

# Digital economy in the UK: a multi-scalar story of the diffusion of web technologies

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## Abstract

This paper maps the participation in the digital economy and its evolution in the UK over space and time. Most of the existing economic geography literature which dealt with the spatiality of the internet employed supply-side measures, such as infrastructural capacity, in order to understand the geography of the digital economy and its potential spatial economic effects. Useful as these approaches might have been, they cannot capture the micro-processes and the characteristics of the individual online behaviour. Using large volumes of archived and geolocated web content, this paper models the diffusion of web technologies over space and time in the UK. The data and geolocation strategy allow to capture these processes at a very granular spatial scale. The modelling approach, which is based on simple spatial analytical methods and on the estimation of diffusion curves at various scales, enables to depict the role of geography and other cognitive factors which drove the diffusion of web technologies. Although the focus is on a recent historical period – 1996-2012 – the results of the analysis depict diffusion mechanisms which can be very useful in understanding the evolutionary patterns of the adoption of other newer technologies.

*Keywords:* keyword1, keyword2

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## 1. Introduction

Geographers were always interested in how new technologies and innovations diffuse across space and, importantly, how such spatio-temporal processes can be modelled. The seminal contribution of [Hagerstrand et al. \(1968\)](#) is illustrative of this early interest. However, the torch of exploring and modelling such processes had been passed to other disciplines such as economics, business studies and sociology well before the ‘cultural turn’ of economic geography ([Perkins and Neumayer, 2005](#)). A potential explanation of lack of studies exploring the diffusion of new and, more specifically, digital technologies across *both* space and time can be attributed to the scarcity of relevant and granular enough data. As [Zook and McCanless \(2022\)](#) highlight, digital activities are hardly ever captured in official data.

This paper aims to reinstate geographers’ interest in how new and digital technologies diffuse over space and time. It adopts a geographic standpoint to explore and map the diffusion of web technologies in the UK over space and time. It does so by employing a novel source of big data which captures the active engagement with web technologies during the 1996 – 2013 period.

The motivation for this paper lies in the fact that there are various stakeholders who are interested in knowing how new digital technologies diffused over space and time use this information to make predictions regarding the diffusion of related future technologies. As per [Meade and Islam \(2021\)](#) a variety of actors have a direct interest in gaining such knowledge including network equipment suppliers; network operators,

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regulatory and local authorities. And despite the spatial heterogeneity of such diffusion mechanisms and the policy relevance, there are very limited attempts in the literature to analyse the diffusion of new digital technologies at a granular level.

the paper answers an empirical question: how did a

[Zook and McCanless \(2022\)](#) Because new digital activities are rarely—if ever—captured in official state data, researchers must rely on information gathered from alternative sources. With this in mind, the overarching aim of this article is outlining an approach for analyzing the “new spaces and geographies” of digital phenomena and practices.

Classifying adopters of a technology along a time axis was pioneered by Rogers (1962), who categorized adopters into five groups as innovators, early adopters, early majority, late majority and laggards.

An a priori approach groups similar countries into segments, where similarity is defined using economic, social, or political covariates. Examples include Hofstede (2001) and Lee (1990). An a posteriori analysis considers segments based on realized market behaviour, for example see Sood et al. (2009). Some studies investigate changing segment membership over time, see Cannon and Yaprak (2011).

[Fritsch and Medrano Echalar \(2015\)](#) Hägerstrand (1952, 1967) was the first scholar to intensively analyze spatial diffusion processes. Based on the empirical observations of the regional spread of process innovations, he hypothesized that new technology is first implemented in the ‘center’ – the large agglomerations – and then moves ‘down’ the spatial hierarchy, the last stop being the ‘periphery’, i.e. remote and sparsely populated regions. There are at least two factors that may explain this pattern: first, the transfer of tacit knowledge via face-to-face contact and second, the absorptive capacity of a region.

