product induces the virtuous circle expected along this path.

On the contrary, if potential suppliers of IT have pessimistic anticipations on the probability to simultaneously enter the IT sector, the initial weakness of the industrial basis play as a barrier to development. In this case, the incentives to adopt and produce IT are inexistent and the small open economy is trapped in a low growth path.

This result explains in the terms of coordination failures why some small regions with narrow industrial basis do not invest in IT. Indeed two regions which have similar technological conditions (IT infrastructure network, level of human capital, learning capabilities, etc.) can implement in this model various growth trajectories. Moreover, these multiple equilibria exist only for initially backward economies. In our perspective, a region sharing these characteristics with an initial basis sufficiently large could encounter a virtuous circle. A corollary of the same result is that actions dedicated to reduce considerably fixed costs may have

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<sup>33</sup> Note that the number of suppliers  $n_1$  corresponds to  $\tilde{n}$  that is the threshold under which IT goods and services are complementary in the sense of Hicks-Allen.



miraculous consequences for a peripheral region. Indeed if fixed costs become very weak, optimistic anticipations could alone have a stimulating impact on the adoption-entry process previously described (i.e. independently of initial conditions).

## CONCLUSION

Information technologies may open a large growth potential for peripheral regions suffering from underdevelopment. Nonetheless growth dynamics induced by an intensive use of these technologies are not a common pattern in all European regions. Until now, technology-based explanations have been emphasised by the literature. For instance, the lack of infrastructures or the low level of human capital have been advocated as important constraints to the diffusion of IT and the modernization of production processes. In our analysis, we show that economic coordination constraints can also play an important role if the decisions to invest in IT inputs give rise to demand complementarities in a decentralised economy.

It is notable that the pecuniary externalities that give rise to cumulative causation dynamics in the model are not of the same kind than the ones allowing for agglomeration processes in the New Economic Geography approach. In the latter models, these are the opportunities to save variable transport costs that produce the adequate incentives for consumers and furnishers to locate closed from each others. In our model, these are the fixed costs combined with demand complementarities which give rise to localized cumulative causation processes.

Our analysis also allows understanding how technological constraints interact with market failures. In the model presented above, too high fixed costs act as an insurmountable barrier. In this case, even an *ex ante* coordination of IT investments could not be sufficient to make a high growth trajectory viable. Indeed, the resource constraint imposed by the high level of fixed costs is such that the economy, without external assistance, is trapped into traditional productive technologies. If technological constraints are loosened (with foreign assistance or infrastructures investment) coordination failures may appear, in particular for regions which lack from a sufficiently developed industrial basis.

These difficulties may be reduced through adequate public policies. It is however required to define the practical modalities under which economic agents will be incited to make the optimal choices in terms of IT investments. This prerequisite for public action seems to be difficult to set up because of the nature of the involved externalities. These are inherent to the multiplicity of IT-intermediate goods and services. None of these inputs plays a key role in this process. On the contrary, productivity gains are the result of the cumulative impact of incremental improvements made by multiple firms. In consequence, the problem is not to subsidize the accumulation of a single identified factor which produces positive externalities but to promote the development of interrelated industrial and services activities in a context where it is difficult to clearly identify the nature of the links existing between the inputs used in the production process.

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