Cloud Computing and National Accounting

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ESCoE Discussion Paper 2018-19

December 2018

ISSN 2515-4664

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Cloud Computing and National Accounting

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Abstract

As the digitalisation of the economy progresses, one of the changes in business models affecting statistics including GDP and trade data is the adoption of cloud computing services in place of fixed investment in computer and communications hardware and the development of own-account software. This rapidly growing phenomenon involves the detachment of the physical location of data and computing processes from their creation, ownership and use, potentially introducing transactions across national borders. In this paper, we construct price indices for cloud services in the UK, showing significant price declines both before and after adjusting for quality in the past few years. We discuss the conceptualisation of a volume measure for cloud services. We discuss the implications of cloud use by businesses for the interpretation of measured business investment, GDP and productivity growth, noting in particular the limitations of measuring total factor productivity through growth accounting, and the importance of double deflation when there are significant changes in the price of intermediate goods such as cloud services. We discuss also the implications for the interpretation of international trade statistics. Finally, we set out the requirements for official statistical surveys to be able to track cloud computing in the future.

Keywords: Cloud computing, productivity, national accounts

JEL classification: E01, L86, D24

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This ESCoE paper was first published in December 2018.

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Abstract

As the digitalisation of the economy progresses, one of the changes in business models affecting statistics including GDP and trade data is the adoption of cloud computing services in place of fixed investment in computer and communications hardware and the development of own-account software. This rapidly growing phenomenon involves the detachment of the physical location of data and computing processes from their creation, ownership and use, potentially introducing transactions across national borders. In this paper, we construct price indices for cloud services in the UK, showing significant price declines both before and after adjusting for quality in the past few years. We discuss the conceptualisation of a volume measure for cloud services. We discuss the implications of cloud use by businesses for the interpretation of measured business investment, GDP and productivity growth, noting in particular the limitations of measuring total factor productivity through growth accounting, and the importance of double deflation when there are significant changes in the price of intermediate goods such as cloud services. We discuss also the implications for the interpretation of international trade statistics. Finally, we set out the requirements for official statistical surveys to be able to track cloud computing in the future.

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1. Introduction

As the digitalisation of the economy progresses, it is becoming apparent that statistics including GDP and trade data are being affected by the business models and practices adopted by firms. One rapidly growing practice is the adoption of cloud computing services in place of fixed investment in computer and communications hardware and the development of own-account software. The practice involves the detachment of the physical location of data and computing processes from their creation, ownership and use, introducing new transactions across national borders. This paper considers the potential significance of the practice for investment and net trade statistics in the national accounts, and for the measurement of capital services and productivity.

Cloud computing refers to a range of software and computing services provided by (mainly) large vendors from their data centres, enabling businesses and consumers to use the services without purchasing their own equipment and/or software, and requiring less in-house expertise. In the UK and elsewhere the market leaders are Microsoft, Amazon, Google, IBM and Salesforce, although there are also smaller data centre providers.

The use of cloud computing globally has increased rapidly during the past five years according to industry data, described in more detail below. The global cloud computing market is large and growing rapidly. According to industry estimates, it was worth $155 billion in 2017 (Figure 1) and is projected to grow to around $250 billion by 2020.[1] Gartner (2016) estimated that in 2016 around $111 billion of business IT spending had been shifted to the cloud, and forecast that this will increase to $216 billion by 2020.[2]

In the UK, ONS reports that one third of UK businesses with more than 10 employees used cloud services in 2015. The UK government proclaimed a 'Cloud First' policy in 2013 for public sector organisations[3] although it is not clear to what degree the policy has been implemented.[4] There are some major public sector users of cloud computing services, however, such as HMRC and DWP, along with a growing number of private sector organisations.[5] There are few official statistics on cloud computing, and this paper explores some of the conceptual and practical difficulties. We show that the prices of cloud services have declined over that period, while quality and range of services has improved. We also construct a quality-adjusted price index for UK cloud services.

Customers in the UK were initially served from data centres in Ireland and continental Europe. Competition for UK customers increased in November 2015, when Amazon and Microsoft announced plans to expand their physical footprint in the country (mainly London initially). Subsequently, in 2016 UK-based data centres opened in September (Microsoft) and December (Amazon). Google opened in July 2017. The expansion has continued, with the latest (mid-2018)

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[1] Gartner expects a total market size of $260 billion; Forrester's estimate is slightly lower at $236 billion; and IDC estimates it will reach $277 billion by 2021.

[2] Gartner press release, 20th July 2016: https://www.gartner.com/newsroom/id/3384720

[3] Government Digital Service, 3rd February 2017: https://www.gov.uk/guidance/government-cloud-first-policy

[4] Stuart Lachlan, Diginomica, 25th April 2017: https://government.diginomica.com/2017/04/25/whatever-happened-cloud-first/

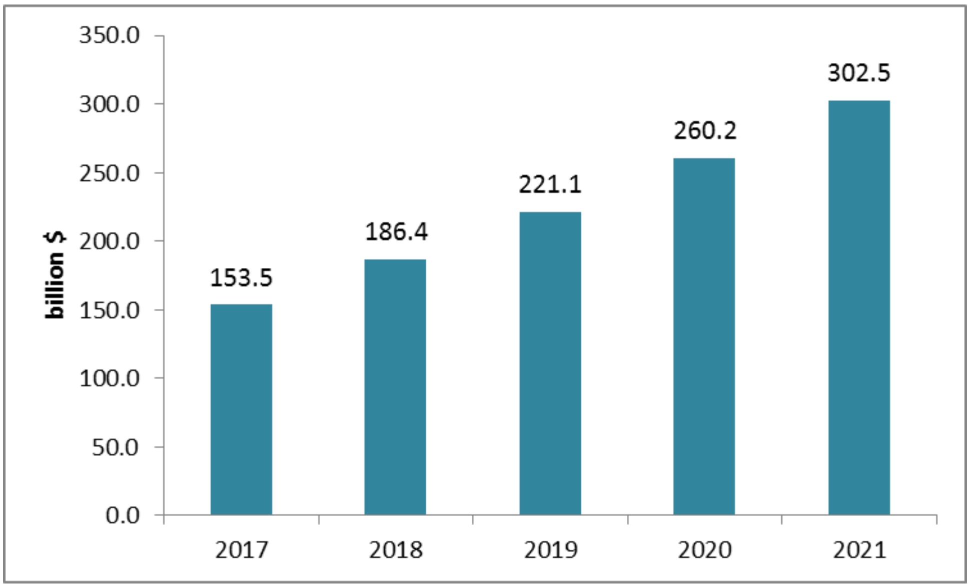
[5] Ian Roberts, HMRC Digital blog, 8th November 2018: https://hmrcdigital.blog.gov.uk/2017/11/08/data-virtualisation-why-we-moved-99-million-accounts/; Juan Villamil, DWP Digital blog, 11th September 2015: https://dwpdigital.blog.gov.uk/2015/09/11/cloud-services-at-dwp/

being Microsoft's installation of an underwater concept data centre off Orkney. According to the market research company IDC, spending in the cloud market in the UK will reach $7.9 billion in 2018, which is similar to Germany but significantly less than the US ($97 billion); and the top three sectors in terms of spending on cloud services, with 40% of total spending in the UK, are banking, retail and manufacturing.[6]

The potential economic impacts of cloud computing could be significant. For example, a study by IDC (2014), for the European Commission, estimated that cloud computing could add €65-165 billion (0.46%-1.09%) to the GDP of EU-28 in 2020 and create 100,000-770,000 firms between 2015-2020. The study estimated that each Euro spent on cloud services replaces between 1.80 – 2.20 Euros previously spent on hardware (mainly), software and associated services.[7]

The academic economics literature on cloud computing is limited, however. Etro (2009) explored the macroeconomic impacts of cloud computing, concluding that it enhances business creation and competition. He portrayed cloud computing as a new general-purpose technology able to reduce fixed entry costs in the form of ICT capital. Byrne et al. (2017) report that as the use of cloud computing has increased rapidly in the United States, the price of using cloud services decreased significantly. They constructed a new quarterly price index for cloud services in the US for 2009 to 2016.

Figure 1. Global cloud market revenue forecast, 2017-2021. Source: Gartner, April 2018



What are the implications of the cloud shift for economic statistics? The increasing use of cloud computing by businesses means they need to invest less in physical ICT equipment such as servers and own-account software development.[8] Hence some 'investment' becomes 'intermediate

[6] IDC press release, 18th January 2018: https://www.idc.com/getdoc.jsp?containerId=prUS43511618
[7] Under the umbrella of the 2012 European Cloud Strategy and the Digital Single Market, the EU aims to support the uptake of cloud services (especially by SMEs); support the development of certifications and standards; and promote security and ability of customers to switch between cloud providers.
[8] Deloitte (2018) reports that using the cloud has reduced the capital expenditure (CAPEX) of businesses by around 19%. Surveyed businesses (N=1488) also stated that the average employee saved around 2.5 hours on per week, leading to a net return of $2.5 per $1 spent in the cloud.

consumption'. Domestic businesses will reduce their investment in hardware as they switch to using cloud services, and may also substitute cloud services for software purchases or development, without (at present) capitalising these purchases. Nevertheless they are still using equivalent capital services provided by such equipment and software. Since business investment - Gross Fixed Capital Formation (GFCF) – is part of the expenditure measure of GDP there are potential implications for measurement of total output and productivity. Furthermore, the price paid by the businesses using cloud services will likely be lower than the cost to them of own-provision of the required computing services, and the quality of the services (access to the most up-to-date versions for instance) will be higher. Hence there could be implications for the deflators that are currently used to deflate some of the IT services consumed in an economy. Even if the purchase of cloud services were correctly to be regarded as an intermediate purchase rather than use of capital services, the failure to double deflate (and quality adjust correctly) would lead to some underestimate of 'true' total factor productivity. We also consider the implications for net trade statistics. Cloud providers may serve UK customers from data centres overseas or more likely in the UK; while they will purchase the IT equipment, which will in principle form part of their reported GFCF in the UK for local data centres, this will be imported. As large purchasers, they will probably pay less for the capital equipment, however.[9]

This paper makes several contributions. We construct price indices for cloud services purchased by businesses. We discuss the conceptualisation of a volume measure for cloud services. We discuss the implications of cloud use by businesses for the interpretation of measured business investment, GDP and productivity growth, in particular given the lack of double deflation and quality adjustment. We discuss also the implications for the interpretation of international trade statistics. Finally, we set out the requirements for official statistics to be able to track cloud computing in future.

2. What is cloud computing and why do businesses use it?

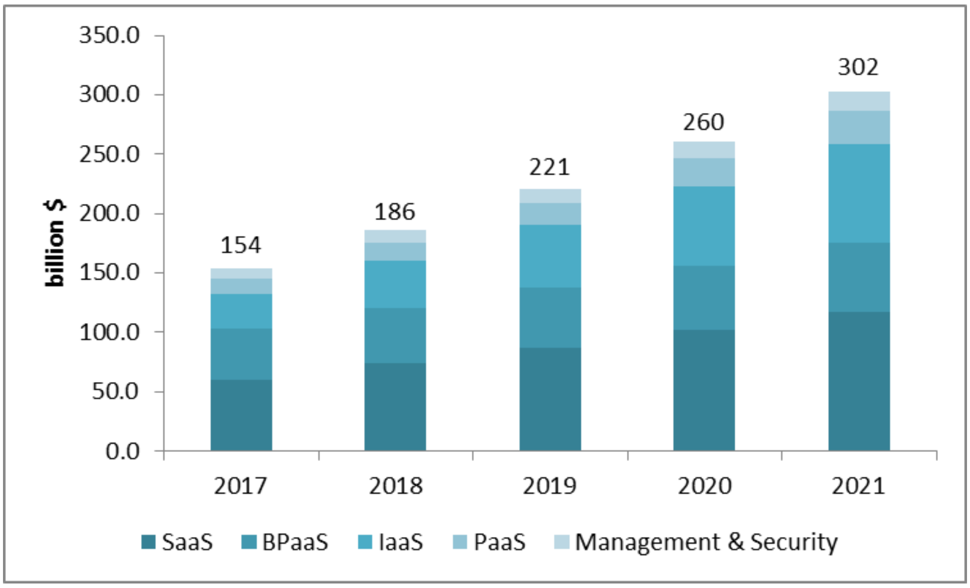
Cloud computing refers to computing services accessed remotely via the internet. The main service categories include storage, software, databases and networking. Newer services are being added, such as machine learning and AI applications, although they are not yet widely used. Two main types of cloud infrastructure are generally distinguished: private and public.[10] The private cloud is hosted specifically for an individual organisation such as a firm or government department, although it can have multiple users (e.g. business units or divisions). The public cloud refers to cloud infrastructure and services that can be accessed by any subscriber, for example for a monthly fee. The key difference from the private cloud is that it is hosted on shared servers in the datacentres of providers, whereas the private cloud consists of dedicated servers.

