ICT and Productivity:
relations and dynamics in a spatial context

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Abstract:

The wide acceleration of Information and Communication Technology (ICT) in the last decades was one of most impressive 'stylized facts' in the economy. Together with this rise of this new technology the impact on productivity was stressed: the 'new economy' has the potential to stimulate productivity growth. Although the considered potential role of ICT in the resurgence of the productivity growth, the real productivity impact stayed out. Solow (1987) formulated this as 'you can see the computer age everywhere but in the productivity statistics'. This paper focuses on the spatial relationship between ICT and productivity in order to contribute in clarifying the complexity of the ICT-productivity paradox. By 'introducing' the spatial dimension we try to gather more information on the stimulating role of ICT on productivity. We quantitatively analyze the relationship between ICT sensitivity and productivity on a low spatial level (that of Dutch municipalities) and test hypotheses about this relation. We wonder whether higher ICT sensitivity (or it's growth) co-locates with higher productivity (and growth). We also test for having a high head start in ICT adoption co-locates with higher productivity levels and whether there is convergence on the regional level (an interesting outcome for regional policy makers). Special focus on the heterogeneity within urban areas is analysed by investigation whether in economic dense regions higher labour productivity is overrepresented and if in urban regions the co-location between ICT (or it's growth) and productivity (or growth) is stronger than in less urban regions. The construction of our data on the regional level produced a unique dataset. Because of the low spatial scale in our analysis we can address the heterogeneity and endogenousness of the differences in urban context.

Keywords: productivity, ict, knowledge economy, regional economic development, urban economics

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1 Introduction

The wide acceleration of Information and Communication Technology (ICT) in the last decades was one of most impressive 'stylized facts' in the economy. The use of ICT in business processes grew hard, prices of ICT applications lowered and the adoption was seen 'almost everywhere'. In the year 2004 approximately 95 percent of all companies in The Netherlands use computers and almost 60 percent of all employees work with a computer (Statistics Netherlands 2005). Together with the rapid ICT adoption ICT was imputed as the motor for new economic growth. In combination with low inflation and low unemployment rates especially the boosting productivity effects of ICT were considered large. Besides being an example of a major technological innovation itself, ICT also enables the creation of new and better (higher added value) applications, streamlining production processes and the lowering of (transportation and transaction) costs. Labelled as the 'new economy' ICT was considered to be a breakthrough technology which should bring us on the threshold of a new wave of socio-economic developments.

Although the considered potential role of ICT in the resurgence of the productivity growth, (for a long time) the real productivity impact stayed out. Solow (1987) formulated this as 'you can see the computer age everywhere but in the productivity statistics'. This paradox: the rapid diffusion of computer technology having little impact on productivity growth, has become a broadly discussed topic in economics. Many studies since than tried to solve the paradox. By analyzing a longer period (Bartelsman & Doms 2000), by differentiation in the measurement of 'ICT' (Becchetti et al 2003, Bavec et al 2003), e.g. by making a distinction in the type of hardware and type of software, or differentiation in measuring 'productivity' (Schreyer & Pilat 2001), by specification in types of economic activities, e.g in ICT producing and ICT using sectors or non-ict using sectors (Vijselaar & Albers 2004, Van Ark & Piatkowski 2004), by making relations with spillover effects stemming from networks (Creti 2001) or by linking the ICT-effect to innovation (Van Leeuwen & Van der Wiel 2003) or organisational changes (Bertschek & Kaiser 2004), contributions were made in clarifying the ICT effect on productivity.

In contrast, analysing the relationship between ICT and productivity in a regional context is relatively scarce. The regional context in mainly introduced by making comparisons between countries (Collecchia & Scheyer 2002, Atrostic et al 2002) or is focussing on the enabling role of ICT in making economic activities ‘footloose’ as the result of the ‘death of distance’ (Cairncross 2001). This ‘end of geography’ implicitly implies that research on the spatial economic effects of ICT is less relevant. On the contrary (to geography as being irrelevant) there are reasons to believe that the development of ICT has had a specific effect on the geographic concentration of economic activity. ICT intensive activities tend to be more concentrated than other economic activities (Acs, 2002). This effect of scale economies is reflected in the ‘new economic geography’ which stresses that agglomeration results from demand linkages. Spatial concentration creates an environment that stimulates further spatial concentration (Puga, 1999). Spatial models used in this framework predict a continuous agglomeration of economic activities. Only if transport costs are sufficiently high, producers outside the agglomeration can survive. Due to these high transportation costs they face less competition for their local demand from more scale efficient competitors of the large agglomeration. However, transport costs and markets are not given. ICT applications lower transport costs of material goods and codified information and by this have a liberating effect on the burden of transport. Given the now lower transport costs because of ICT, scale economies become most relevant. These are lowest at the location with the largest production: the agglomeration. A lowering of transport costs by ICT will induce further agglomeration. Non-urban locations are cumulative confronted with lower scale economies (Krugman, 1996). The pull of scale economies is larger than the push of transportation costs. As long as the models use two sectors of production (manufacturing and agriculture) the inevitably of non-urban decline is robust (Kilkenny, 1998). If we relate also this spatial perspective to the second assumption, indicating upgrading, this results in a fourth assumption which does not assumes spatial convergence like the third assumption, but rather spatial divergence by which central locations will profit.

Besides these effect on costs there are more nuances in regional and local circumstances that can be of influence in the relation between ICT and productivity. First it is arguable that besides firm internal factors that contribute to productivity, also external factors, such as spatial externalities and agglomeration economies can have their impact on productivity. Many authors have justified the existence of cities and other population clusters by the existence of externalities and increasing returns to density (Krugman 1991, Le Bas & Miribel

2005). It is assumed that particularly urban agglomerations with their diversified production structure, labour supply, physical and social infrastructures create externalities which foster organizational innovations (Van Oort & Atzema, 2004). Spatially then theories which relate non-technological knowledge to concentrated growth patterns become relevant (Gaspar & Glaeser, 1998). Spatial dynamics are related to processes of cumulative causation in which particularly knowledge supply and spill over plays a role. If non-technological innovations come to the fore, then above all also knowledge capital becomes important.