[Bento and Fontes \(2015\)](#) The concept of absorptive capacity has also been applied in the TIS context in terms of the construction of capacity needed to transfer and implement a new technology in the receiving country (cf. Van Alphen, 2011), with repercussions for the nature of system functions

[Bednarz and Broekel \(2020\)](#) larger local technological niches (at least from a demand perspective) are more likely to be formed in urban areas than in rural ones, which is in line with the work of Hägerstrand (1965a,b). However, size is not the only regional characteristic that may matter in this context. Regions also differ in accumulated experiences and the presence of tacit knowledge with respect to products, as well as in actors’ propensity share this knowledge among producers (Martin et al., 2019)

To summarize the discussion, first, here the diffusion process is self-perpetuating as initial use stimulates further use. Second, it follows a disequilibrium path as the level of users is always lower than the number of potential users (Stoneman 2002).

The criticisms are mainly based on the fact that although the approach gives an idea of aggregate (industry or household) behaviour, it does not focus on the individual’s (firm or household) adoption process

[Morrill et al. \(1988\)](#) Spatial diffusion is the process by which behavior or characteristics of the landscape change as a result of what happens elsewhere earlier. Spatial diffusion is the spread of the phenomenon, over space and time, from limited origins

Contagious diffusion=> spatial autocorrelation  
expansion-type diffusion

The work by the communication sociologist Everett Rogers (1962, 1971, 1983) has emphasized the role of information, communication, formal and informal media, opinion leaders and social networks, and economic and psychological constraints on acceptance. Rogers’s work stresses the decision mechanism of the potential adopter; the work of Rogers partitions the adopter’s process of choosing to accept a new phenomenon or trait into five stages: stage 1—the potential adopter gains knowledge or awareness of an innovation; stage 2—persuasion is exercised to adopt; stage 3—a decision is made to adopt; stage 4—the decision to adopt is implemented; stage 5—the adopter confirms the decision to adopt. In Rogers’s stage theory there may be a

substantial time lag between when a potential adopter becomes aware of the new characteristic and when a decision is actually made to adopt.

Hägerstrand considered diffusion to be a fundamental geographic process: Whatever the phenomenon being diffused might be, one may consider it in the context of a larger universal process of spatial diffusion.

Leibowicz et al. (2016) Diffusion is a spatial (Hagerstrand, 1967) as well as a temporal process, and historical evidence confirms that technologies diffuse at different times, at different rates, and to different extents in different places, and can be significantly influenced by policies (Victor, 1993).

Lastly, it can be globally optimal for innovative economies to deploy advanced technologies more than what is locally optimal if this enables faster diffusion in less advanced regions that could benefit from the technology.

wilson201281 Early on in their lifecycle, new technologies are crude, imperfect, and expensive (Rosenberg, 1994). New energy technologies are attractive for their ability to perform a particular task or deliver a new or improved energy service (Fouquet, 2010). This is often circumscribed by a particular set of needs in a particular context: a market ‘niche’. End-users in niche markets are generally less sensitive to the effective price of the energy service provided or have a higher willingness to pay for its performance advantages (Fouquet, 2010). Thus initially, performance dominates cost competitiveness (Wilson and Grubler, 2011). Market niches afford some protection from competitive pressures, allowing technologies to be tested and improved in applied settings, reducing uncertainties with performance or market demand (Kemp et al., 1998). Costs may only fall substantively after an extended period of commercial experimentation, concurrent with the establishment of an industrial base and characteristic moves towards standardisation and mass production (Grubler, 1998). The influence of accumulating production experience on costs is captured by the concept of learning.

grubler1990rise The scale of spatial innovation diffusion is similar to that of temporal diffusion models: hierarchically decomposed.

Grubler (1990) Later Hagerstrand conceptualized physical “barrier” effects like lakes or uninhabited areas, which, in addition to distance, act as further retarding effects on diffusion. These are formalized in the form of “zero” or “half” contact multipliers on the (distance decaying) message flows.

Grubler (1990) With respect to the formalization of the communication flows Hagerstrand defines a “mean information field” (MIF), in which the probability of communication is a negative function of distance between individuals

Perkins and Neumayer (2005) Theoretical models disagree as to why firms adopt innovations at different times. Epidemic models emphasize information (Griliches 1957). Certain firms are hypothesized to adopt earlier because they come into contact with, and learn from, adopters of the new technology before others. Economic models, on the other hand, predominantly emphasize firm heterogeneity (Ireland and Stoneman 1986). Firms adopt technologies at different times because they differ with respect to various organizational and environmental variables influencing the economic returns from adoption (Blackman 1999).