The following main categories of cloud service are: Software as a Service (SaaS); Infrastructure as a Service (IaaS); Business Processes as a Service (BPaaS); and Platform as a Service (PaaS). The provision of software services via the cloud is currently the largest segment of the market and will

[9] In 2017 GCFC accounted for approximately 17% of UK's GDP, in volume terms according to the ONS: https://www.ons.gov.uk/economy/grossdomesticproductgdp/articles/aninternationalcomparisonofgrossfixedcapitalformation/2017-11-02
[10] A full definition of key cloud computing terms is provided in Appendix A.

continue to be in the next years (Figure 2). However, in terms of growth the provision of IT infrastructure services (which includes data storage and computing services) stands out.

Figure 2. Global cloud market revenue forecast by individual cloud services, 2017-2021. Source: Gartner, April 2018



2.1 Benefits of adopting cloud computing services

The use of cloud computing services means users do not need to purchase their own IT equipment. The main advantages are:

- **Cost savings** as hardware and software does not need to be purchased, installed, managed and maintained but instead can be rented as needed. This also reduces the under-utilisation of installed capacity.
- **Flexibility and scalability** as services can be purchased on a "pay-as-you-go" basis and hence easily scaled up if needed, including in the short term.
- **Global accessibility** as users can access services from anywhere using different devices as long as they are connected to the internet. It also allows rolling out applications to a global user base faster.
- **Functionality and performance** are better as more services can be accessed (including sophisticated ones such as machine learning and artificial intelligence software) while computing speeds are generally higher, which allows for more complex and/or data-intensive computations, and software is frequently updated.
- **Reliability and security** when compared to in-house provision, due to redundancy and backup across different data centre locations secured with state-of-the-art security software, and in secure premises.

Other advantages that are discussed with regard to cloud computing are easier certification of data processes and compliance with regulations (e.g. ISO or GDPR), business innovation and expansion (IT teams can focus on core activities), and energy savings due to economies of scale and energy efficiencies at large data centres.

2.2 Barriers to adoption

There are also a number of barriers and risks for users and providers of cloud computing services. On the user side the biggest perceived risks or barriers are data security, data location regulations, limits to data portability or 'vendor lock-in', and uncertainty about costs and savings.[11] Other issues include concerns about compliance, reliability and local support, loss of control over upgrades and backups, software compatibility and interoperability of services. However, between 2012-2015 these have changed in terms of order of importance. While concerns over data security, costs, loss of control and reliability have all decreased significantly, other risks have gained in importance as measured by the proportion of Chief Information Officers mentioning it as a concern. A survey by IDC (2014) of firms that had adopted cloud services showed that the majority actually reported an improvement in the security of their IT systems. Other areas that respondents said had improved included that cloud vendors keep their IT systems up-to-date, and they were easier to use, more reliable and flexible than standard in-house systems.[12]

There will also be shifts in demand for cloud computing depending on the capacity and cost of 'edge' computing, i.e. in the hardware and devices users might purchase, and the software available to run on these. For example, data processing is becoming feasible and cheaper with new chip designs, and will be attractive for applications requiring low latency.[13]

In addition, there are barriers on the provider side. According to the European Commission (2017), their biggest concerns are data location regulatory requirements, provision of local support, trust and privacy issues, information security and procurement rules. A lack of awareness and understanding on the part of existing and potential users was mentioned as barrier to more widespread adoption.

3. Overview of main cloud services providers

The location of the data centre is important for clients to decide whether to switch to the cloud and which provider to choose. A key reason is data security and compliance with data storage laws, but physical proximity also reduces latency rates. We provide a map of major data centers located in the UK in Figure 3.

The main providers globally are Microsoft (including Azure), Amazon Web Services (AWS) and IBM; and other players include Salesforce, Oracle, SAP, Google and Alibaba. These players are also the largest the UK market, though UKCloud has a niche market share in IaaS for government clients. Each offers all or some of the main cloud services related to computing, storage, networking and databases (see Table 1). Their respective market shares differ depending on the market segment.

[11] Relevant surveys: Bain & Company (reported in Brinda and Heric, 2017); Deloitte (reported in European Commission, 2017); and CFO Research (2012).

[12] We do note that these results are based on a survey and it is possible that firms with worse in-house IT are more likely to adopt cloud services earlier, as it "can only get better". Hence it is not likely that their experiences will translate into the same level of satisfaction for all firms.

[13] The delay in carrying out an instruction to transfer data.

While Amazon's AWS is the global market leader in some categories (mainly IaaS), in terms of total global cloud revenue Microsoft ($18.6 billion) is just ahead of Amazon ($17.5 billion) and IBM ($17 billion).[14] However, there are ongoing discussions on how to 'measure' the cloud resulting in different estimates depending on what is included. Cloud providers themselves often report revenues by adding different services together, making it difficult to get a clear picture. The market is not particularly concentrated with the exception perhaps of IaaS (Table 2), as there are a sizeable number of smaller providers in some segments. Overall, IDC predicts that in 2018 SaaS will be the largest cloud computing service capturing two thirds of total spending. This will mainly be on applications for enterprise resource management (ERM) and customer relationship management (CRM). This is followed by IaaS, and PaaS with spending mainly on data management software.[15] As shown in Figure 2, Gartner's predictions also see SaaS ahead of IaaS at $71 and $46 billion, respectively. By 2020 SaaS is projected to increase to $100 billion and IaaS to $72 billion, and hence before BPaaS ($54 billion)[16] and PaaS ($21 billion). For the IaaS market, Gartner reported that AWS captured almost 52% of the total market of $23.6bn in 2017 (see Table 2). The closest competitor was Microsoft with around 13%, followed by Alibaba, Google and IBM.

Table 1. Overview of IaaS cloud service product by broad categories and 3 large providers. Source: Own elaboration based on company websites

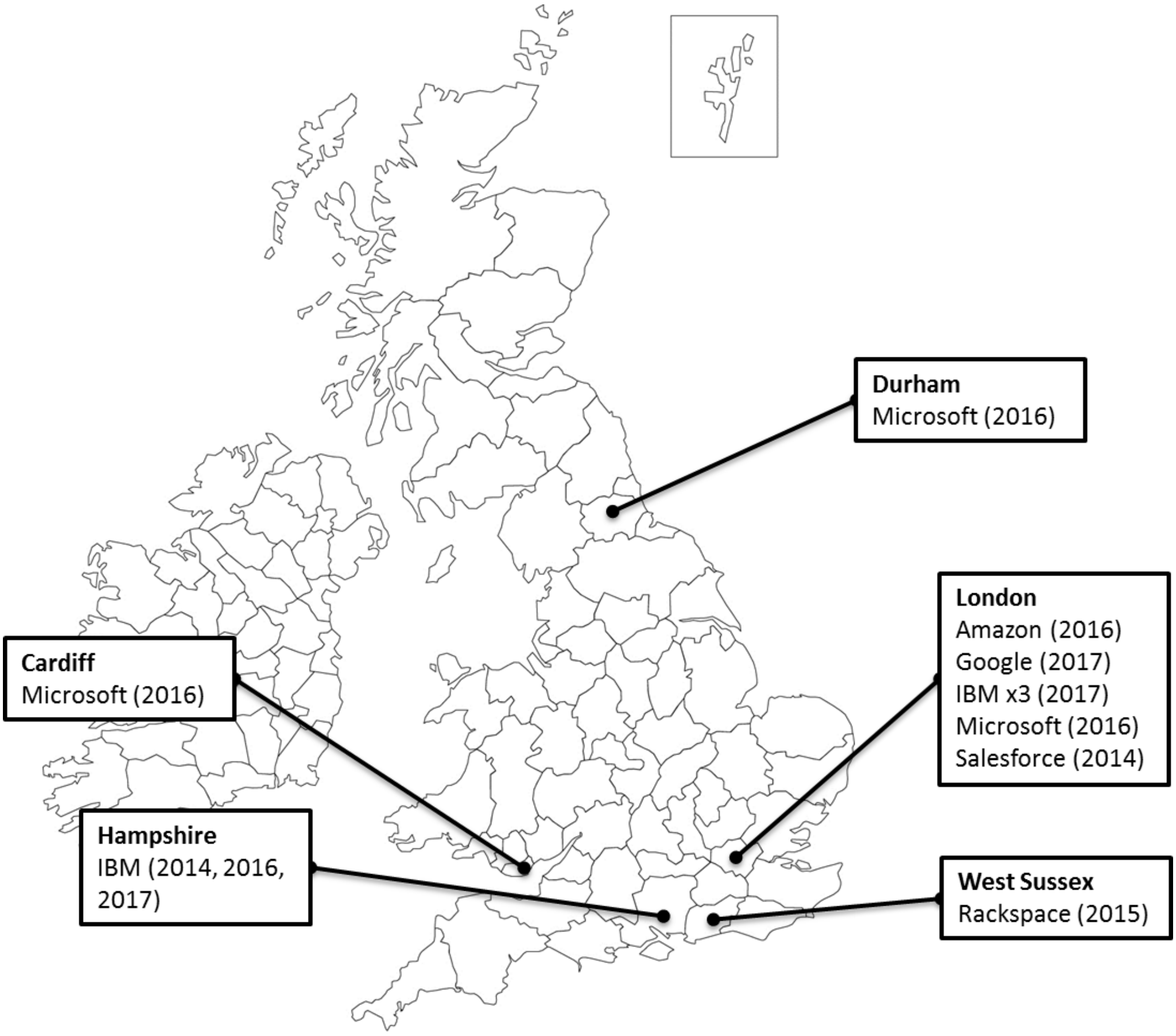
Cloud service	AWS	Microsoft	Google
Compute	Amazon Elastic Compute Cloud (EC2); AWS Lambda; Elastic Load Balancing	Azure virtual machines, Azure App Service	Google Compute Engine and Google App Engine
Storage	Amazon Simple Storage Service (S3); Amazon Elastic Block Store (EBS)	Azure Blob service, Azure virtual hard disks (VHDs)	Google Cloud Storage
Networking	Amazon Virtual Private Cloud (VPC)	Azure virtual network (VNet)	Google Cloud DNS and Google Cloud Interconnect
Databases	Amazon Relational Database Service (RDS); Amazon DynamoDB; Amazon Aurora	Azure Cloud SQL Database, Azure SQL Data Warehouse, Azure Table Storage, CosmosDB	Google Cloud SQL, Google Cloud Datastore, and Google Cloud Bigtable

Table 2. IaaS market share by provider. 2016-17. Source: Gartner, August 2018

Company	2017 revenue	2017 share	2016 revenue	2016 share	2015-16 growth
	million $	%	million $	%	%
Amazon	12,221	51.8	9,775	53.7	25
Microsoft	3,130	13.3	1,579	8.7	98.2
Alibaba	1,091	4.6	670	3.7	62.7
Google	780	3.3	500	2.7	56
IBM	457	1.9	297	1.6	53.9
Others	5,902	25	5,392	29.6	9.5
Total	**23,580**	**100**	**18,213**	**100**	**29.5**

[14] Bob Evans, Forbes, 5th February 2018: https://www.forbes.com/sites/bobevans1/2018/02/05/why-microsoft-is-ruling-the-cloud-ibm-is-matching-amazon-and-google-is-15-billion-behind/#211c55501dc1
[15] IDC press release, 18th January 2018: https://www.idc.com/getdoc.jsp?containerId=prUS43511618
[16] BPaaS refers to Business Process Outsourcing that is provided via the cloud.

Figure 3. Map of UK datacentre by main cloud providers



Source: Authors based on company websites and press releases

Amazon Web Services

AWS operates four regions in Europe, compared to five in North America, eight in Asia-Pacific, and one in South America. The company entered the European market by opening its first data centre in Dublin in November 2007. This was followed by expansion in Frankfurt (October 2014), London (December 2016), Paris (December 2017) and Stockholm (2018). In terms of computing products AWS initially only offered its storage product S3 from Ireland, but followed up with the compute product EC2 in December 2008. Interesingly, AWS reports that before opening the London Region it already served more than 100,000 UK-based customers out of the Dublin and Frankfurt regions.[17]

Microsoft Azure

[17] Caroline Donnelly, 1th December 2016: https://www.computerweekly.com/news/450404606/AWS-opens-UK-datacentre-region-to-meet-pent-up-demand-for-locally-hosted-cloud

Microsoft currently operates eight regions in Europe. Of these two each are located in France, Germany and the UK, with additional ones in Ireland and the Netherlands. Starting in July 2009, its cloud services to European customers were initially provided from Dublin ("North-Europe"). IDA Ireland reported that the initial investment in Dublin was £500 million, followed by a $130 million expansion in 2012 employing 50-70 people.[18] In December 2013 Microsoft announced an additional $230 million to add 15,700m^2 to the data centre, taking it to a total of 54,255m^2. First announced in September 2013,[19] the data centre in Amsterdam was opened in August 2016 at a cost of $2.7 billion. It is roughly twice the size of the facility in Dublin, at 110,000m^2 of floor space.[20] Regarding its physical footprint in the UK, Microsoft announced that the three data centres in London, Durham, and Cardiff were fully operation on the 7 September 2016.[21] In October 2016 Microsoft said that to date it had invested $3 billion in datacentres in Europe.[22]

Google Cloud Platform

Google currently runs one data centre in the UK, which opened in London in July 2017. This follows existing European data centres in Belgium (2010), Finland (2011) and Dublin (2012, 2016). The cost of the London facility is not known but the company already had invested €550m in Belgium (Google announced additional investments of €250m in 2018), €800m in Finland and $265m in Dublin. The London data centre was reported to reduce latency rates in the UK by 40-80%, according to Google, when compared to using the facility in Belgium. In the same year another data centre opened in Frankfurt (September 2017) and in 2018 Google opened its 14th region and the latest European data centre in Eemshaven, Netherlands (January 2018) at a cost of $640 million.