In relation to this, Rosenthal and Strange (2001) made – empirically – a distinction between knowledge supply and knowledge spillover effects. For the supply of knowledge, knowledge workers are important (Florida 2002; Lambooy *et al.* 2001). These are supposed to be social competent, network sensitive and aimed at cooperation. Kolko (2002) confirms this in relation to ICT: the slow regional convergence of high skill level IT using industries is due to their high skill level rather than their usage of IT as such. It is assumed that ICT reduces distance-related burdens for many resources, and therefore enterprises concentrate on the locational preferences of the most important (and least mobile) production factor: labour (Van Oort *et al*., 2003b). And this knowledge supply is found particularly in the larger urban regions. For employers searching for rather immobile knowledge workers, a location near these workers is attractive (Horan *et al*., 1996; White, 1999). Boarnet (1994) earlier showed that urban employment changes are endogenous to labour market supply changes. This constitutes an important departure from past patterns of urban development in which labour supply was largely exogenous to residential location. That worker residential preferences appear to be extremely important for industrial location is also confirmed by several empirical studies (Glaeser & Kahn, 2001). For the Netherlands, using a spatial two stage least squares model with instrumental variables Bruinsma et al (2003) confirm this.

An extension of the supply approach concentrates on knowledge spillover. Spatial concentration of activities increases the opportunities for interaction and knowledge diffusion. The agglomeration of labour makes workers more productive (Black & Henderson, 1999; Ciccone, 2002). Spill over minimizes the cost of obtaining knowledge. Costs of acquiring knowledge are sunk costs, and city-specific human capital can be exploited locally at virtually zero marginal costs (Simon & Nardinelli, 2002). Especially face-to-face contacts and networks are important. To reduce interaction costs, face-to-face contacts of knowledge workers take place in agglomerated (urban) environments. Knowledge workers benefit from being near other knowledge workers. Proximity to knowledge networks is of utmost importance for creating spill-over, stressing the interchange of knowledge in localized networks. Learning, an essential element of endogenous growth mechanisms, is related to these networks (Lucas, 1993, Beardsell and Henderson, 1999).

Empirical research on knowledge spill over reveals that the (physical) spatial reach of influence is rather small and that urban borders are only seldom crossed. Knowledge is apparently most fruitfully exchanged around the corner of the street (Jaffe *et al.*, 1993, Rosenthal & Strange, 2001). Result of the strong spatial knowledge distance decay is a strong increasing return at the location where knowledge is most present, the urban agglomeration (Acs, 2002). In this, the role of ICT is not subsidiary, but forms the glue in facilitating more efficient networks (Gaspar & Glaeser 1998). More emphasis on networks, facilitated by ICT, coincides with a growing importance of knowledge workers and for knowledge networks within and between organizations (Van der Laan, 2001).

In this paper we analyses the relation between ICT and productivity in a regional context. By descending to a low geographical scale and by making a distinction in types of urban environments we get a better grip on the potential stimulating ICT effect. First we clarify in the rest of this paragraph why we analyse the ICT-productivity relation in a regional context. We focus on small scale municipal spatial patterns of change in the Netherlands. After that we formulate our research questions and hypothesis and give insight in our data and mythology (2) and the description of the variables (3), we discuss the research results related to each hypothesis in a separate paragraph (4-6). Paragraph 7 summarizes our conclusions.

2 ICT and productivity: questions and hypothesis

In this paragraph we formulate our research questions. Our main goal is to analyse the potential productivity stimulating effect of ICT. ICT can contribute to labour productivity growth directly through capital deepening, but as Bartelsman and Hinloopen (2000) stated, ICT-use plays also a role via ‘unknown’ aspects hidden in the increases of productivity. These hidden factors are related to the manner ICT is implemented in organizations and human capital. Also Bresnahan *et al.* (2001) showed how effects of ICT on economic growth strongly depend on simultaneous changes in the organization and the application of human capital. If organizations only concentrate on ICT-investments, productivity effects are smaller compared to those of organizations which do not apply ICT. ICT does not function as an element on its own, but is embedded in the organization and in people, i.e. knowledge (Steijn, 2001). Before we analyse the capital deepening effect of ICT we first focus is on the embeddedness of ICT in organisations and human capital. Our first question then is whether there is a positive relationship between the intensity of ICT-use within companies and the level of education of their employees. This hypothesis has been already put forth by Roach (1991), Berndt et al. (1992) and Stiroh (1998), which argue that, even though ICT may substitute for labour, it also increases white collar productivity and hiring rates.

Our analysis in this paper are focussed on the regional level, especially our last two hypothesis. Also for the relationship between education and ICT this regional level is relevant. Ideally we want to investigate this relation on the micro-level of the firm or establishment. Since data on this level is scarce, our analysis on the meso-level (Dutch municipalities) give in to objections of the macro-level (having less detail).

Hypothesis 1: Higher ICT sensitivity co-locates with higher demand for skilled labour

After controlling for the 'human capital' effect within the relation between ICT and productivity we now focus on the direct capital deepening effect of ICT on labour productivity. As said in the introduction ICT has the potential effect to stimulate the productivity. We now directly analyse the link between ICT and productivity.

Hypothesis 2: Higher ICT sensitivity co-locates with higher productivity

We also test whether the growth of ICT over time (1996-2002) contributed to a higher level of productivity in 2002. Our assumption is that the increase in ICT will have a stimulation effect on performance.

Hypothesis 3: Higher growth of ICT sensitivity in recent years co-locates with higher productivity levels

Within this analysis we also want to know whether a high starting point in the past has influenced the growth potential. Does a high level of ICT adaptation in the past influence the productivity levels nowadays (the head start effect), or is there a catching up effect leading to regional convergence? We expect that having a strong basis and a head start position in de past will be positive for productivity levels now. This can for instance stem from more experience and the greater network externalities of the early adapters.

Hypothesis 4: A high head start in ICT adoption co-locates with higher productivity levels

After analysing static relations between ICT and productivity we now we focus on the dynamics in ICT sensitivity and their effect on productivity growth. Is it really the growth in ICT adaptation that stimulates productivity growth? We expect that the growth in ICT positively influences the productivity growth.

Hypothesis 5: Higher ICT growth co-locates with higher productivity growth

Our analysis in testing these five hypothesis are based on productivity defined as *labour productivity*, measured as the gross value added per employee (full time equivalents) (see appendix 1 for explanation). Being labour productivity the dependent variable, and ICT an independent variable that influence productivity, we control our regressions for the Capital/Labour-ratio (in a region). Following the production function (Solow 1957), a rise in capital over labour will contribute to labour productivity. This is the general capital deepening effect of investments. Alternatively, the C/L-ratio growth can also be interpreted as process innovation, taken broadly, which is expected to contribute to labour productivity (Frenken et al 2005). In all the models we ran de C/L-ratio or the growth of the C/L-ratio is an important control variable for sectoral endownments.