Either way, the strong assumption is that developing countries can acquire modern technology innovated in developed economies, often at a fraction of the original research and development (R&D) costs, thereby leapfrogging many decades of technological progress (Teece 2000).

The first involves a country’s geographical location. Recent empirical work suggests that diffusion is “geographically localized” (Globerman, Kokko, and Sjöholm 2000; Keller 2002; Milner 2003) in that a technology diffuses faster in a country where it is already more widely diffused in neighboring countries. Underlying these regional effects are contagion and contact with prior users or producers of technology.

Ding et al. (2010) Rogers (1995) characterized early adopters as knowledgeable risk takers. Griliches (1957) looked at the rate of return for early adopters and characterized them as profit maximizers. The geographer Hagerstrand (1967) was focusing on the character of early adopters in the transmittal process that produces

follow-on participants in the process. Space was treated as a contiguity system with embedded characteristics producing barrier elements to the diffusion process.

Ding et al. (2010) REVIEW ON Technological Diffusion

Perkins and Neumayer (2011) Two main mechanisms are identified in the literature to explain diffusion: (1) epidemic-type dynamics whereby contact with previous adopters stimulates uptake as potential adopters learn about a new innovation; and (2) economic-type mechanisms whereby potential users adopt a new innovation as it becomes more profitable, useful, or valuable, with uptake characteristically spreading as costs become lower, performance improves, or the potential uses of the innovation grow over time.

To this extent, our results contribute to a growing body of work that has sought to caution against claims about the supposed novelty of the Internet and the suggestion that it is somehow different.

Wilson (2012) Logistic growth describes an initial period of gradual diffusion as a technology is introduced as a new commercial application, moving then through a rapid, exponential growth phase, before slowing and eventually saturating (Grübler et al., 1999). The substitution of incumbent technologies by new competitors leads to subsequent decline and eventual obsolescence.

## 2. Literature review {#sec2} MAYBE SKIP THIS??

Beardsell and Henderson (1999) To characterize evolution of the computer industry, we examine the distribution of relative employment across cities in 1977 and how that distribution changes over time to 1992

There is no tendency of relative size distributions of urban computer employment to collapse, go bimodal, or fully spread. Overall computers exhibit some turbulence, with dramatic big winners and losers among cities. In attracting or repelling an industry, urban heterogeneity is important. Large, well educated cities near San Jose have much greater chances of attracting high-tech employment and less of losing it

Bednarz and Broekel (2020) spatial innovation diffusion By using Bayesian survival models with time-dependent data of wind turbine deployment and firm foundation for 402 German regions between the years 1970 and 2015, we show that the spatial evolution of the German wind energy industry was more strongly influenced by local demand–pull than local supply–push processes.

The industry’s initial locations are distributed relatively arbitrarily and unpredictably, as their needs in terms of resources and skills are diverse and distinct from the older existing industries (Boschma and Lambooy, 1999). Consequently, emerging industries are characterized by relatively high degrees of freedom in terms of location. In later extensions of the concept, the assumption of the randomness of locations was revised with greater importance assigned to regional conditions (Boschma and Lambooy, 1999; Fornahl et al., 2012).

Perkins and Neumayer (2005) analyze whether the rate at which new producer technologies diffuse is significantly influenced by (1) latecomer advantage and (2) engagement with the global economy via trade and foreign investment

Indeed, precisely because of these latecomer advantages, developing countries<sup>1</sup> are believed to be well placed to catch up with developed ones (Gerschenkron 1962; Abramovitz 1986).

Fritsch and Medrano Echalar (2015) analyze the spatial diffusion of laser technology research in West Germany from 1960, when this technology began, until 2005.