Others

IBM currently operates 6 data centres in the UK, of which two are located in London (opened in 2017), and additional facilities in Chessington (2014), Portsmouth (2014), Farnborough (2016) and Fareham (2017). The initial centre in Chessington was reported to have space for 150 racks, 4,000 physical nodes, 15,000 servers and a floor space of 10,000 square feet.[23] IBM has been reporting year-on-year growth in cloud revenue since 2012, when total revenue was just over $2bn, reaching $17bn in 2017. Also cloud as a service on its own grew strongly from $1bn to $10.3bn in the period between 2012-2017.

Salesforce opened its first European data centre in London in October 2014, built by NTT Communications Europe. Two additional European centres followed in 2015, based in Frankfurt and Paris. The company reported annual revenues of more than $10 billion in the fiscal year 2017/18,

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[18] IDA Ireland press release, 23rd February 2012: https://www.idaireland.com/newsroom/microsoft-to-expand-its-d

[19] Rich Edmonds, Windows Central, 28th September 2013: https://www.windowscentral.com/microsoft-looking-invest-new-netherlands-data-center

[20] Peter Judge, Datacenterdynamics.com, 10th August 2016: http://www.datacenterdynamics.com/content-tracks/design-build/microsofts-2bn-netherlands-data-center-revealed/96753.fullarticle

[21] Initial plans for expansions to the UK were officially revealed on the 10th November 2015, a week after Amazon.

[22] Microsoft press release, 3rd October 2016: https://news.microsoft.com/europe/2016/10/03/microsoft-increases-european-cloud-investment-to-3-billion-unveils-cloud-policy-recommendations/

[23] IBM press release, 19th July 2017: http://www-03.ibm.com/press/uk/en/pressrelease/52861.wss

which is almost double the figure for 2015. It acquired MuleSoft in March 2018 with the strategic aim to enhance its PaaS products, and also holds a stake in Dropbox.

4. Cloud use in the UK

As noted, the cloud market in the UK is expected to have reached $7.9 billion (approximately £6bn) in 2018. Although a small figure in the context of total business investment (£195bn in 2017), it reflects a combination of significant and increasing consumption of IT capital services and rapidly decreasing prices (as we show below). Business use of the cloud to some degree is quite extensive. According to Eurostat, around 35% of businesses in the UK purchased a cloud service at some point in 2015 (see Figure 4). This share is lower than in Scandinavian economies but well above the EU average of 21% and significantly higher than in Germany (16%), France (17%) and Italy (22%).

Figure 4. Percentage of enterprises that buy any cloud service, comparison by EU countries, 2015. Source: Eurostat

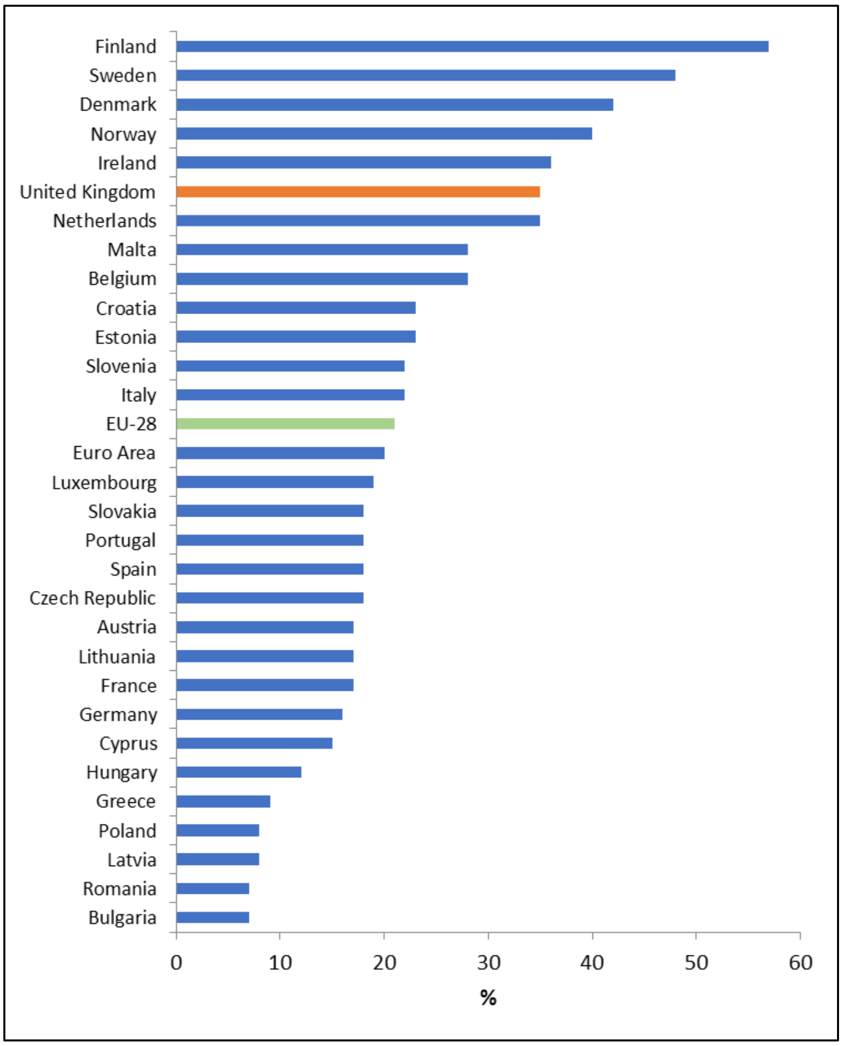
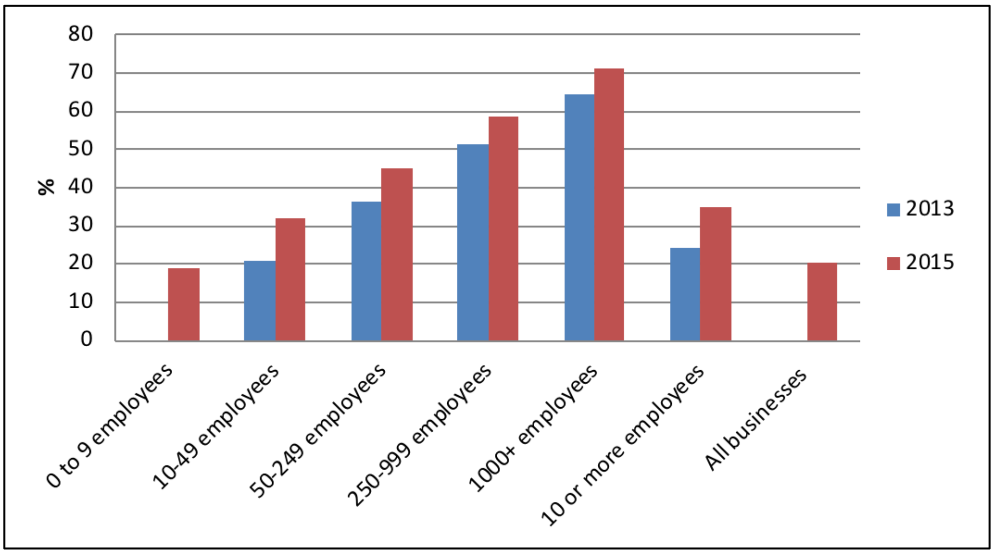


Figure 5. Percentage of enterprises that purchase any cloud service in 2013 and 2015, by firm size bands. Source: E-commerce Survey, ONS



4.1 Differences in the usage of cloud services by company size

The ONS E-Commerce Survey indicates that business size is positively associated with the use of cloud services (see Figure 5).[24] While in 2015 around 30% of enterprises with 10-49 employees purchased cloud services this figure increases to 70% for businesses with more than 1,000 employees. The average for all firms (including small firms) is 21%; compared to 2013, cloud purchases increased by 10.7 percentage points for firms with more than 10 employees.[25] This was driven mainly by those with 10-49 employees, which saw an increase of 11.2 percentage points, compared to 6.5 percentage points for firms with more than 1,000 employees. Cloud providers agree that large businesses are more likely to use cloud services, especially the more sophisticated ones, but they also add that at the same time start-ups are increasingly likely to be cloud-native, as are most tech businesses. Deloitte (2018) reports that there are more than 300,000 businesses in the US that would not be able to operate without cloud services, including start-ups relying on new business models. Jon and McElheran (2017) describe how young firms that 'rent' IT equipment via the cloud have a higher survival and growth rate and levels of productivity.

When looking by type of service, some additional distinctions emerge.[26] Between 2013 and 2015 the share of large businesses using the cloud to run computing software (SaaS) increased from just below 20% to 26%, and the share using the cloud to store data from 37% to 47%. Similar increases were visible for use of customer relationship management (CRM) software and finance & accounting software. The strongest increase was registered for the use of the cloud for the use of email. Cloud services related to hosting of databases increased only moderately from 34% to 36%. For smaller

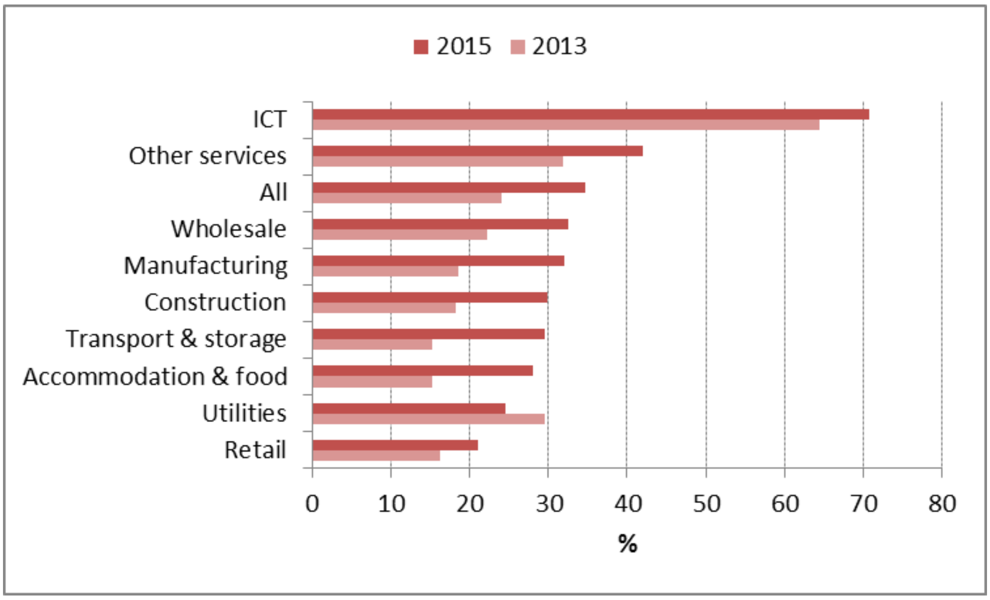
[24] This includes using the cloud for any of the following services: email, office software, hosting of business' database, storage of files, finance or accounting software, CRM software, or computing capacity to run own software. Figures on adoption rates for each individual service are reported in Appendix B.
[25] See Appendix B.
[26] See Appendix B.

firms with 250 to 1,000 employees the trends are largely similar, apart from cloud-based CRM software, which remained stable.

4.2 Differences in the usage of cloud services across sectors

The use of cloud services differs between sectors (Figure 6). While more than 70% of firms in the ICT sector use the cloud in some way, the comparable figure for Retail is only 21%.[27] Manufacturing and Wholesale trade have relatively high usages of cloud services, as well as 'Other services' which includes real estate activities and professional, technical and scientific business services. By comparing figures for 2013 and 2015 we see that the Transport & storage sector increased its use of the cloud by almost 15 percentage points.[28] This is followed by Manufacturing (13.4 percentage points) and Accommodation & food services (12.9 percentage points). Surprisingly, the Utilities sector saw a decline of 5 percentage points.[29]

Figure 6. Proportion of businesses purchasing cloud computing services in 2013 and 2015, by industry sector. Source: E-commerce Survey, ONS.



