

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

1. Introduction

Geographers were always interested in how new technologies and innovations diffuse across space and time and, importantly, how such spatio-temporal processes can be modelled. After all, diffusion together with invention and innovation are considered the pillars of technological change (Das, 2022). 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 the lack of geographical studies exploring the diffusion of new and, more specifically for this paper, digital technologies across *both* space and time can be attributed to the scarcity of relevant and granular enough data. As Zook and McCannless (2022) highlight, digital activities are hardly ever captured in official data.

This paper offers such a contribution: a geographical study illustrating how a new technology that is the web diffused over space and time in the UK at a high level of spatial granularity during the 1996 – 2012 period. It does so by employing a novel source of big data which captures the active engagement with web technologies during that period. By addressing this empirical question this paper exemplifies how the combination of data sources which escape the traditional social science domain and adequate research methods can offer new lenses to geographical research regarding the understanding of technological diffusion.

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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 and use this knowledge to make predictions regarding the diffusion of related *future* technologies. As per [Leibowicz et al. \(2016\)](#), historical studies agree on the fact 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](#))”. [Meade and Islam \(2021\)](#) highlight that a variety of actors have a direct interest in gaining such knowledge including network equipment suppliers; network operators, regulatory and local authorities. These processes and their effects vary a lot across scales: although the diffusion of a new technology might not be optimal at a local level, it might be beneficial from a global perspective as it could lead to faster diffusion to less advantaged places ([Leibowicz et al., 2016](#)). 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 detailed geographical level.

Technological diffusion, which is by definition an aggregated process, can be discussed in parallel with individual adoption mechanisms. On the one hand, [Rogers \(2010\)](#) identifies early adopter of new technologies as ‘knowledgeable risk takers’ and [Griliches \(1957\)](#) as ‘profit maximisers’ ([Ding et al., 2010](#)). Such individual agents are rewarded because of their attitude towards new technologies and innovations. On the other hand, [Perkins and Neumayer \(2011\)](#) attribute diffusion to two processes: (i) epidemic-like mechanisms, which are governed by distance, proximity and social interactions, and (ii) by economic mechanisms as new innovations are adopted by users as they become more profitable, valueable and useful.

This paper focuses on the diffusion of the web as new technology during the 1996 – 2012 period. This was an exciting period for digital technologies as it corresponds with the commercialisation of the internet and, consequently, its almost universal adoption. The reader is reminded that it was only in 1994 when Netscape Navigator was introduced, a year before Microsoft’s Internet Explorer ¹. Also, only 9 per cent of UK’s households had access to the internet in 1998 ([Office for National Statistics, 2018](#)), the web included mostly static webpages, there were no social media and web browsing was happening exclusively from desktop PCs as there were no smartphones ([Tranos et al., 2021](#)). Hence, it is fair to say that the study period captures the very early stages of the diffusion of a new technology that is the web. This is key point in the lifecycle of a new technology. Firstly, during this period new technologies are expensive, crude and imperfect ([Rosenberg, 1994](#); [Wilson, 2012](#)). A simple comparison between Web 1.0 and Web 3.0 applications clearly illustrates this ([Tranos, 2020](#)). During this period the performance of a new technology is the main attraction and not the cost to access and use it ([Wilson and Grubler, 2011](#)). There is a broader theoretical discussion in the literature regarding the motivation behind early adoption. As summarised by [Perkins and Neumayer \(2005\)](#), on the one hand, epidemic models highlight the role of interpersonal contacts as a way for new technologies to diffuse. On the other hand, economic models underline the importance of heterogeneity. Different firms have different structures and business plans, which define the potential economic returns of the adoption of a new technology and, therefore, the choice to adopt a new technology becomes an individual option. From a broader and evolutionary perspective, initial conditions are essential for the creation and evolution of path-dependent technological development trajectories ([Neffke et al., 2011](#); [Simmie et al., 2014](#)). This argument is even more relevant when the focus is on Information and Communication Technologies (ICT) because of the commonly found lag between investment and economic returns as reflected in the Solow paradox ([Acemoglu et al., 2014](#); [Brynjolfsson et al., 2018](#)).

Importantly, the data used here depicts the *active* engagement with the web in the UK as it contains all the commercial websites archived by the Internet Archive ² that include a mention to at least one valid UK postcode in the web text. Websites are identified as commercial ones if they are part of the .co.uk second level domain (SLD). Also, the act of creating a website is understood here as active engagement with the web vis-à-vis the more passive act of browsing the web or having an internet connection ([Tranos et al., 2021](#)). Previous studies have focused mostly on more passive notions of engaging with digital technologies

¹<https://www.theguardian.com/global/2015/mar/22/web-browser-came-back-haunt-microsoft>

²<https://archive.org/>.

such as internet adoption and internet speeds (e.g. [Blank et al., 2018](#); [Riddlesden and Singleton, 2014](#)). More details about the data and the data generation process can be found in Section XX. **ADD DATA DESCRIPTION, WHY .CO.UK**

[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

[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 ([Grubler et al., 1999](#)). The substitution of incumbent technologies by new competitors leads to subsequent decline and eventual obsolescence.

2. Literature review

Geographical diffusion is a synthesis of different processes. On the one hand, we can identify purely spatial or, in other words, contagious processes. Adjacency and, more broadly, distance are the key drivers of diffusion. This perspective draws similarities with epidemics: innovation just like pathogens spreads because of contagion and, consequently, proximity and exposure ([Hivner et al., 2003](#)). On the other hand, we can identify hierarchical processes. Instead of horizontal distance-based diffusion mechanisms, the top-down hierarchy of urban systems drives diffusion. In reality, the synthesis of these two processes represents how new technologies diffuse over space and time ([Morrill et al., 1988](#)).