Perkins and Neumayer (2011)

Lengyel et al. (2020) We see that the OSN spread almost exclusively from the original location (the capital Budapest, with an order of magnitude more inhabitants than the next size town) to various parts of the country in the early phase of the life-cycle. Later, diffusion became less mono-centric and other towns also emerged as spreaders. Our findings support the idea that spreading initially happens to large distances and becomes more local over time. This is illustrated and discussed later in Figure 2I.

Papagiannidis et al. (2015)

Leibowicz et al. (2016) for energy There is no generally accepted theory that explains diffusion rate heterogeneity across technologies, but several factors are considered important. Greater unit scale and larger market size contribute to slower diffusion. Requirements for interrelated technologies or complex infrastructures also hinder the diffusion process (Grubler, 2012).

Mobile phones benefited from early deployment in recreational boats and automobiles, where the traditional competitor was not a viable option. In the early stages of diffusion, performance is a more important driver of adoption than cost competitiveness. Typically, significant cost reductions only occur once the technology reaches a deployment level capable of supporting standardization and mass production (Wilson, 2012).

Leibowicz et al. (2016) Empirical evidence supports the validity of Schmidt's Law over a wide range of technologies, time periods, and geographical contexts. A recent meta-analysis of technology up-scaling found that diffusion accelerated moving from the core to the rim and periphery for technologies as diverse as natural gas power, oil refineries, and automobiles (Wilson, 2009). One historical example that conforms particularly well to Schmidt's Law is the diffusion of coal power in Europe (Grubler, 2012). England emerged as the core region for coal power because it had legal and economic institutions that incentivized scientific pursuits, domestic coal reserves, and a clear industrial motivation to replace water power with coal. ...

Ding et al. (2010) model the spatial diffusion of mobile telecommunications in China as well as its determinants. regional socioeconomic characteristics play an important role in determining the timing, speed, and level of mobile telecommunications diffusion in China

Bento et al. (2018) explore What determines the duration of formative phases for energy innovations in different markets? We are interested both in initial markets (also: core, lead, first mover, early adopter) where formative phases prepare technologies for mass commercialization, and in follower markets (also: periphery, lag, late adopter) where accelerated formative phases may benefit from diffusion and spillovers.

### 3. Materials and Methods

Wilson (2012) growth function description in p. 86

from R:  $\text{Asym}/(1+\exp((x_{\text{mid}}-\text{input})/\text{scal}))$  using the terms from Wilson  $k/(1 + e^{(t_0 - t)/\text{scal}})$

Wilson:  $k(1 + e^{-b(t - t_0)})$  So,  $\text{scal} = -1/b$

The curve is symmetric\* around  $t_0$

**minimum R<sup>2</sup> = 95%**, see also Grubler (1990)

The literature usually uses the saturation level as the asymptote. I am using the total number of websites as we cannot compute a rate.

Moran's I as Ding et al. (2010) **TODO** for  $t_0$ , diffusion speed

#### 3.1. Results

Hexagon density maps: reflect the spatial structure of Britain. Websites are associated in places where people live and work.

**TODO** maps at the local authority level per firms and discuss patterns

Neighbourhood effect: diffusion proceeds outwards from innovation centers, first "hitting" nearby rather than far-away locations (Grubler 1990)

- Moran's I: for OA and LAD over time **TODO** add 0s
- LISA maps: for OA and LAD over time More and less expected clusters. Different scales show different results

- Website density regressions: for OA and LAD over time **TODO** add 0s Similar pattern

Hierarchy effect: from main centers to secondary ones – central places

- Gini coefficient. Almost perfect polarisation of web adoption in the early stages at a granular level  
More equally diffused at the Local Authority level Plateau overtime

S-shaped diffusion curves

- S for LADs per firm and OA. **TODO**: OA per firm? fix firms over time.
- Fast and slow LAs map. There is clustering
- **TODO** check s\_uk\_firm\_11
- ranks: there is stability and movement

### 3.2. 3.2 Case study approach

## 4. Digital technologies and spatial structure: a global view

## 5. The impact of ICT on the US and the UK spatial structures

## 6. Discussion and conclusions

contrary to results from future studies regarding social media (Lengyel et al., 2020), web technologies did not exclusively spread from a central location.

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