4.3 Consumer use of cloud services

There is also considerable personal use of the cloud, mainly storage (e.g. Dropbox, Google Drive, Microsoft OneDrive, Apple iCloud). The proportion of people using cloud storage services in the UK increased from 39% to 42% between 2014 and 2016 and it is slightly higher for men (44%) than for

[27] Includes firms with a minimum of 10 employees. The survey excludes financial services, public administration, education, households, and arts & entertainment.

[28] Details reported in Appendix B.

[29] Considering that the ONS uses surveys based on a representative sample of businesses, each estimate falls within a confidence interval. Hence the focus should be on relative differences across sectors rather than interpreting the exact magnitude of a share of businesses using cloud services.

women (41%).[30] A breakdown by age groups further shows that the personal use of cloud services is inversely associated with age. Overall, apart from people above 65, all age groups showed an increase between 2014 - 2016.

5. Implications of cloud services for national accounts

5.1 Implications of cloud services for measuring GDP and productivity

The fundamental issue is that cloud services do not require on-premises investment and installation of hardware or software. A first implication could be the reduction in business investment in tangible assets, and also intangible assets such as own-account software or data. The shift to purchasing cloud services is, at least for now, unlikely to be capitalised in company accounts. It is likely to be treated as an operating expense. We would therefore like to know the price paid for these purchases for the purposes of correct double deflation to calculate real terms GDP. The reduced capital investment by cloud users will be at least partially offset by increased investment by cloud providers, although they are likely to be able to purchase the required capital assets at a lower price given the scale of their purchases. Finally, there will be implications for net trade in services figures. Data centres are increasingly being located in the UK but some cloud services may be provided from overseas. The location of data centers and prices paid for equipment by cloud providers will also have implications for net trade in goods statistics.

We begin by considering the general issues for the measurement of GDP and productivity, turning in later sections to the construction of a quality-adjusted price index for cloud services, and to the trade issues.

Investment expenditure (gross fixed capital formation or GFCF) is one of the key components of GDP, whereas businesses' purchases of intermediate goods and services are netted off the final, value added, GDP figures. Here we consider how the growing use of cloud services could have implications for measured GDP in nominal and volume terms, and also for the estimate of capital services used in calculating productivity. One of the consequences of switching to purchasing services from cloud service providers is that private and public organisations can reduce their own capital investment in ICT hardware and software while benefiting from capital services that are no worse in quality and likely better than the in-house ones they replace. Gartner's estimate of the shift from traditional IT spending to cloud services of around $111bn globally was spent in 2016 represents around 15% of total IT spending (on business process outsourcing, application software, application infrastructure services, and system infrastructure). Thanks to economies of scale, big cloud service providers are able to deliver the same or a better level of capital services using less equipment overall (European Commission, 2014). Though, it might need to be replaced more regularly if the average usage is higher.

The question whether cloud expenditure should be recorded as capital expenditure (capex) or operating expenditure (opex) is thus central when considering the implications of increasing use of

[30] See Figures 19 and 20 reported in Appendix B.

cloud services in modern economies. This is currently under debate in the accountancy profession.[31] It seems likely that most businesses are currently recording expenditure on cloud services as an operating expense. Software implementation and development costs could still be capitalised, if the business has the full right to the software and can also run it outside the cloud. But the extent to which businesses are developing their own software using cloud services, as opposed to using public cloud software, is unlikely to be significant. A recent report by Deloitte (2017) highlights, too, that switching between cloud providers is difficult and costly in itself, so it might not be possible in practice to run elsewhere own-account software developed using particular cloud infrastructure.

To the extent that businesses are substituting cloud purchases recorded as operating expenditure for purchases of hardware and some software recorded as Gross Fixed Capital Formation in GDP; and to the extent that they are paying a lower price for a higher quality of capital service, then there is some "vanished capital" compared to the counterfactual no-cloud world. The substitution will affect calculations of total factor productivity. The issues have some similarities to issues of measuring intangible capital services (Corrado et al 2013) or the treatment of leases (Moussaly & Wang 2014) for growth accounting purposes. In the usual framework, following Brynjolfsson, Rock & Syverson (2017) for example,

$$Y + zI = f(A, K, L, N)$$

where Y is output, I is cloud capital with price z, A is total factor productivity, K is other capital, L labour and N unmeasured intangible capital, with rental prices r, w and h respectively. The measured Solow residual will be

$$S' = dY/y – (rK/Y * dK/K) – (wL/y * dL/L)$$

.which will differ from the 'true' residual by the term

$$(zI/Y * dI/I) – (hN/Y * dN/N)$$

This will be negative – that is, measured TFP growth will understate the 'true' rate – if the growth rate of investment in cloud capital (weighted by its output share) is greater than the (weighted) growth rate of the stock of the capital services, which is likely to be the case early in the adoption of the new cloud model.

However, TFP calculations also need to take account of the investment (within the borders) in IT equipment by cloud service providers. As discussed above, this is likely to be somewhat lower than the business investment it replaces, but will still be a significant amount. The net effect on measured GDP of the switch to the cloud may therefore be small.

There is, nevertheless, potential mismeasurement in terms of TFP calculations. The importance of cloud service purchases as an intermediate good by businesses implies the need for careful double deflation to calculate the real gross value added: if the intermediate consumption deflator is lower

[31] See for example Deloitte (2017) *Capitalising your Cloud*: https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/technology/deloitte-uk-capitalising-your-cloud-booklet.pdf; or PWC (2015) *Making sense of a complex world: Cloud computing— the impact on revenue recognition*: https://www.pwc.com/gx/en/communications/publications/assets/pwc-cloud-computing-and-revenue-recognition-whitepaper.pdf

than the output deflator currently applied in many national statistics, there is a downward bias in gross value added estimates which scales with the nominal amount of intermediate consumption and the difference between the two deflators:

$$\text{Bias} = \text{Intermediate consumption (nominal)} * (P_o - P_{IC})/(P_o * P_{IC})$$

where P_o is the output deflator and P_{IC} the intermediate consumption deflator; and similarly, if there is a 'true' intermediate consumption deflator lower than is currently measured.[32] Cloud services also need to be taken into account in the capital services term in the usual growth accounting calculation. The statistical practice uses observable investment expenditure as a source for measuring the input of capital services. Recent ONS figures indicate a contraction in capital services in the ICT sector in the UK since 2009 (although of course the issue discussed here relates to the capital services firms across *all* sectors derive from ICT capital).[33]

There is a further issue in the use of conventional growth accounting at all to measure productivity improvements from process innovations, including the use of cloud services but also the extensive use of outsourcing and other process improvements. GDP is a value added construct, whereas firms produce gross output. Conventional growth accounting's value added approach is valid as a method for evaluating productivity change if and only if: intermediate inputs are separable from measured inputs of capital and labour services; there are no changes in the rate of outsourcing; and in addition there is perfect competition and homogeneous use of technology (Bishop and Hepburn, 2013). Standard growth accounting linearises the usual Cobb-Douglas production function as

$$\ln Y = \ln A + b_k \ln K + b_L \ln L$$

where Y = O – M, M being a vector of intermediate inputs and O being gross output. The alternative grow ouput specification is

$$\ln O = \alpha + \beta_K \ln K + \beta_L \ln L + \beta_M \ln M$$

where the β coefficients are the output elasticities of each input. If the assumption that intermediate inputs are non-separable is invalid, we want to compare the estimate of total factor productivity in the value-added approach with the true elasticities. Assuming constant returns to scale for simplicity, and setting the derivatives equal to factor prices in the usual way, then

$$M = (\gamma/A)*Y$$

where γ is a constant. Subsitution of the gross output production function into the value added production function, and simplifying using the above relationship between M and Y when the first order conditions for profit maximisation are satisfied, then

[32] In the UK the ONS is currently progressing implementation of double deflation, which will lead to real GVA revisions: https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/articles/doubledeflation/methodsandapplicationtouknationalaccountsexperimentalstatistics

[33] ONS, UK productivity research summary: February 2018 https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/articles/ukproductivityanalyticalrelease/february2018

$$\ln Y = \ln A + \ln(1 - \gamma/A) + \frac{\beta_K}{1-\beta_M} \ln K + \frac{\beta_L}{1-\beta_M} \ln L$$

Estimates of TFP using a value-added approach will be biased estimates of gross-output TFP and the size of this bias will be increasing in β_M. The gains to productivity from process improvements are better addressed using a gross output and production function approach. Certainly, if growth accounting is based on GDP, it is important to apply correct double deflation to the inputs used in its construction.

5.2 The cloud and measurement of UK investment

Is there any sign of the cloud shift in the UK's investment figures? We consider this first by looking at gross fixed capital formation (GFCF) data.[34] At this stage we present aggregate data although these potentially mask very different trends at the firm level. The figures will anyway be at best suggestive as there are many factors contributing to the observed trends (e.g. increasing overall demand of IT services).

The ONS estimates GFCF based on business surveys and deducts disposals from acquisitions to get a net investment figure (not total stock). From 2015 the Quarterly Acquisitions and Disposals of Capital Assets Survey (QCAS) and the Annual Acquisitions and Disposals of Capital Assets Survey (ACAS) were introduced as more detailed versions of the previous Quarterly Survey of Capital Expenditure (QCPX/Capex). As a result of these changes more detailed business investment figures for hardware (hardware vs telecoms) and software (own-account vs purchased) by broad sector became available. These are examined in Sections 5.2.1 and 5.2.2.

In addition, we also look at the capital investment in IT infrastructure equipment by cloud service providers in Section 5.2.3. This is likely replacing some of the expenditure previously undertaken by firms. Due to scale economies we would expect aggregate investment to be somewhat lower than on a counterfactual no-cloud basis. It could also be reduced compared to this counterfactual to the extent that data centres serving the UK are located in a different country and the service is provided across borders. However, it is also possible that the overall use of IT services has increased over time.

5.2.1 Gross Fixed Capital Formation in hardware

As of 2015 the ONS asked businesses specifically for investment in 'computers and peripheral devices' (i.e. 'hardware') and 'telecoms equipment'.[35] Together they constitute investment in ICT equipment. Table 3 lists annual figures for business investment in machinery and equipment

[34] It is further interesting to note that among all OECD countries the UK spends on average the least on GFCF as a share of GDP (ONS, 2017). The average spending between 1997-2017 was 16.7%, compared to 20.5% in Germany, 20.8% in the US and 21.7% in France.

[35] This prompted some firms to report 'Telecoms' investment that had previously been recorded as 'Other' investment in machierny and equipment (thanks to colleagues at the ONS for clarifying this). The ONS has since made adjustments to account for this reallocation across categories.

between 1997- 2017, including its sub-assets. This shows a sharp drop just after the financial crisis. However, from then onwards investment has been on the rise again until it dropped again in 2017.

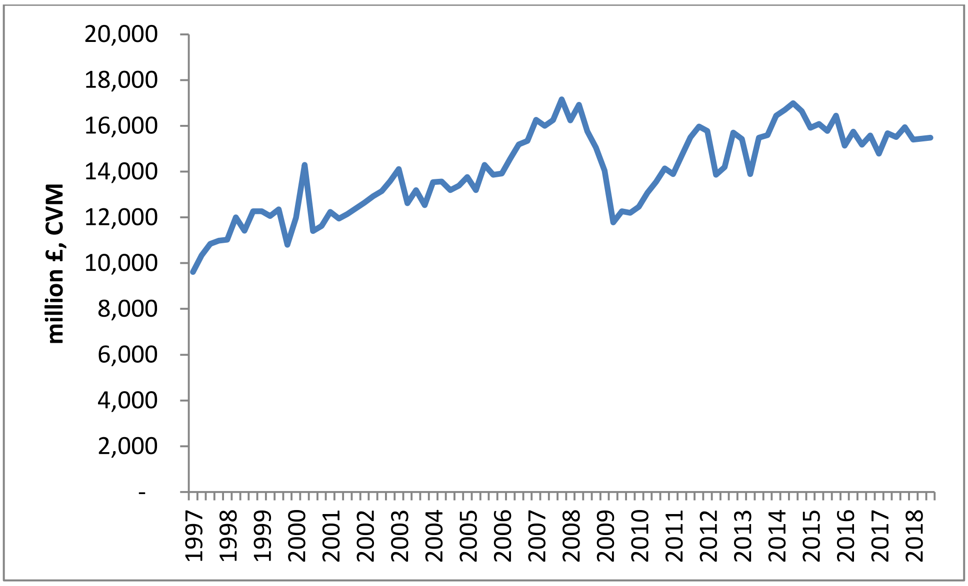
When looking specifically at investments in ICT equipment we see that the drop starts as early as 2013, with the largest fall of £2.8 billion in 2015. If we break ICT equipment into its sub-assets we can see that this fall is driven by lower investment in hardware (minus £2.14 billion), as well as telecoms equipment (minus £660 million). Quarterly figures for net investment in 'ICT' and 'Other' equipment in the UK are available until Q3 2018 (see Figure 7). They show that investment in 2018 is largely in line with 2017, and if anything looking even lower.