All our analysis on the relationship between ICT and productivity are on the regional level: that of 496 Dutch municipalities. This low spatial scale is the aggregated level of all firms (measured by establishments) within a municipality. On that low scale not all data are available, so we construct data by combining different data sources. Our main source is the LISA dataset, which contains all Dutch business establishment by their exact location, the number of jobs and their SIC-code (economic activities in 5 digit numbers): e.g. in 2002 more than 800.000 individual establishments were result in the dataset. Because of the very detailed distinction in economic activities this file is suited for linking of statistics on a more aggregate level (for example national, Nuts-2, Nuts-3) to a low regional scale. The data on ICT (Statistics Netherlands) are based on national statistics with a distinction in over 58 different SIC-codes (2 digit level). The data on productivity (value added and employment) from the National Account of Statistics Netherlands are based on 103 economic sectors. The regionalization of the productivity statistics was in a second step corrected for differences in value added and labour for regional productivity statistics: which have more regional detail, but less sectoral detail (Statistics Netherlands, Frenken e.a 2005 and Broersma & Oosterhaven 2004).

We expect that due to regional differences in production environments and firm external (spatial linked) factors on their productivity and the ICT adoption, the relationship between ICT and productivity can be influenced. Urbanisation economies might play a role: the benefits for firms that arise when locating near to firms (irrespective of their activity). External economies, available to all local firms irrespective of sector, arise from urban size and density can influence the productivity of firms and when analyzing productivity effects in a spatial context we want to control for these effects. We expect that there are positive productivity effects in economic dense areas (Ciccone & Hall 1996). In our analysis we take into account the employment density (employment in full time equivalents per square kilometre). Due to urbanisation economies we expect that this density will have a positive effect on productivity (and we wonder whether the ICT adoption 'on top of' this density effect is still 'visible' in the productivity).

Hypothesis 6: In economic dense regions a higher labour productivity is overrepresented

The counter part of the urbanisation economies are the negative externalities that firms experience in these dense areas, think of congestion, pollution etc. A sharp rise in density can cause this negative effects because the local and regional circumstances might not adapt as fast as the density has risen. In our analysis we also take the dynamics in density into account. A negative significant score on the change of density implies that there are negative external effects rising from concentration of economic activities.

Our assumption is that urbanisation economies matter, and we want to analyse whether the relation between ICT and productivity differs in a urban or spatial context. We now focus on different types of regions and agglomerations. After testing the hypothesis on the relation between ICT and productivity on the regional level we introduce the urban dimension in a more specific way. By introducing different spatial regimes of urbanisation we control for spatial and urban heterogeneity in these types of regions. We wonder whether the ICT stimulating effect on productivity is higher in urban (economic dense) areas. For this analysis we introduce a spatial typology (see next paragraph) which makes a distinction in central cities, suburban areas and more rural area's. We expect, due to agglomeration effects, the strongest relationship between ICT and productivity in central cities. Besides the city level we distinguish in national zoning regimes: the Randstad core region, the so-called intermediate zone and the national periphery, where we expect that in the Randstad (the most urban part of the Netherlands) productivity is higher due to higher ICT-levels. We focus on this spatial differentiation to address the spatial heterogeneity (and –theoretical- differences in regional 'performance'). Out two sets of spatial regimes each indicates aspects of urban structures at different spatial scales.

Hypothesis 7: In urban regions the co-location between ICT and productivity is stronger than in less urban regions

Also the dynamics in ICT in relation to productivity growth within the distinguished spatial regimes are analysed. We expect that in the most urban area's the ICT dynamics result in the strongest productivity growth.

Hypothesis 8: In urban regions the co-location of growth in ICT and productivity growth is stronger than in less urban regions

Spatial typology

This paragraph (intermezzo) gives insight in the spatial regimes and the motivation to choose these spatial levels in our analysis. The geographic literature provides clues for non-contiguous (regime) types of urban spatial dependence. Quality of life aspects, regional labour markets, specialised urban networks and city size appear as significant locational considerations knowledge intensive firms (Van Oort 2004). The spatial structures of urban heterogeneity are descriptively presented in this study following two sets of spatial regimes, each indicating aspects of urban structures at different spatial scales.[1]

1. On the macro-level, three national zoning regimes have been distinguished: the Randstad core region, the so-called intermediate zone and the national periphery (figure 2a). Distinguishing between macro-economic zones in the Netherlands is based on a gravity model of total employment concerning data from 1996. The Randstad region in the Netherlands historically comprises the economic core provinces of Noord-Holland, Zuid-Holland and Utrecht, the intermediate zone mainly comprises

[1] At a later stage we will use methods including indicators of spatial autocorrelation (Van Oort, 2002)

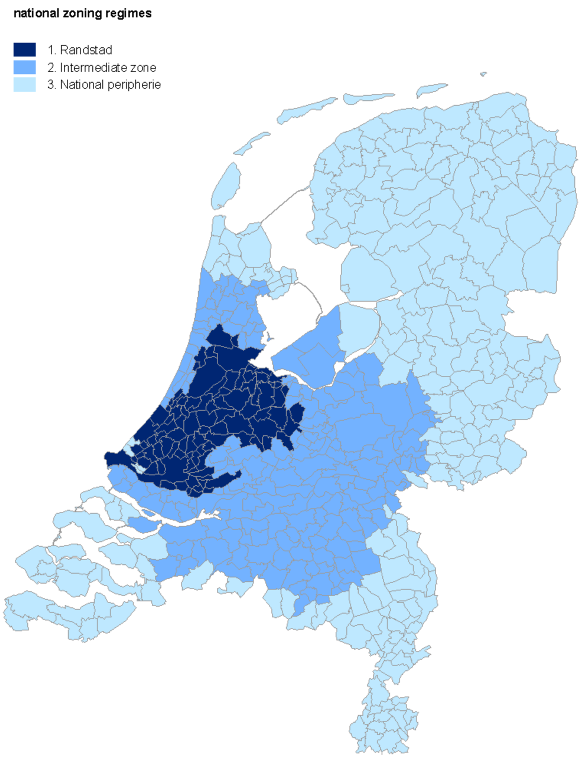
the growth regions of Gelderland and Noord-Brabant, while the national periphery is built up by the northern and southern regions of the country. This zoning distinction is hypothesised as important in many studies on endogenous growth in the Netherlands, in the sense that the Randstad region traditionally has better economic potential for development (cf. Van Oort 2004).