These ideas were firstly introduced by Torsten Hägerstrand and his thesis entitled ‘Innovation Diffusion as a Spatial Process’ ([Hagerstrand et al., 1968](#)). Hägerstrand was the first one to identify diffusion as a geographical process. The starting point was the idea that diffusion is based on passing information through social networks, which themselves tend to be defined by geography. Hence, he identified the ‘neighbourhood’ effect of how information, and consequently, innovation diffuse. He used agricultural innovations to test and model his ideas using Monte Carlo simulations. Hägerstrand also incorporated the role of hierarchy and how some phenomena maybe firstly adopted in larger cities and then diffuse to second tier ones. This is a sequential instead of a simultaneous process, which resembles the ‘lead-lag’ spatial acceleration effect in market research ([Bento et al., 2018](#); [Peres et al., 2010](#)). Hägerstrand maybe more widely known for highlighting the role time plays in the diffusion of innovations: an early-pioneering period, a middle fast accelerating period and a final saturation one [[Morrill et al. \(1988\)](#)].

The temporal dimension was further explored by Everett Rogers and his seminal work on ‘Diffusion of Innovations’ ([Rogers, 2010](#)). Rogers being a sociologist his work focused not on the diffusion of innovations over space and time, but instead on the adoption of new technologies and innovations by individuals and the individual mechanisms that drive the decisions behind adoption. He identified five groups of individuals regarding their adoption speed: innovators, early adopters, early majority, late majority and laggards. Key mechanism of diffusion and adoption is always communication and how knowledge is transferred within a social system. Therefore, all approaches agree on the S-shaped diffusion and cumulative adoption pattern ([Grubler, 1990](#)).

Schmidt’s Law empirically illustrates a similar pattern. *Core* and usually highly agglomerated regions is where new technologies are invented and commercially deployed [[Grubler \(1990\)](#); [grubler1990rise](#)]. This is where the first adopters tend to be based. Then, technologies spread to the *rim* and eventually to the *periphery*. Although adoption pace might be higher when new technologies finally arrive to the periphery, the saturation levels there may never reach the ones in the core because of the lack of infrastructure or other necessary institutions ([Leibowicz et al., 2016](#)). [Grubler \(1990\)](#) effectively summarises the three key

characteristics of the spatial diffusion process: (i) the cumulative level of adoption follows an S-shaped pattern just like purely temporal models; (ii) diffusion is shaped by a hierarchy effect in a form of a centrifugal force: from core to periphery; and (iii) diffusion is also shaped by distance and a neighbourhood effect and contaminate nearby locations.

The remaining of this section reviews empirical studies which analysed the diffusion on new technologies over space and time. Although the spatial dimension is present in most of the following studies, the level of spatial detail is almost always more coarse than the one adopted here. To begin with [Beardsell and Henderson \(1999\)](#) studied the evolution of the computer industry in 317 US metro areas during the 1977 – 1992 period using employment data. Their analysis indicated that the relative size distribution holds for urban computer employment and also urban heterogeneity is essential in explaining this distribution. [Bednarz and Broekel \(2020\)](#) focused on wind turbines and modelled their spatial diffusion across 402 German regions during 1970 – 2015. Their key finding is that local demand than local supply was the main driving factor.

At a global scale [Perkins and Neumayer \(2005\)](#) analyzed if the diffusion rate of new technologies is driven by a latecomer advantage and the engagement with the global economy via foreign direct investments and trade. Their results illustrate that indeed latecomers and developing countries experience diffusion of new technologies more rapidly than early adopter and developed countries. At the same scale, [Perkins and Neumayer \(2011\)](#) explored whether the adoption of previous communication technologies that is mail, telegrams and telephones was shaped by similar socioeconomic factors as the internet. Their results indicated common patterns regarding the drivers behind the adoption of different communication technologies.

Turning to studies that share more technological and scalar similarities with this paper, [Ding et al. \(2010\)](#) modelled the spatial diffusion of mobile telecommunications across regions in China. Their analysis indicated that socioeconomic characteristics are important determinants of the timing, speed and the level of mobile diffusion within China. Using data from a Hungarian online social network, [Lengyel et al. \(2020\)](#) analysed its adoption and the churn at a very granular spatial level. Their results are in agreement with early theoretical and empirical contributions reviewed here: assortativity, urban scaling and distance are the key drivers of spatial diffusion. At a global scale [Papagiannidis et al. \(2015\)](#) modelled the diffusion of different web technologies and practices. Interestingly, they did so by using similar, but less extensive data as the one used here. Their analysis illustrated how the diffusion of different web technologies and practices follow an S-shaped pattern as well as the different diffusion rates of the different technologies and practices.

3. Materials and Methods

For instance, we can approximate digital economic activities in a region by measuring the volume of commercial webpages by considering only .co.uk websites, which are dedicated to commercial activities (Thelwall, 2000). Such commercial websites are used to exchange information, support online transactions and share opinions (Blazquez & Domenech, 2018). Although nothing prevents a UK-based company from adopting a generic TLD such as.com and, indeed, such cases escape our data, we do not expect that such omissions could affect our results given the popularity of the .uk ccTLD: UK consumers prefer to visit a .uk website when they are searching for products or services (Hope, 2017); and anecdotal evidence indicates that during the first half of 2000, three .co.uk domains were registered every minute (OECD, 2001). Also, as Table 1 demonstrates, .co.uk was the most popular SLD under the .uk ccTLD in 2000. Hence, we use the total volume of all the archived webpages in a region as a proxy for the level of digitization. We start the analysis by focusing on commercial webpages (.co.uk).

[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 R2 = 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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