Overall this is suggestive, as in 2016 Amazon and Microsoft started expanding with their own data centres in the UK; although this would not explain why business investment in ICT equipment already dropped in 2015. However, as reported by AWS, a large number of UK businesses were buying coud services abroad before that and prices dropped significantly in 2015 (see next section). This drop is also unlikely to be driven by a change in surveys by the ONS (in 2015), as investment in 'Other' equipment between 2014 and 2015 only increased modestly by £250 million. However, more research is needed to attribute this to a 'cloud shift' of on-premise ICT equipment.

Table 3. Annual Gross Fixed Capital Formation (GFCF) in machinery & equipment (M&E) and Intellectual Property Products (IPP) in the UK, by asset. CVM in million £, seasonally-adjusted. 1997-2017. Source: ONS

	M&E	Breakdown 'M&E'			Breakdown 'ICT'		IPP	Breakdown 'IPP'		
		Transport	Other	ICT	Hardware	Telecoms		R&D	Software	Other
1997	52,282	12,187	38,327	5,856	4,202	1,654	41,949	20,038	15,343	6,568
1998	58,791	13,829	39,663	7,668	5,669	1,999	42,521	21,074	15,606	5,841
1999	56,506	10,528	37,628	9,143	6,481	2,663	45,590	23,591	16,366	5,633
2000	58,255	10,423	37,244	10,403	6,874	3,530	48,519	24,406	18,037	6,076
2001	57,892	10,876	42,056	7,759	5,279	2,480	46,656	23,331	17,435	5,890
2002	66,599	16,198	45,090	8,220	5,425	2,796	46,383	24,265	16,966	5,152
2003	64,840	14,212	43,548	9,162	6,504	2,659	47,016	24,307	17,565	5,144
2004	64,360	12,430	42,021	11,180	7,446	3,734	48,457	24,435	18,106	5,916
2005	66,267	11,600	43,802	11,940	7,796	4,145	53,515	26,633	18,915	7,967
2006	70,095	13,094	44,181	14,282	9,238	5,045	53,755	27,170	20,179	6,406
2007	75,212	12,001	47,924	17,145	11,586	5,560	57,451	30,090	20,618	6,743
2008	72,445	11,064	45,878	17,427	11,776	5,652	58,857	30,885	21,322	6,650
2009	57,884	9,767	35,836	13,621	9,128	4,494	55,325	29,036	20,054	6,235
2010	65,060	13,416	38,223	14,536	9,649	4,888	57,532	30,450	20,565	6,517
2011	66,595	9,055	44,023	15,317	10,313	5,003	57,776	29,636	21,558	6,582
2012	68,465	11,092	43,555	15,250	10,432	4,818	59,129	29,376	22,837	6,916
2013	69,099	10,937	43,099	16,667	11,531	5,137	61,752	30,706	24,032	7,014
2014	80,309	15,895	49,798	15,693	11,220	4,472	62,036	30,552	24,909	6,575
2015	84,465	21,783	50,049	12,893	9,080	3,812	60,130	31,663	21,937	6,530
2016	86,119	25,854	47,690	12,575	9,003	3,572	60,669	32,367	22,149	6,153
2017	83,890	23,254	47,670	12,966	8,954	4,012	62,285	32,518	23,574	6,193

Figure 7. Quarterly Gross Fixed Capital Formation (GFCF) in ICT equipment and other machinery & equipment in the UK. CVM in million £, seasonally-adjusted. Q1.1997 – Q3.2018. Source: ONS



5.2.2 Gross Fixed Capital Formation in software

The use of cloud services can also impact the way in which firms purchase and invest in software, as software can now be used on a subscription basis. This can be relatively standard software such as email and office products (e.g. Microsoft 365, Google Calendar or Hotmail). Examples of more sophisticated services are Customer Relationship Management (CRM) software as for example offered by the market leader Salesforce, and some new ML and AI software applications. SaaS potentially reduces costs and enhances the productivity of firms as they only need to pay for what they actually use. In addition, the applications can be run remotely (e.g. using the browser) without the need to install and update the software in house; users can access the latest versions from their provider.

In Table 3 we show the business investment in intellectual property products (IPP) from 1997 to 2017. In terms of sub-assets this can be broken down into software, R&D and 'other' IPP. While annual investment in software dropped in 2014, it subsequently increased again between 2015 and 2017. In addition the R&D figures increased from 2015, which can include some development of software.[36] Comparing software investment over time is difficult as quarterly figures by the ONS are not yet seasonally-adjusted and converted into chained volume measures. Nevertheless, when looking at the latest ONS figures for 2017 it appears that 45% of business investment in software is purchased software, while the remaining 55% is invested on an own-account basis.[37]

[36] We are grateful to one anonymous reviewer for pointing this out.
[37] ONS, user requested data, February 2018: https://www.ons.gov.uk/economy/grossdomesticproductgdp/adhocs/008110totalgrossfixedcapitalformationindustrysplitforresearchanddevelopmentpurchasedsoftwareownaccountsoftwaremineralexplorationandartisticoriginals

All in all, software investment figures do not at this stage suggest a significant shift to the cloud. However, it is not clear to what degree purchased software is currently capitalised by businesses.

5.2.3 IT infrastructure equipment spending by cloud service providers

To get a perspective on purchases of relevant IT infrastructure for the cloud, we look at sales figures of the major equipment manufacturers selling to cloud service providers. Typical products include servers, storage platforms and switches among other IT equipment for data centres. IDC estimates that spending on IT infrastructure for the use in cloud environments reached $43.4 billion in 2017.[38] Compared to 2016, this represents growth of 27.3% and is reported to be mainly driven by Amazon, Facebook and Google. The latter two have announced continuing big increases in capital spending. Public cloud data centres accounted for two thirds of this spending. IDC expects this market to grow to $52 billion in 2021 with public cloud datacentres accounting for 82% of the annual investment.[39] IDC also reports that in terms of growth the Western European market outperformed the US and Canada.

Table 4 shows the main hardware providers for cloud infrastructure equipment, Dell, New H3C Group (includes HP), and Cisco.[40] Other providers include IBM, Huawei, Inspur and NetApp. All these grew out of the US or China, highlighting the importance of a large domestic market to achieve economies of scale in this type of manufacturing.[41] Much of the production occurs in China, although supply chains are reportedly complex.[42] Looking at the growth rates of IT infrastructure providers for public and private cloud data centres, it is apparent that cloud services must be displacing some traditional in-house IT spending. In fact, IDC reports that non-cloud IT spending is estimated to have declined by 2.6% in 2017 although it still accounts for 57% of IT infrastructure spending. This proportion is predicted to fall to below 45% by 2021.

[38] IDC press release, 29th March 2018: https://www.idc.com/getdoc.jsp?containerId=prUS43705018
[39] IDC press release, 17th January 2018: https://www.idc.com/getdoc.jsp?containerId=prUS43508918
[40] IDC press release, 11th January 2018: https://www.idc.com/getdoc.jsp?containerId=prUS43496018
[41] For example, Apple disclosed that it will invest $10 million on the expansion of US datacentres between 2018-22; Apple press release, 17th January 2018: https://www.apple.com/newsroom/2018/01/apple-accelerates-us-investment-and-job-creation/. To do so it has already acquired more than 7,000 acres of land as reported by Tim Bradshaw in the FT, 9th November 2018: https://www.ft.com/content/9bb07b56-e2ab-11e8-8e70-5e22a430c1ad
[42] Richard Waters, FT, 7th August 2018: https://www.ft.com/content/7697243a-9479-11e8-b67b-b8205561c3fe

Table 4. Cloud IT infrastructure global revenue and market share by vendors. 2016-17. Source: IDC, March 2018

Equipment provider	2017, Q4		2016, Q4		Year-on-year growth
	Revenue (million)	Market share	Revenue (million)	Market share	
1. Dell Inc	$1,887	14.70%	$1,466	14.60%	28.70%
2. HPE/New H3C Group	$1,544	12.10%	$1,414	14.10%	9.20%
3. Cisco	$1,020	8.00%	$952	9.50%	7.10%
4. Huawei	$560	4.40%	$417	4.10%	34.40%
4. IBM	$518	4.00%	$328	3.30%	58.10%
ODM Direct	$4,176	32.60%	$2,853	28.40%	46.40%
Others	$3,096	24.20%	$2,629	26.10%	17.80%
Total	$12,801	100.00%	$10,058	100.00%	27.30%

Notes: ODM = Original Design Manufacturer (unbranded hardware), as opposed to OEM = Original Equipment Manufacturer (e.g. IBM, Dell)

6. Prices of cloud services

In order to develop an appropriate deflator for companies' purchases of cloud services, for the correct deflation of intermediates, we need price and volume measures for these services. In principle, it is straightforward for statistical offices to collect figures for the revenues of cloud service providers, once the set of providers is identified and the relevant subset of revenues appropriately classified in the surveys. However, distinguishing prices and volumes is challenging. We turn to these questions in this section and the next.

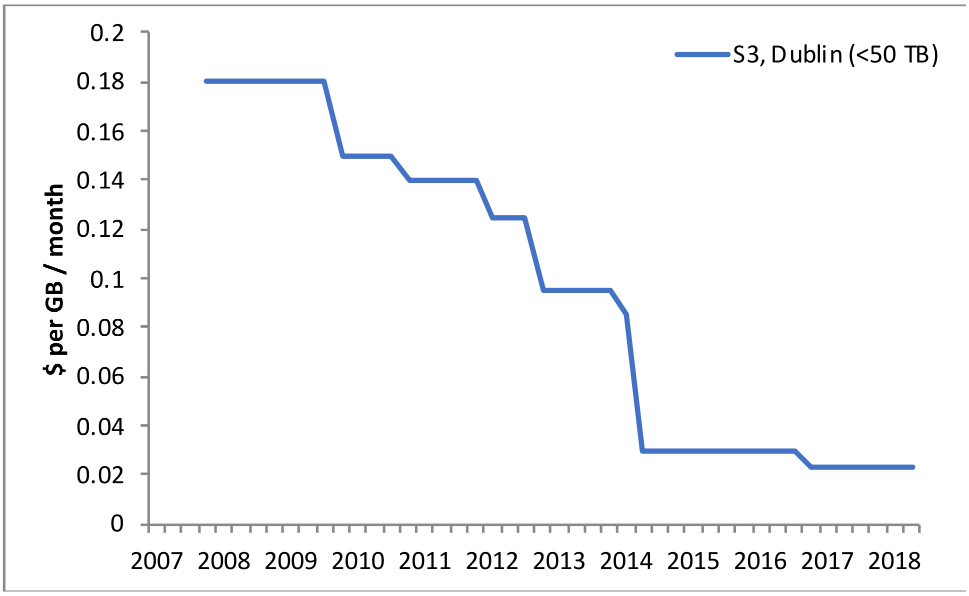
In trying to construct a price index for cloud services used by businesses in the UK, there are several issues. The first is that there are multiple products, which are difficult to compare across providers.[43] For instance, storage, compute and ML services are distinct from each other in terms of the communications, storage and computer processing requirements, and will also be packaged differently by different providers. Other factors, particularly latency, also affect pricing, which consequently differs by region. Customers face hundreds of prices. Secondly, there is almost continuous quality improvement. Every cloud provider, in what is a growing and reasonably competitive market, aims to be at the forefront of the technology in each of the applications. Finally, constructing a single cloud services price index requires expenditure weights, and these are not available; although there are market research estimates of the share of revenue by type of service, cloud providers understandably do not make this information publicly available. In this section we begin by describing pricing by the major cloud providers. These are constructed from information available online. We then construct a crude price index adjusting nominal prices for quality improvements for a number of products offered by AWS. We also show nominal prices for Google.

[43] For example, a quick look at the list of products on the AWS website shows that there are 21 different product categories with a total of 144 different products (as of September 2018). In addition, there are an increasing number of customisations for each product that the user can order. For example, the compute product EC2 has 5 different areas of customization, of which one (e.g. 'storage optimized') alone can have up to 30 different instance types. Similarly, Microsoft Azure lists 399 different products split into 18 product categories on its website, and Google Cloud Compute has at least 13 product categories and 108 products (in addition to the G Suite with Gmail, Calendar, Drive).

6.1 Pricing by major providers

There has been a long sequence of price reductions in AWS services, which has tended to act as price leader in the market. Based on press releases and online price lists we tracked them for a number of products (see Appendix D). In Figure 8 we show the evolution of nominal prices for the standard AWS storage product S3 for the Dublin data centre.[44] Since November 2007 the nominal price has dropped by around 87% to from $0.18 to $0.023 per GB/month. The biggest reductions took place in December 2009 (-17%), December 2012 (-24%) and April 2014 (-65%). Similarly, if we look at the AWS Glacier storage product which was introduced at $0.01 per GB/month in Q3-2012, nominal prices have since dropped by 60% to $0.004 (see Figure 9). In terms of prices, Microsoft has pledged in 2013 to at least match AWS prices and also delivered on a number of price reductions.[45] Quality improvements are more important when it comes to computing products, which will be reviewed below in Section 6.2.