2. On the meso-level we distinguish a labour market induced connectedness regime from a non-connectedness regime (figure 1b). This spatial regime concerns commuting based labour market relations. In the figure, core and suburban municipalities together comprise the connected regime, as opposed to the other types of locations that are characterised as non-connected. The classification is based on the dependency of a municipality's population upon employment and services proximity and accessibility. The literature finds in general that urban areas in the connected regime show higher economic growth and innovation rates than areas in the non-connected regime (e.g. Anselin *et al.* 2000). As becomes clear from figure 1b, locations in the connected regime are not necessarily adjacent to each other.

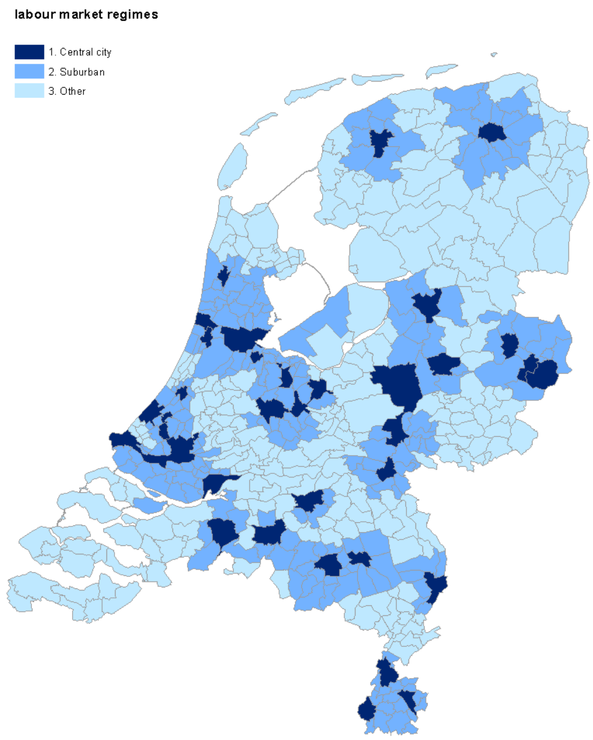
In sum, these two aspects of spatial heterogeneity constitute two spatial levels of urban constellation: the urban level itself (and within that the functional (commuting) region) and the meso-level 'agglomerative fields' of the Randstad core region compared to its adjacent intermediate zone and the national periphery.

Figure 1 **Spatial typology**

a.) National zoning spatial regimes



b.) The labour market spatial regimes



3 Statistics and spatial patterns

This paragraph shortly describes the most important statistics of out main variables.

Table 1 shows the descriptive statistics. Because not every variable is normally distributed also log transformations are included.

Table 1 Descriptive statistics

	Minimum	Maximum	Mean	Std. Deviation
Productivity 2002[1]	30.055	160.231	61.244	9.551
Log Δ Productivity 1996-2002[1]	-0,09	0,36	0,076	0,0368
ICT sensitivity 2002[2]	0,53	1,27	0,745	0,1061
Log Δ ICT sensitivity 1996-2002[2]	-0,05	0,38	0,160	0,0451
Absolute Δ ICT sensitivity 1996-2002[2]	-0,09	0,50	0,228	0,0695
Capital / Labour ratio 2001[3]	0,08	0,15	0,104	0,0127
Log Δ Capital / Labour ratio 2001/1996[3]	-0,14	0,17	0,040	0,0573
Density 2002	7.3	2413	254	370
Log Δ Density 1996-2002	-0.142	0.248	0,.050	0,053
Education Low 2002 (share in total) [4]	0,19	0,40	0,32	0,0361
Education Middle 2002 (share in total) [4]	0,36	0,48	0,45	0,0125
Education High 2002 (share in total) [4]	0,15	0,42	0,24	0,0435
Average Education level 2002[4]	1,76	2,21	1,92	0,0790
Rel Δ Education Low[4]	-0,24	0,32	-0,09	0,0499
Rel Δ Education Middle[4]	-0,12	0,12	-0,03	0,0213
Rel Δ Education High[4]	-0,21	1,01	0,25	0,1413
Rel Δ Average Education level[4]	-0,07	0,12	0,04	0,0206

N=496 (Dutch municipalities)

1) Productivity is the gross value added per fulltime equivalent (in euro's). Source: Statistics Netherlands (National Accounts), LISA, Frenken e.a (2005) Broersma & Oosterhaven (2004), Operation: Netherlands Institute for Spatial Research

2) ICT sensitivity is the number of computers per job. Source: Statistics Netherlands and LISA, Operation: Netherlands Institute for Spatial Research

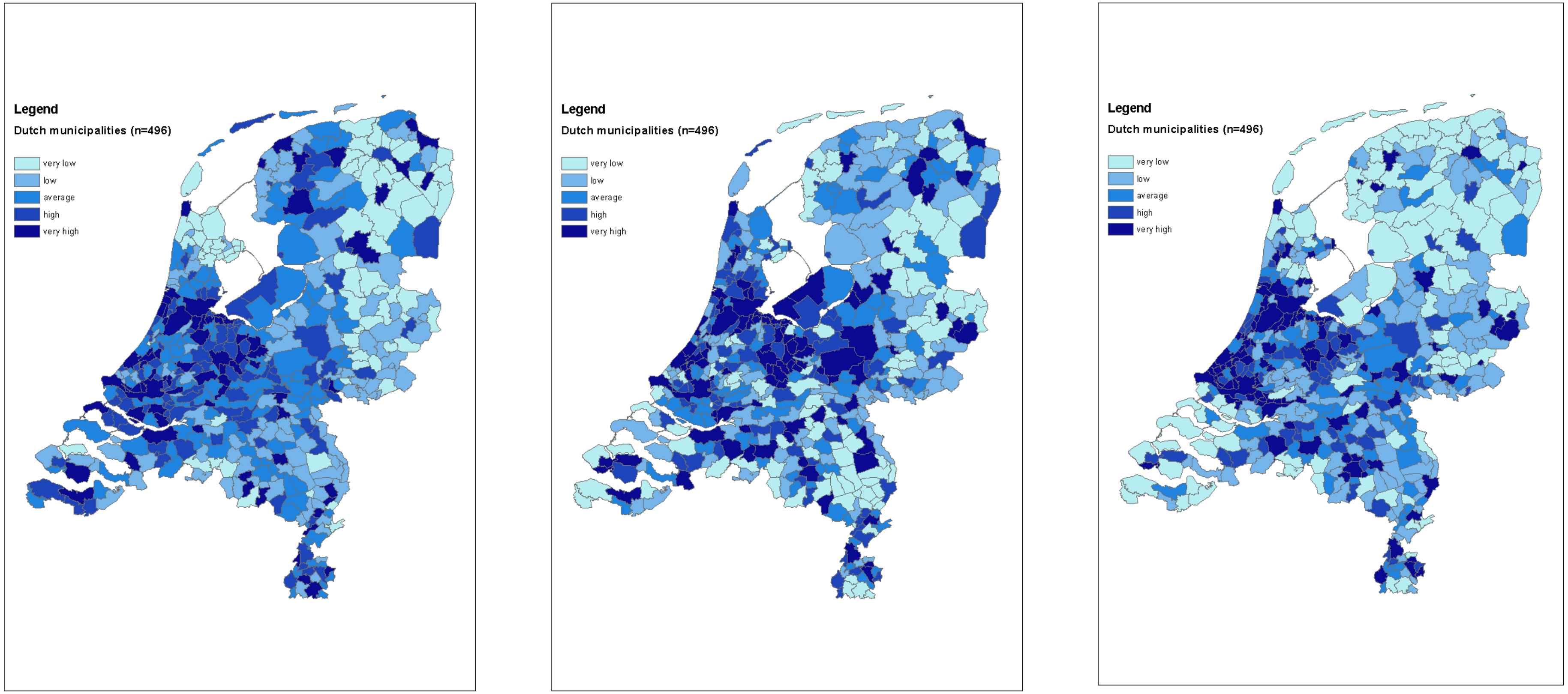
3) The Capital / Labour ratio is de capital stock divided by the amount of employment (fte): Frenken e.a (2005), Broersma & Oosterhaven, LISA

4) The average education level is the weighted average (respectively with the weights: 1,2,3) of the educational levels: high (university and higher vocational education), middle (intermediate vocational education, higher general secondary education and pre-university education) and low (lower general secondary education and lower vocational education) by the number of jobs working in these levels. Source: Statistics Netherlands (National Accounts), LISA. Operation: Netherlands Institute for Spatial Research

Figure 2 maps the variables productivity and ICT sensitivity. Figure 2a shows that the labour productivity is the highest in the western part of the Netherlands (the Randstad) in which the four big cities Amsterdam, Rotterdam, The Hague and Utrecht are localized. In general cities are more productive than the more rural areas and the peripheral parts of The Netherlands. Figure 2b also shows the close relationship between the ICT-intensity and cities or agglomerations. The most ICT-sensitive parts of the Netherlands are in the Randstad and in big and middle-sized cities. These maps subscribe to our main hypotheses that ICT and productivity both are linked to 'agglomerations'.

Figure 2 Spatial pattern of productivity and ICT-sensitivity

a) Productivity (log) b) ICT sensitivity (log) b) Employment per km2 (log)



In the map the values are standardized scores (z-scores): < -,085 = very low, -0,85 - -0,25 = low, -0,25 - +0,25 = average, 0,25 – 0,85 = high, > 0,85 = very high

In paragraph 4-6 we test our hypothesis. To summarize:

Hypothesis 1:	Higher ICT sensitivity co-locates with higher demand for skilled labour
Hypothesis 2:	Higher ICT sensitivity co-locates with higher productivity
Hypothesis 3:	Higher growth of ICT sensitivity in recent years co-locates with higher productivity levels
Hypothesis 4:	A high head start in ICT adoption co-locates with higher productivity levels
Hypothesis 5:	Higher ICT growth co-locates with higher productivity growth
Hypothesis 6:	In economic dense regions a higher labour productivity is overrepresented
Hypothesis 7:	In urban regions the co-location between ICT and productivity is stronger than in less urban regions
Hypothesis 8:	In urban regions the co-location of growth in ICT and productivity growth is stronger than in less urban regions

The construction of our data on the regional level produced a unique dataset. Because of the low spatial scale in our analysis we can address the heterogeneity and endogenousness of the differences in urban context.

4 Does more ICT-use co-locate with a higher demand for skilled labour?

Our hypothesis is that a higher ICT sensitivity leads to a higher demand for skilled labour: the white collar effect. For testing this hypothesis we correlate the level of ICT sensitivity to the average educational level and the three separate levels of education high, middle and low. Table 2 summarizes the results of the correlation analysis. It shows that the level of ICT sensitivity is highly correlated with the average educational level and the high educational level. The table also shows that there is a strong negative correlation between the share of low educated employment and the ICT-sensitivity.

Table 2 Pearson Correlation ICT sensitivity and educational levels (2002)

	ICT sensitivity	Average educational level	Education level high	Education level middle	Education level low
ICT sensitivity	1	,758(**)	,747(**)	-,408(**)	-,761(**)
Average educational level	,758(**)	1	,993(**)	-,602(**)	-,990(**)
Education level high	,747(**)	,993(**)	1	-,689(**)	-,968(**)
Education level middle	-,408(**)	-,602(**)	-,689(**)	1	,485(**)
Education level low	-,761(**)	-,990(**)	-,968(**)	,485(**)	1

** Correlation is significant at the 0.01 level (2-tailed). N= 496 (Dutch municipalities)

Because of the high correlation between the ICT-sensitivity and the average and high educational level (over 0,7), and possible arising multicolliniarity problems, in the rest of our analysis in this paper we do *not* include the level(s) of education as separate factors.

5 Does ICT co-locates with productivity?

In this paragraph we wonder whether ICT sensitivity, representing the intensity of the use of ICT, goes together with a high level of productivity. We expect that the higher the ICT sensitivity, the higher the productivity will be (*hypothesis 2*). We also expect that the higher the growth of ICT sensitivity in recent years, the higher the productivity levels will be (*hypothesis 3*), and that a head start in ICT adoption leads to higher productivity levels (*hypothesis 4*). Our last assumption on the relation ICT and productivity is that growth causes growth: the higher the ICT growth, the higher the productivity growth (*hypothesis 5*). Within all these assumptions we take the C/L-ratio and the urbanisation economies into account. The C/L is a correction variable for general capital deepening. The density variable tests the existence of a positive urbanisations economies, resulting in a higher productivity (*hypothesis 6),* and their dynamics.

To analyse these relations we conducted six regression analysis. Table 2 summarizes the results. Model 1 tests whether a higher ICT sensitivity co-locates with a higher productivity. All thee variables are highly significant and show positive relations. This means that indeed high labour productivity levels and a high ICT sensitivity go hand in hand. Also the general capital deepening (C/L-ratio) influences productivity, but ICT has his own independent effect on productivity on a regional level: the higher the ICT levels, the higher the productivity levels. Hypothesis 2 is accepted for our data. We also see that urbanisation economies stand on their own, with an independent effect on productivity (hypothesis 2 is accepted).