Figure 8. AWS quarterly S3 prices per GB / month (standard storage, first 50 TB, Dublin). 2007-2018. Source: AWS press releases and price lists

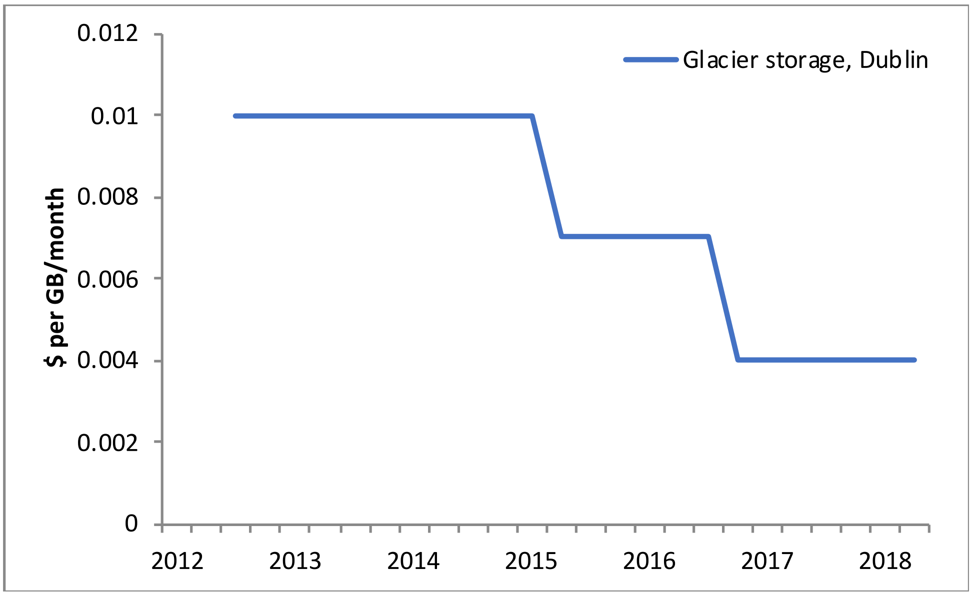


Analysing prices for Google Cloud Platform over time is difficult as the regional allocations changed from "Europe/Asia" between 2013 to Q4 2016, to "Europe" for the first half of 2017, and finally "London" as of Q3 2017. However, prices mainly dropped in Q2 2014 and Q2 2015 (see Appendix E). Conversely when Google launched the London data centre, its second region in Europe, nominal prices were slightly higher when compared to Belgium. Its third region in Europe, Frankfurt, follows the higher pricing of London. Prices for different computing products dropped by around 55-60% between 2013 and 2018, with the largest reduction in Q2 2014 (similar to AWS).

[44] Prices for the storage of 1 GB over 450 TB / month start at $0.022 and over 500 TB / month at $0.021. Infrequently used data can be stored at $0.0125, with a 'Glacier Storage' option at $0.004. The latter has data retrieval times between 3-5 hours. Prices for the London region are around 1 cent higher (https://aws.amazon.com/s3/pricing/, accessed on 2. March 2018).

[45] See Appendix D for details.

Figure 9. AWS quarterly price index for S3, 1 GB / month (Glacier storage). Q3-2012 = 100. 2012-2018. Source: AWS press releases and price lists



6.2 A quality-adjusted price index

We would like a price index for all cloud services, adjusted for quality change. Zhang (2016) and Byrne et al. (2017) construct US price indices based on hedonic regressions for AWS compute products (or 'instances' in AWS language). The characteristics they use in the regressions are those advertised online by the providers: for example, processing power (ECU), memory (GiB) and storage (GB) for compute products. Prices are collected from the AWS website using a web archiving tool.[46] They report annual price declines in double digits since 2009 for the three product types they consider (storage, compute, and databases). As in our case they suffer from the limitation of not having data on quantities (for reasons discussed below) and hence each observation in their regressions receives an equal weight. Another issue for their hedonic regressions is that many observable characteristics such as processor memory and storage do not actually change over time, while the speed nevertheless increases. We do not consider this kind of hedonic approach further due to insufficient observations, and discuss below why we anyway consider that ECU alone is the most appropriate processor characteristic which should be used to adjust nominal prices for quality improvements.

For the purpose of constructing a UK price index that adjusts for product quality we focus on prices charged by Amazon Web Services. According to IDC, AWS controls more than 50% of the $1bn+ UK market in IaaS and it is likely that their price and quality adjustments will be followed by other providers in the market. In fact, as noted, Microsoft has pledged to match AWS prices. Considering

[46] For their analysis Byrne et al. (2017) rely on data from the web crawling tool archive.org (or 'Wayback Machine'). We do the same for the period before March 2014. However, for later periods the tool does not work reliably due to backend changes in the AWS website (as of then it only shows most recent prices from 2018). From December 2015 onwards (to March 2018) we have access to official price lists from AWS. For the period in-between, we rely on AWS press releases on product updates and price reductions: https://aws.amazon.com/blogs/aws/ec2-instance-history/

that AWS only launched a datacentre in London in December 2016, we will use Dublin prices. Those are similar to London prices in terms of levels and trend for the overlap periods.[47]

Nominal prices for cloud services have fallen continuously over the last few years. However, quality improvements for computing products can be significant so looking at nominal prices from price lists alone would miss an important part of the story. The cloud services market is characterised by frequent introductions of new and better products. However these improvements are not necessarily based on 'observable' characteristics such as the number of cores (vCPU), memory (GiB) or storage (GB), but rather the technology (and power) in the underlying processors. It can be expected that future competition between providers will more heavily concentrate on product quality and differentiation rather than prices. Hence, these quality trends are becoming more important.

For example, AWS introduced the latest EC2 M5 instances in November 2017 and claimed that compared to the previous M4 instances they provide up to 14% improvement in performance for the same price.[48] At the same time the number of cores, memory and storage remained unchanged. Rather, more modern Intel Xeon Platinum processors were introduced that can provide twice as many FLOPS per core compared to the older Intel Xeon 'Broadwell' or 'Haswell' processors. Similarly, the previous upgrade from M1 to M3 instances led to a performance improvement of up to 50% according to AWS, based on more efficient Intel Xeon 'Sandy Bridge' or 'Ivy Bridge' processors.[49]

This demonstrates that each upgrade was accompanied by the introduction of more powerful processors, leading to quality improvements even if the price did not change. Hence simply using the full list of observable characteristics (such as the number of virtual CPUs), as in Byrne et al, to construct an index would likely not capture all quality improvements over time. It would merely tell us something about elasticities between characteristics and prices within a given time period. Table 5 lists the continuous introduction of new general purpose computing products by AWS, including the 'EC2 Computing Units' (ECU) measure. The latter was developed by AWS to track the processing performance of instances. Based on this we can see in that the processing power increased from 4 ECU in M1 instances (General Purpose, Large) to 6.5 ECU in M3 and M4 and 10 ECU in the latest M5 instances. In other words, even if the nominal price for this product range would have stayed flat, the 'performance per dollar' would have increased by 250%.

For the calculation of our price indices we will group products by instance classes, e.g. 'small' or 'large', regardless of the generation (M1, M3, M4, M5). This allows us to approximate the 'true' reduction in prices over time as we can adjust for quality improvements.

[47] Prices are usually quoted in US Dollar, whether looking at the Dublin or London Region. Hence we expect that exchange rate fluctuations play a minor role here.
[48] AWS press release, 28th November 2017: https://aws.amazon.com/about-aws/whats-new/2017/11/introducing-amazon-ec2-m5-instances/. AWS product description, accessed November 2018: https://aws.amazon.com/ec2/instance-types/m5/
[49] AWS website: https://aws.amazon.com/about-aws/whats-new/2012/10/31/announcing-amazon-ec2-m3-instances-and-m1-price-drop/

Table 5. Overview of AWS EC2 General Purpose instance types. Dublin. Source: AWS press releases

Instance type	Introduced	ECU	vCPUs	Memory (GiB)
M1 General Purpose small	Aug'06	1	1	1.7
M1 General Purpose medium	Mar'12	2	1	3.75
M1 General Purpose large	Oct'07	4	2	7.5
M1 General Purpose xlarge	Oct'07	8	4	15
M3 General Purpose medium	Jan'14	3	1	3.75
M3 General Purpose large	Jan'14	6.5	2	7.5
M3 General Purpose xlarge	Oct'12	13	4	15
M3 General Purpose 2xlarge	Oct'12	26	8	30
M4 General Purpose large	Jun'15	6.5	2	8
M4 General Purpose xlarge	Jun'15	13	4	16
M4 General Purpose 2xlarge	Jun'15	26	8	32
M4 General Purpose 4xlarge	Jun'15	53.5	16	64
M4 General Purpose 12xlarge	Jun'15	124.5	40	160
M4 General Purpose 16xlarge	Sep'16	188	64	256
M5 General Purpose large	Nov'17	10	2	8
M5 General Purpose xlarge	Nov'17	15	4	16
M5 General Purpose 2xlarge	Nov'17	31	8	32
M5 General Purpose 4xlarge	Nov'17	61	16	64
M5 General Purpose 12xlarge	Nov'17	173	48	192
M5 General Purpose 24xlarge	Nov'17	345	96	384

Weighting issues

Vendors of cloud services do not publish or share any information on sales by category or product. At most, some annual reports or estimates by industry analysts reveal quarterly revenue earnings for their global cloud computing divisions as a whole. Hence, as in the case of related studies, information on the sales of individual products are out of reach (see Byrne, Corrado and Sichel, 2017; Byrne, Oliner and Sichel, 2017). In addition, the fact that the 'product' in this case is actually a service, makes it much more difficult to get a grip on how much of total revenue is generated by which cloud product, especially as providers may use pricing strategies such as bundling or upselling. There is no equivalent to 'scanner data' that would allow us to collect information from retailers or wholesalers. Further, products are often not comparable across vendors in a straightforward way.

Without the ability to weight individual products we need to make an assumption regarding when 'old' products should drop out of our sample. This is important, as the frequent introduction of new products means that older products become obsolete for the majority of customers since price/performance ratio is better for newer products. However, older products remain available in the price lists and hence would bias our estimates if few firms buy them but they retain the same weight in the index as newer products. The availability of sales data by products would help us to overcome this limitation, as we would observe when demand is shifting away from older products over time. As it is, we need to assume that all customers switch once the price of a new product drops below the one of the older version. Considering that the adoption rate of cloud services is still increasing annually this assumption almost certainly holds true for new customers who are unlikely to enter the market using an inferior product in terms of price/quality ratio.

We focus on two standard AWS products (storage S3, compute EC2) as they are reported to be the most widely-sold products by the market leader in 2017.[50]

Results

To generate a quality-adjusted price index we compute the price per ECU – the measure for the performance of virtual servers – and compare them to the nominal price index by product class.[51] When a product class is first introduced, e.g. "M1 General Purpose large" in October 2007, the index is set to 100 (see Table 5 for all product introduction dates).

The only two product classes that are available for AWS customers fo the entire period from Q1-2010 to Q3-2018 are EC2 'large' and 'x.large' instances. We plot their nominal and quality adjusted prices (Linux) in Figures 10 and 11. In the period 2010 – 2014 both indices move in a synchronous way, whereas from Q1-2014 the quality-adjusted index is declining more rapidly. This demonstrates that quality-adjusting prices in for cloud services is crucial. Figures plotting nominal prices are provided in Appendix D.

To get a better understanding of the magnitude of these price drops we have computed the price reductions in percentage terms for the whole period of availability for each instance class. This is done for two operating systems (Linux and Windows), though trends are the same for both. Calculations for all 10 classes are shown in Table 6. If we stick to our previous example we can see that nominal prices for large and x.large instances have dropped by more than 58% between Q1-2010 and Q3-2018. If we quality-adjust these figures the price reduction reaches around 83% for large and 78% for x.large instances. Quality-adjusting our price index hence shows a price drop that is 20 to 27 percentage points higher than an index based on nominal prices. The scale of these declines is not all that surprising given recent findings concerning telecommunications services (Abdirahman et al, 2017).

By looking at the other instances classes we can see that the quality-adjusted index falls more rapidly. For more recent and larger instances (10xlarge+) this is not the case since they were introduced as entirely new instance classes with M4 and M5 processors. A lack of a comparable class in the previous period means that quality-adjustment cannot yet make a difference.

[50] 2nd Watch, 'Top 30 Most Popular AWS Products 2017': http://2ndwatch.com/wp-content/uploads/2018/01/2017Top30AWSProducts.pdf
[51] A product class refers to the instance sizes as describes in Table 5, e.g. 'small' or 'large'.

Figure 10. Price index, large instances, Linux, Q1-2010 – Q3-2018. Source: Own calculations based on AWS data.