Model 2 takes the dynamics of the independent variables into account and analysis whether these dynamics influence the level of productivity. Once again all three independent variables are highly significant. Growth in ICT co-locates with high productivity levels and seems to condition a good performance. Also hypothesis 3 holds. Remarkable is the significant negative value of the growth in economic density. Firms in regions that showed a sharp rise in density, for instance by their own growth or by firm migration processes, have lower productivity levels (on the aggregate level of a municipality). This probably indicates negative externalities due to this rise of concentration of activities.

Model 3 contains static as dynamics variables in relation to the level of productivity. All relations found in model 1 and 2 holds, except for the positive influence of ICT growth. This variable is no longer significant in explaining high levels of productivity. We also see a drop in the influence of the growth of the C/L-ratio (but still significant). So capital and ICT deepening become less import. They seem to be replaced in the regression by the dynamics in density that became highly significant, but with a negative character. Overall, based on model 3, hypothesis 3 is not robust. Negative (spatial) externalities overshadow the ICT-effect.

Model 4 tests for the head start effect: is a high level of ICT in 1996 a good condition for productivity growth over the periode 1996-2002? This model shows that this effect does not appear. Only a high starting point of the C/L-ratio is significant and positively. We also see that urbanisation economies do not effect productivity growth.

Model 5 relates dynamics of the independent variables to productivity growth. We see that growth in ICT is highly significant and co-locates with productivity growth. Even correcting for general capital deepening ICT growth has an independent effect. Hypothesis 5 holds, even though the negative effects of the growth of density. Model 6 combines model 4 and 5. All relations are robust. Most important is that growth in ICT co-locates with productivity growth (hypothesis 5 is accepted)

6 Do cities or urban regions perform different?

We saw an important role for urbanisation economies. Spatial economic concentration is a positive factor in relation to productivity levels. But growth in density has a negative effect on the level of productivity and to productivity levels as well. We now focus on the relation between ICT and productivity in a spatial context. We expect that in urban areas (cities and agglomerations) there will be an extra effect of ICT due to network effects in combination with agglomeration effects (knowledge spillovers) that are important for ICT and knowledge intensive firms. All models in paragraph 4 are now split in the spatial regimes (model a till f).

First we made a distinction in national zoning regimes: Randstad-Intermediate Zone-National Periphery (model a till c). Table 2 shows that the general positive relation between ICT and productivity also holds in the Randstad. The is a very strong positive relation between the ICT sensitivity and productivity in the most agglomerate part in the Netherlands. Combining the static number of ICT and the C/L-ratio with their dynamics in the recent past shows a robust relation of ICT sensitivity and productivity. ICT has a stronger relation with productivity than general capital deepening in the Randstad. Although growth in ICT in the period 1996-2002 does not co-locate with high levels of productivity. This argues for a possible saturation point in the agglomeration that has the highest ICT-sensitivity in the Netherlands. In the Randstad we see after all that also the head start does not influence productivity growth. Neither does ICT growth foster productivity growth (model 5a).

Remarkable is the national periphery (the national part that is the less dense) that also show a positive significant relation between the level of ICT and productivity, but most remarkable is that growth in ICT sensitivity co-locates with productivity growth. This catching-up effect is good news for policy-makers who wants to stimulate the convergence of regions within the country.

Second we made a distinction in urban zoning regimes: Central cities-Suburbs-Rest. The general conclusions on the level of agglomerations (Randstad) also hold on the level of central cities. ICT sensitivity and high productivity co-locate in cities. But also in the suburbian parts and the more rural areas in the Netherlands this co-location exists. The strongest relation is although is in the most rural parts. If in this rural parts there are ICT-sensitive parts, these are on average the most productive. And in suburbs and the rural parts there is a positive relation between growth of ICT and productivity growth. So also on this more urban specific level catching-up effects are applying.