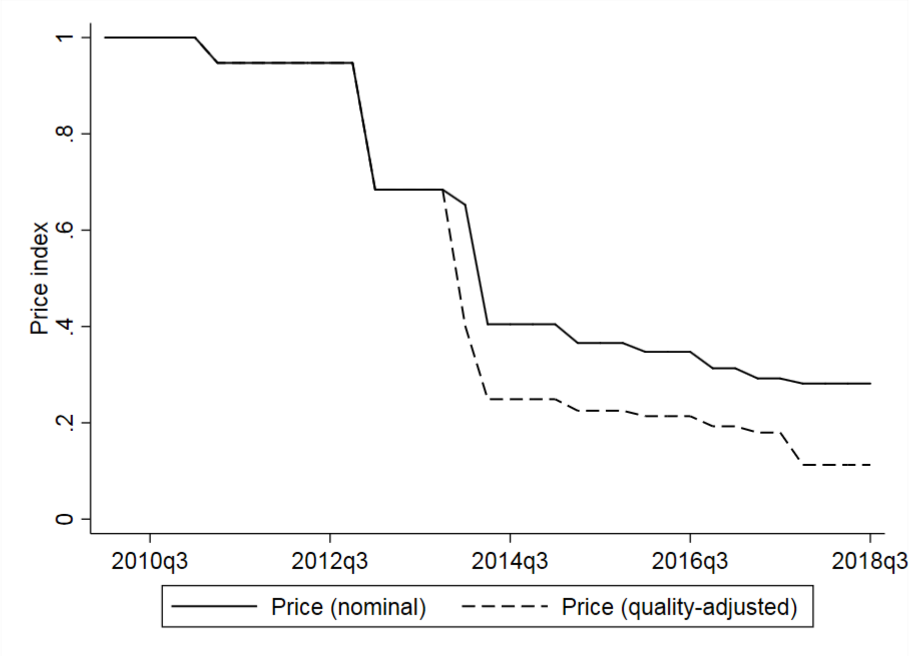


Figure 11. Price index, x.large instances, Linux, Q1-2010 – Q3-2018. Source: Own calculations based on AWS data.

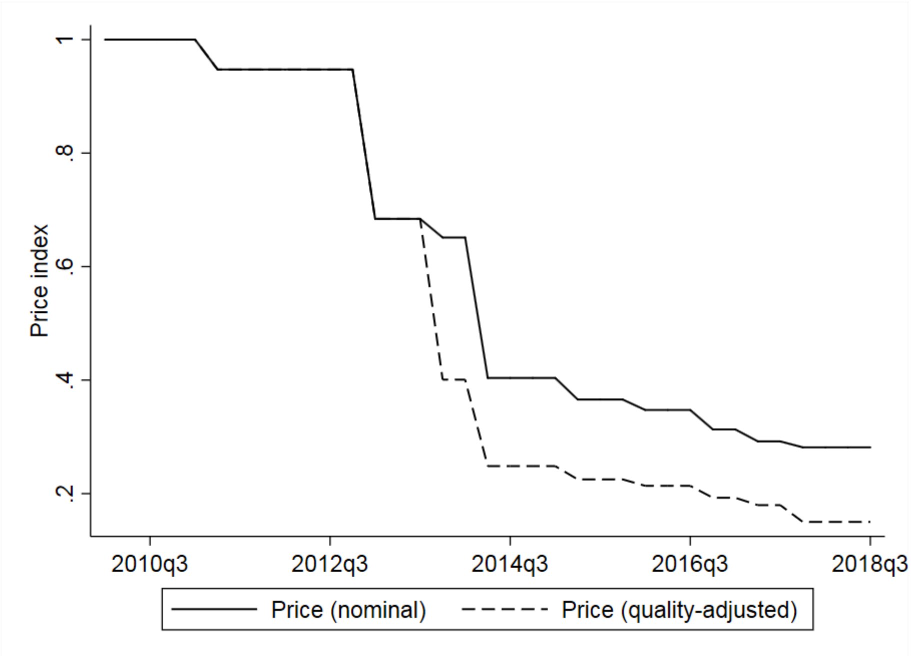


Table 6. Total and average price drop (nominal and quality-adjusted) by instance class, AWS, 2010-2018. Source: Own calculations based on AWS prices.

Instance class	Operating system	Start quarter	End quarter	Total quarters	Total price drop		Average quarterly drop	
					Nominal	Adjusted	Nominal	Adjusted
Small	Windows	Q1-2010	Q4-2013	16	24.17%	24.17%	1.51%	1.51%
	Linux				31.58%	31.58%	1.97%	1.97%
Medium	Windows	Q1-2012	Q1-2015	13	41.84%	61.23%	3.22%	4.71%
	Linux				57.29%	71.53%	4.41%	5.50%
Large	Windows	Q1-2010	Q3-2018	35	58.54%	83.42%	1.67%	2.38%
	Linux				71.84%	88.74%	2.05%	2.54%
Xlarge	Windows	Q1-2010	Q3-2018	35	58.54%	77.89%	1.67%	2.23%
	Linux				71.84%	84.98%	2.05%	2.43%
2Xlarge	Windows	Q1-2013	Q3-2018	23	59.39%	65.94%	2.58%	2.87%
	Linux				61.09%	67.37%	2.66%	2.93%
4Xlarge	Windows	Q2-2015	Q3-2018	14	20.72%	30.47%	1.48%	2.18%
	Linux				23.02%	32.49%	1.64%	2.32%
10Xlarge	Windows	Q2-2015	Q3-2017	10	19.12%	19.12%	1.91%	1.91%
	Linux				20.14%	20.14%	2.01%	2.01%
12Xlarge	Windows	Q4-2017	Q3-2018	4	0.00%	0.00%	0.00%	0.00%
	Linux				0.00%	0.00%	0.00%	0.00%
16Xlarge	Windows	Q3-2016	Q3-2017	5	16.82%	16.82%	3.36%	3.36%
	Linux				15.95%	15.95%	3.19%	3.19%
24Xlarge	Windows	Q4-2017	Q3-2018	4	0.00%	0.00%	0.00%	0.00%
	Linux				0.00%	0.00%	0.00%	0.00%

7. Quantities of cloud services

Given the inherent complexity of constructing the price indices, especially on an ongoing basis by statistical agencies, a less ad hoc approach than used above would be to develop an independent volume measure, which could be combined with revenue data to derive a unit value index. However, this is not at all straightforward.

There is some industry information indicative of volume of use. For instance, in 2017 AWS reported total sales of $17.4 billion, of which $5.1 billion were realised in Q4 alone. Compared to 2016 this is a 43% increase. Operating income increased from $1.3 billion to $2.1 billion. Microsoft reported that cloud computing revenue in 2017 reached $18.9 billion, which includes Azure, but also Office 365.[52] Google stated that its cloud business – which includes Google-Suite[53] - added around $1 billion to

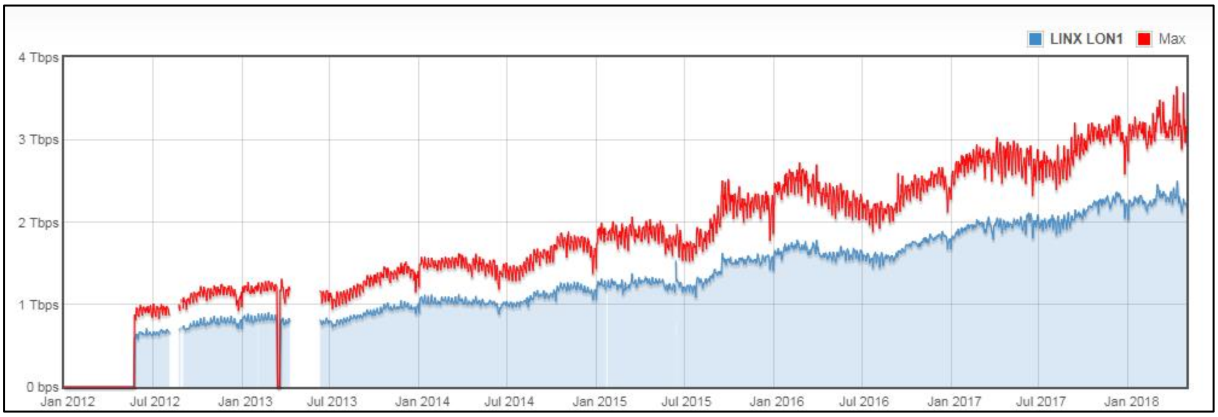
[52] Microsoft earnings release, Q4.2017: https://www.microsoft.com/en-us/Investor/earnings/FY-2017-Q4/press-release-webcast
[53] The Google G-Suite includes services such as Google Docs, Google Sheets and Gmail

Alphabet's revenue in Q4-2017, and has around 4 million paying customers, including many consumers.[54]

Microsoft further reported that as of June 2015 it had more than 1 million servers in its 100+ datacenters globally, hosting more than 30 trillion data objects, and processing more than 1.5 million requests per second. In April 2013 Microsoft stated that it had 1.5 million virtual machines for its 200,000 customers.[55]

In terms of UK data flows, the London Internet Exchange (LINX) is one of the largest Internet Exchanges in terms of maximum throughput of data. It operates 11 Points-of-Presence (PoPs) in London, and regional exchanges in Manchester (since 2012), Edinburgh (2013) and Cardiff (2014). In May 2018 the IXP in London (LON1) had a monthly average throughput of 2.28 TB per second and an all-time maximum of 3.6 TB on 11th April 2018 (Figure 12).

Figure 12. LINX LON1 Internet Exchange Point. Throughput per second. 2012-2018. Source: LINX website



However, it is striking that in our discussions with the cloud providers there was no consensus as to how to conceptualise the volume of service. This did not seem to be a significant choice variable for the businesses, perhaps because demand is currently growing so rapidly. Their investment decisions consist either of installing new racks of servers, new units in the racks, or new fibre links in existing datacentres – making a judgement about capacity given demand and the scope for managing demand peaks – or building a new data centre. The lumpy investment decision to spend a large sum on a new data centre will depend on expected growth in customer demand but also issues such as tolerance for latency in emerging applications and local regulation such as where data must be held.

One possibility would simply be to survey how much cloud providers are spending on IT equipment, and deflate that using equipment prices. The key equipment consists of servers and their varying types of processors (increasingly specialized for certain computational activities, such as GPUs and TPUs in addition to CPUs), fibre cables (hundreds of millions of these have been installed), routers, switches, motherboards, etc and other more prosaic items such as the server racks. Some of these

[54] https://www.cnbc.com/2018/02/01/google-cloud-revenue-passes-1-billion-per-quarter.html (accessed on 3. April 2018)
[55] https://beta.techcrunch.com/2013/04/16/windows-azure-announces-general-availability-and-promises-to-match-any-aws-price-drop/?_ga=2.159349882.1196447215.1522838059-850465404.1513084901

purchases are modular, but in other cases the cloud service provider will assemble more basic elements themselves.

Thinking more fundamentally about quantities, there are three core services in cloud provision: data storage; computer processing; and communication in and out of the data centre. Conceptually, these would be measured by: terabytes per period; megaflops per processor per unit time; and gigabytes of bandwidth. In practice, it would be impossible to separate storage from computation inside a data centre, however.

Even if it were possible to count the underlying physical characteristics determining usage volumes, the capacity utilisation rate would also be needed to construct an economic volume measure. Some in the industry see the relationship between the prices they charge and usage volumes in a manner similar to electricity pricing: there is a peak loading problem. A data centre has a maximum capacity (in three dimensions), the service is consumed as used, and otherwise the capacity is unused, and demand fluctuates. Finally, data centre outage is not acceptable and performance must remain constant. Some price variations in the services offered take the form of speed to perform the service. However, this is a complex optimisation problem, used as a demand management tool. At present, the market is expanding sufficiently fast that it would be reasonable to assume a high rate of capacity utilisation.

In practice, are there reasonable proxies for the volume of cloud services being used? Possibilities include:

- Number of fibre links into data centres, and their maximum capacity (bandwidth for external connections)
- Data flow volumes in and out of datacentres
- Mflops of installed capacity
- Internal bandwidth
- Physical footprint of data centres (requiring assumptions about capacity and also geographical location of data centres serving UK customers)

It is fair to say none of these is either easy to collect or wholly satisfactory. We do not consider a unit value index approach to be feasible. For all the challenges, using a somewhat ad hoc price index as calculated above to deflate nominal revenues and derive a volume measure may therefore be the easier option.

8. Implications of cloud services for trade figures

The use of cloud computing services means that the physical location of data and computing processes is detached from their creator, user, owner, and potentially their regulator. The fact that these processes and transactions can also occur across national borders means that they have potential implications for a country's balance of payments. Here a distinction needs to be made between the trade in cloud services and cloud-related goods (such as servers), where the latter is more likely to be captured in current statistics (UNCTAD, 2013). We will review each separately below, though they are intrinsically connected. It is possible that goods and services trade act as substitutes to some extent, since the physical expansion of cloud providers via new datacentres allows them to provide services locally without the need to record them as service imports or exports.