Table 2 Regression model Productivity and ICT in a spatial context

		Log Productivity 2002				Log D Productivity (2002 / 1996)		
		Model 1	Model 2	Model 3		Model 4	Model 5	Model 6
General OLS	Constant	0,000	0,000	0,000	Constant	0,000	0,000	0,000
		(0,000)	(0,000)	(0,000)		(0,000)	(0,000)	(0,000)
	Log ICT sensitivity 2002	0,277		0,296	Log ICT sensitivity 1996	-0,093		0,063
		(5,471)		**(5,134)**		(-1,886)		(1,045)
	Log C/L-ratio 2002	0,293		0,249	Log C/L-ratio 1996	0,115		0,146
		(7,464)		**(5,828)**		**(2,563)**		**(3,342)**
	Log Density 2002	0,158		0,171)	Log Density 1996	0,071		-0,043
		(3,128)		**(3,378)**		(1,441)		(-0,795)
	Δ ICT sensitivity abs 1996-2002		0,182	-0,046	Δ ICT sensitivity abs 1996-2002		0,159	0,219
			(4,222)	(-0,897)			**(3,634)**	**(3,844)**
	Δ C/L-ratio abs 1996-2001		0,250	0,107	Δ C/L-ratio abs 1996-2001		0,087	0,100
			(5,817)	**(2,466)**			**(1,992)**	**(2,266)**
	Log Δ Density (2001/1996)		-0,088	-0,133	Log Δ Density (2001/1996)		-0,209	-0,217
			(-2,063)	**(-3,399)**			**(-4,818)**	**(-5,025)**
	R^2	0,245	0,114	0,273		0,019	0,074	0,098
	Adjusted R^2	0,241	0,109	0,264		0,013	0,069	0,087
	N	496	496	496		496	496	496
		Model 1a	Model 2a	Model 3a		Model 4a	Model 5a	Model 6a
Randstad	Constant	0,163	0,352	0,093	Constant	0,353	,984	0,266
		(1,925)	**(3,488)**	(0,901)		**(3,096)**		(1,661)
	Log ICT sensitivity 2002	0,431		0,402	Log ICT sensitivity 1996	-0,191		-0,163
		(7,114)		**(4,922)**		(-1,922)		(-1,605)
	Log C/L-ratio 2002	0,246		0,155	Log C/L-ratio 1996	-0,034		0,038
		(2,737)		(1,424)		(-0,249)		(0,253)
	Δ ICT sensitivity abs 1996-2002		0,208	0,006	Δ ICT sensitivity abs 1996-2002		0,103	0,101
			(3,684)	(0,079)			(1,334)	(1,213)
	Δ C/L-ratio abs 1996-2001		0,181	0,167	Δ C/L-ratio abs 1996-2001		0,110	0,068
			(1,839)	(1,556)			(0,822)	(0,500)
	R^2	0,376	0,213	0,398		0,042	0,039	0,067
	Adjusted R^2	0,362	0,195	0,370		0,020	0,016	0,024
	N	90	90	90		90	90	90
		Model 1b	Model 2b	Model 3b		Model 4b	Model 5b	Model 6b
Intermediair Zone	Constant	0,138	0,133	0,146	Constant	0,016	-0,016	-0,008
		(2,919)	**(2,589)**	**(3,073)**		(0,235)	(-0,235)	(-0,117)
	Log ICT sensitivity 2002	0,235		0,266	Log ICT sensitivity 1996	-0,119		-0,122
		(4,390)		**(3,868)**		(-1,604)		(-1,638)
	Log C/L-ratio 2002	0,298		0,227	Log C/L-ratio 1996	0,132		-0,138
		(5,701)		**(3,691)**		(1,622)		(1,691)
	Δ ICT sensitivity abs 1996-2002		0,098	-0,062	Δ ICT sensitivity abs 1996-2002		0,125	0,125
			(1,710)	(-0,889)			(1,596)	(1,610)
	Δ C/L-ratio abs 1996-2001		0,253	0,116	Δ C/L-ratio abs 1996-2001		0,072	0,084
			(4,829)	**(1,999)**			(1,010)	(1,176)
	R^2	0,228	0,128	0,250		0,030	0,019	0,051
	Adjusted R^2	0,219	0,117	0,233		0,018	0,008	0,028
	N	175	175	175		175	175	175
		Model 1c	Model 2c	Model 3c		Model 4c	Model 5c	Model 6c
National Periphery	Constant	-0,173	-3,048	-0,161	Constant	-0,113	-0,057	-0,064
		(-2,278)		**(-2,064)**		(-1,535)	(-0,766)	(-0,839)
	Log ICT sensitivity 2002	0,331		(0,361)	Log ICT sensitivity 1996	-0,071		-0,063
		(4,438)		**3,765**		(-,964)		(-0,869)
	Log C/L-ratio 2002	0,262		0,246	Log C/L-ratio 1996	0,111		0,135
		(4,068)		**(3,690)**		(1,856)		**(2,223)**
	Δ ICT sensitivity abs 1996-2002		0,154	-0,059	Δ ICT sensitivity abs 1996-2002		0,164	0,179
			(1,811)	(-0,573)			**(2,054)**	**(2,250)**
	Δ C/L-ratio abs 1996-2001		0,116	0,065	Δ C/L-ratio abs 1996-2001		0,015	0,040
			(1,456)	(0,833)			(0,201)	(0,525)
	R^2	0,137	0,029	0,140		0,018	0,020	0,044
	Adjusted R^2	0,129	0,021	0,125		0,009	0,011	0,027
	N	231	231	231		231	231	231

		Log Productivity 2002			Log D Productivity (2002 / 1996)			
		Model 1d	Model 2d	Model 3d		Model 4d	Model 5d	Model 6d
Central city	Constant	0,002	0,286	0,039	Constant	-0,141	-0,344	-0,466
		(0,012)	(1,229)	(0,204)		(-0,644)	(-1,327)	(-1,397)
	Log ICT sensitivity 2002	0,374		0,384	Log ICT sensitivity 1996	0,137		0,098
		(3,873)		**(3,575)**		(0,796)		(0,628)
	Log C/L-ratio 2002	0,307		**0,327**	Log C/L-ratio 1996	-0,059		-0,017
		(4,303)		**(3,879)**		(-0,407)		(-0,133)
	Δ ICT sensitivity abs 1996-2002		0,158	-0,038	Δ ICT sensitivity abs 1996-2002		0,265	0,287
			(0,855)	(-0,278)			(1,283)	(1,332)
	Δ C/L-ratio abs 1996-2001		0,130	-0,037	Δ C/L-ratio abs 1996-2001		0,320	0,310
			(1,464)	(-0,532)			**(3,224)**	**(2,979)**
	R^2	0,609	0,088	0,614		0,023	0,290	0,300
	Adjusted R^2	0,582	0,025	0,557		-0,044	0,241	0,196
	N	32	32	32		32	32	32
		Model 1e	Model 2e	Model 3e		Model 4e	Model 5e	Model 6e
Suburbs	Constant	0,086	0,016	0,064	Constant	0,018	-0,038	-0,017
		(1,419)	(0,248)	(1,002)		(0,240)	(-0,506)	(-0,230)
	Log ICT sensitivity 2002	0,297		0,323	Log ICT sensitivity 1996	-0,062		-0,054
		(4,573)		**(3,898)**		(-0,834)		(-0,718)
	Log C/L-ratio 2002	0,263		0,192	Log C/L-ratio 1996	0,143		0,152
		(3,926)		**(2,298)**		(1,609)		(1,726)
	Δ ICT sensitivity abs 1996-2002		0,110	-0,058	Δ ICT sensitivity abs 1996-2002		0,162	0,164
			(1,734)	(-0,754)			**(2,256)**	**(2,263)**
	Δ C/L-ratio abs 1996-2001		0,245	0,098	Δ C/L-ratio abs 1996-2001		0,050	0,054
			(4,033)	(1,346)			(0,732)	(0,765)
	R^2	0,176	0,092	0,185		0,013	0,028	0,042
	Adjusted R^2	0,169	0,084	0,169		0,004	0,019	0,024
	N	218	218	218		218	218	218
		Model 1f	Model 2f	Model 3f		Model 4f	Model 5f	Model 6f
Rest	Constant	-0,062	-0,029	-0,017	Constant	-0,026	0,071	0,048
		(-1,035)	(-0,425)	(-0,267)		(-0,423)	(1,075)	(0,729)
	Log ICT sensitivity 2002	0,431		0,438	Log ICT sensitivity 1996	-0,096		-0,072
		(6,776)		**(5,744)**		(-1,520)		(-1,147)
	Log C/L-ratio 2002	0,324		**0,282**	Log C/L-ratio 1996	0,108		0,137
		(5,952)		(5,005)		(1,953)		**(2,487)**
	Δ ICT sensitivity abs 1996-2002		0,187	-,302	Δ ICT sensitivity abs 1996-2002		0,159	0,171
			(2,650)				**(2,336)**	**(2,501)**
	Δ C/L-ratio abs 1996-2001		0,271	2,582	Δ C/L-ratio abs 1996-2001		0,105	0,121
			(3,637)				(1,460)	(1,701)
	R^2	0,234	0,081	0,255		,025	0,032	0,062
	Adjusted R^2	0,228	0,074	0,242		,017	0,024	0,047
	N	246	246	246		246	246	246

All variables are standardized values (z-scores)

7 Conclusions

The wide acceleration of Information and Communication Technology (ICT) in the last decades was one of most impressive 'stylized facts' in the economy. Together with this rise of the new technology the impact on productivity was stressed: the new economy should boost productivity and growth. Although the considered potential role of ICT in the resurgence of the productivity growth, the real productivity impact stayed out. Solow (1987) formulated this as 'you can see the computer age everywhere but in the productivity statistics'. This paper focuses on the spatial relationship between ICT and productivity in order to contribute to this productivity paradox. By 'introducing' the spatial dimension we try to gather more information on the stimulating role of ICT on productivity. We see a concentration of ICT sensitive firms and higher productivity in urban areas and wonder whether this co-location is stable when correcting for general capital deepening (C/L-ratio) and urbanisation economics (advantages of economic density) and taking the urban and spatial heterogeneity into account.

Our main goal is to analyse the potential productivity stimulating effect of ICT. First we test for the influence of education: ICT does not function as an element on its own, but is embedded in people, i.e. knowledge. By analyzing the correlations between ICT sensitivity and educational skills of labour we observe a mutual dependency that causes multicolliniarity problems. Because of the large correlations we do not take education as a separate factor into account. ICT sensitivity and a high average level of education or a high amount of high educated employees go hand in hand. Within the analyses of the ICT effect on productivity there is a 'white collar' effect.

Analyzing the relation between a high level of ICT sensitivity and high productivity our testing in different models show that indeed high labour productivity levels and a high ICT sensitivity go together in a regional context. Also the general capital deepening (C/L-ratio) influences productivity, but ICT has his own independent effect on productivity on a regional level. We also see that urbanisation economies stand on their own, with an independent effect on productivity. Taking dynamics into account and testing whether these dynamics influence the level of productivity the models show again all three independent variables being highly significant. Growth in ICT co-locates with high productivity levels and seems to condition a good performance. Remarkable although is the significant negative value of the growth in economic density. Regions that showed a sharp rise in density have lower productivity levels. This probably indicates negative externalities due to this rise of concentration of activities.

When combing static and dynamics variables all relations hold, except for the positive influence of ICT growth. This variable is no longer significant in explaining high levels of productivity. We also see a diminishing role for the growth of the C/L-ratio (but still significant). So capital and ICT deepening become less import. These variables seem to be outperformed in the regression by the dynamics in density that became highly significant, but with a negative character. Overall the hypothesis that higher growth of ICT sensitivity in recent years co-locates with higher productivity levels is no robust.

When analyzing the growth in ICT in relation to productivity growth we see a highly significant co-locating of ICT growth with productivity growth. Even correcting for general and sectoral capital deepening, ICT growth has an independent effect, even though there are negative effects of the growth of density.

Overall we saw a significant negative value of the growth in economic density on the co-location of *growth* ICT sensitivity and a high productivity. This negative influence disappears when analyzing the co-location of *growth* ICT sensitivity and a *growth* of productivity. This relation seems to be robust. Taking the urban heterogeneity (the distinction in urban regimes) into account might give more insight because it seems that negative (spatial) externalities overshadow the ICT-effect on the level of productivity. And secondly because of head start effects a high starting level of ICT is a good condition for productivity growth.

Our models show that the positive relation between ICT and productivity also holds in the Randstad. There is a very strong positive relation between the ICT sensitivity and productivity in the most agglomerate part in the Netherlands. Combining the static number of ICT and the C/L-ratio with their dynamics in the recent past shows a robust relation of ICT sensitivity and productivity. Although growth in ICT in the period 1996-2002 does not co-locate with high levels of productivity. This argues for a possible saturation in the agglomeration that has the highest ICT-sensitivity in the Netherlands. In the Randstad we see that also the head start does not influence productivity growth. Neither does ICT growth foster productivity growth. Remarkable is the national periphery (the less economically dense national part) where a positive significant relation between the level of ICT and productivity exists, but most remarkable is that growth in ICT sensitivity co-locates with productivity growth in the periphery. This catching-up effect is good news for policy-makers who want to stimulate the convergence of regions within the country.

The distinction in urban zoning regimes: central cities-suburbs-rest shows that the general conclusions on the level of agglomerations (Randstad) also hold on the level of central cities. ICT sensitivity and high productivity co-locate in cities. But also in the suburban parts and the more rural areas in the Netherlands this co-location exists. The strongest relation is although is in the most rural parts. If in this rural parts there are ICT-sensitive parts, these are the most productive. And in suburbs and the rural parts there is a positive relation between growth of ICT and productivity growth. So also on this more urban specific level catching-up effects are applying.

Overall the co-location between ICT and productivity is robust: on a regional level we see that the higher the ICT sensitivity, the higher the levels of productivity and that the higher the growth in ICT sensitivity the higher the productivity growth is. Taking the spatial heterogeneity into account give the insight that the cating-up effect due to growth in ICT in the national periphery, the suburbs and rural parts in the Netherlands more than average co-locates with a rise in productivity. Regions seem to convergence.

The importance of the regional context, the mayor conclusion in this paper, is the reason that in our future research we want to investigate this context more closely. First we want to apply a fixed-effects modelling approach in which location specific characteristics are controlled for over various (sub) time period of analysis. Secondly we want to apply multi-level analysis to control for firm level characteristics (recently new constructed data –not in this paper- allow for these analysis-extensions).

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Appendix 1 Data, Methodology and spatial typology

Data & Methodology

Education

$$[1]\ average \cdot education_{SECTOR} = \frac{low + 2 \times middle + 3 \times high}{total}$$

$$[2]\ average \cdot education_{REGIO} = \frac{\sum jobs_{SECTOR} \times average \cdot education_{SECTOR}}{total \cdot jobs}$$

High = University and Higher Vocational Education (WO & HBO)
Middle = Intermediate Vocational Education, Higher General Secondary Education and Pre-university Education (MBO, HAVO & VWO)
Low = Lower General Secondary Education and Lower Vocational Education (MAVO & LBO)

Information and communication technologie

$$[3]\ ICT - index_{SECTOR} = \frac{number \cdot computers}{total \cdot jobs}$$

$$[4]\ ICT - index_{REGIO} = \frac{\sum jobs_{SECTOR} \times ICT - index_{SECTOR}}{total \cdot jobs}$$

Productivity

[PM]
…
…