8.1 Goods trade related to cloud services

There are a number of categories in international trade statistics that can be used to investigate the trade in servers which are a crucial (though not the only) component of datacentres. Following the UNCTAD 2013 World Information Report, servers can be imported under three sub-categories of 'automatic data processing machines' (see Table 7).

The largest and most relevant category is HS 847150, covering computer servers without keyboard and monitors. According to UN Comtrade, global exports in this category exceeded $38bn in 2017, with the largest exporters being Mexico, USA, Czech Republic and China (see Appendix E). Global imports on the other hand reached $55.5bn with the leading importers being the USA, Japan, China and Germany.

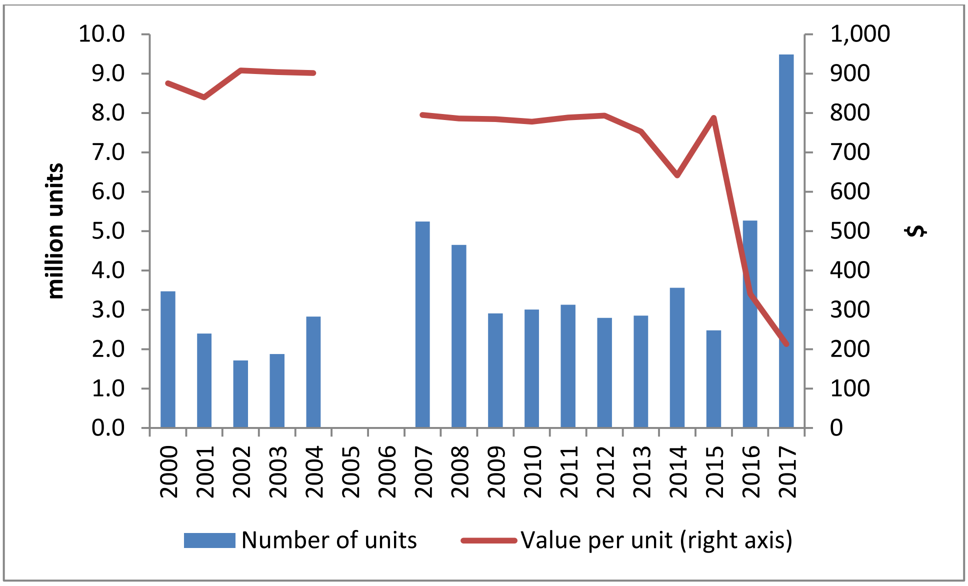
In 2017 the UK imported almost 19 million servers under category HS 847150, with a total value of around $2bn. This means that on average each device cost around $106, though unit prices differ across providers and specific products. The main source countries for UK imports were Czech Republic, Netherlands, China, Germany and USA. However, when looking at the number of servers the largest source country is Japan, followed by China, Netherlands, Czech Republic and Germany.

Overall it is difficult to say to what degree these were directly related to cloud computing. To get a better understanding – and considering that cloud services are a relatively recent phenomenon – Figure 16 looks at the evolution of UK imports over time. Two stylised facts stand out. First, it is striking that while the number of imported server units was relatively flat following the financial crisis it increased significantly in 2016 and 2017.[56] For example, while in 2015 the UK imported around 2.5 million servers under HS 847150, this number increased almost 4-fold to 9.5 million by 2017. This is notable considering that the majority of large scale datacentres by Microsoft, Google and Amazon all opened in these two years (discussed in Section 3). Looking at data for the Netherlands, which has also experienced an expansion is large scale data centres we can observe a similar trend regarding the number of imported servers (see Figure 34, Appendix E).

The second interesting observation is that despite the large increase in the number of imported servers, the total value of imports remained flat at around $2bn (see Figure 14). This also means that the unit value decreased dramatically as demonstrated by the line in Figure 13. The most obvious explanation is that large buyers receive discounts for bulk orders.

[56] Similar trends can be observed for HS 874149 (see Figures 33-34, Appendix E) which had a total import value of around $1 billion in 2017. On the other hand units under HS 847141 increased only in 2016 but dropped sharply in 2017 (see Figures 35-36, Appendix E). The latter had a total import value of $330 million in 2017.

Figure 13. UK imports of servers (HS 847150). Number of units and average unit price, 2000-2017. Source: UN Comtrade



In addition to the obvious difficulty in estimating the degree to which these imports are used in datacentres of cloud service providers, there is the issue of time lag between building datacentres and the reduction in on-premise servers. It is entirely possible that as more firms switch to cloud computing services in the coming years and major datacentres are completed, the number of imported servers will decrease. On the other hand a higher utilisation rate and need to stay up to date could also mean that large cloud service providers renew their equipment more regularly than firms with their own datacentre.

Can cloud computing then be seen in the trade in goods? Although the number of imported units has increased significantly in the last two years, there has not been an increase in the total value of imports. We speculate that this is linked to the ability of large providers to buy in bulk, likely paying a lower price, and also to go directly to the manufacturers to buy ‘unbranded’ equipment.

Figure 14. UK imports in servers (HS 847150). Total value in bn$, 2000-2017. Source: UN Comtrade

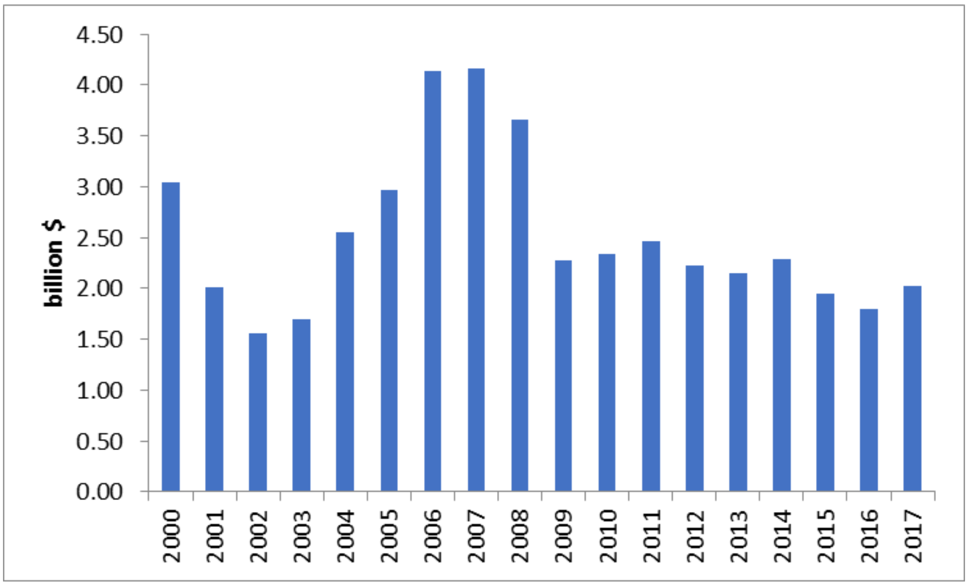


Table 7. Goods trade classifications related to construction of datacentres. Source: UNCTAD (2013)

HS code	Description
847141	Data processing machines; digital, automatic, (not portable, analogue or hybrid), comprising in the same housing at least a central processing unit, an input and output unit, whether or not combined
847149	Data processing machines; digital, automatic, (not portable, analogue or hybrid), presented in the form of systems, n.e.s. in item no. 8471.41
847150	Digital processing units; other than those of subheadings 8471.41 and 8471.49, whether or not containing in the same housing one or two of the following types of unit: storage units, input units or output units

8.2 International trade in cloud services

Berry and Reisman (2012) estimate that in 2010 public cloud computing services accounted for 3.4% ($1.5bn) of US service exports. In addition, they look at sales of US-owned affiliates and report that around 0.5% ($1.4bn) of their sales are likely to be related to cloud computing. Based on our review of the largest providers in the UK it is unlikely that there are a large number of cloud services exports and hence we focus on the import side here.

To do so we can look at two data sources. The first is the UN Comtrade database on services, and second is the ONS International Trade in Services Survey (ITIS), designed to capture cross-border sales and purchases of services involving firms resident in the UK. However, both currently do not directly specify 'cloud services', making it difficult to identify their share in total trade. Our approach will follow Berry & Reisman (2012), in that we use the share of IT spending on cloud services to approximate the share of cloud computing in UK imports. As a basis we take figures on service trade in software and other IT services such as databases or online services.

In the case of Comtrade this is relatively easy as we take the category covering "Computer and information services".[57] In 2016 the UK reported total imports of $14.5bn under this category, which is equal to 7% of total service imports. Compared to $13.6bn in 2010 this represents only a modest increase, though this is more than ten times higher than the $1.3bn recorded in 2000.

Table 8. IT service related questions in International Trade in Services survey. Source: ONS, 2017.

Number	Question coverage	Related cloud service	Value 2016
19	Imports of '*Copyrighted literary works, sound recordings, films, television programmes and databases*' without transfer of ownership; including '*any computer programmes or databases that are copyrighted*'	SaaS	$4.679bn
22	Imports of *'Telecommunication services'*; incl. *e-mail, business network services, teleconferencing, internet backbone services, internet access services, and online access services*; excl. *database services*	SaaS, PaaS, IaaS	$4.947bn
26	Imports of *'Information services'*; incl. *database services,* and *web search portals*	SaaS, PaaS, IaaS	$1.041bn
6	Imports of *'Accountancy, auditing, bookkeeping and tax consulting services'*	BPaaS	$1.070bn

Arriving at a similar figure in the case of ITIS is more difficult as several questions cover related expenses by firms (see Table 8). For example, question 19 includes licensing of programmes and databases (among other items), while question 22 covers e-mail, internet backbone and online access services. Similarly, question 26 asks for data base services and web search portals. Finally, question 6 asks about 'Accountancy, auditing, bookkeeping and tax consulting services' as a sub-category of Business and Professional Services. We include them here as they are increasingly shifting to the cloud (BPaaS). When adding total service imports across these questions we arrive at a total of $11.737bn.

By using the cloud shift rates as provided by Gartner (see Figure 15) and market share data from IDC we calculate a crude approximation for the share of cloud computing in the UK's services imports. Obviously we need to account for the fact that different types of services have different propensities to be purchased via the cloud. Gartner estimates cloud shift to be 25% for SaaS, 7% for IaaS, 6% for PaaS and 35% for BPaaS (see Figure 18). In addition, according to IDC data 71.3% of cloud spending in 2016 was related to SaaS, with 17.6% on IaaS and 11% on PaaS (excluding other cloud services).

Hence, for the Comtrade figures we can apply the following formula to calculate the share of cloud services in imports, multiplying the amounts in the different categories by the relevant cloud shift parameter:

$$(0.713 * 0.25 + 0.07 * 0.176 + 0.06 * 0.11) * \$14.5bn = 0.19717 * \$14.5bn = \$\mathbf{2.86bn}$$

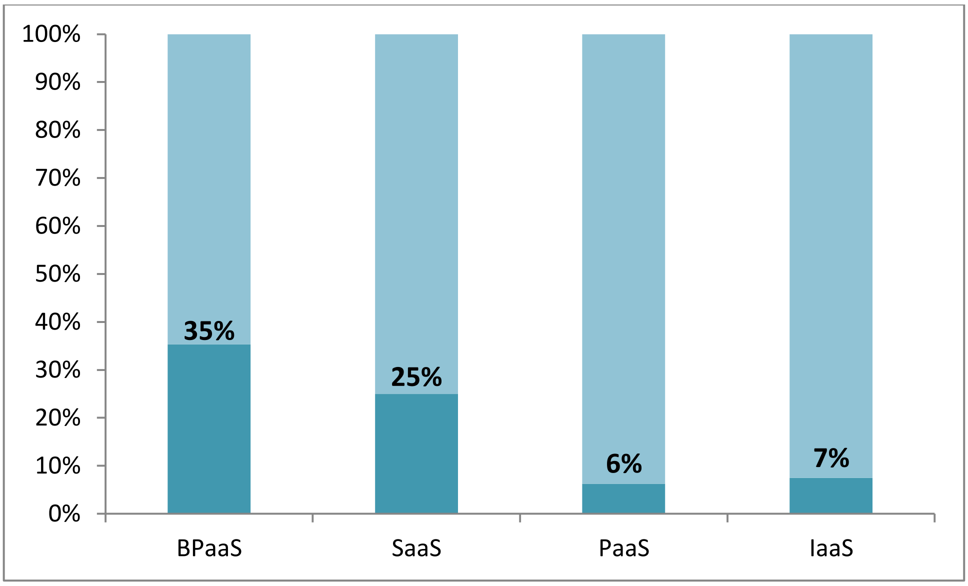
[57] According to the UN International Trade Statistics Yearbook 2016 this category covers "hardware and software-related services and data-processing services; news agency services include the provision of news, photographs, and feature articles to the media; and database services and web search portals (search engine services that find internet addresses for clients who input keyword queries)".

For the ITIS figures we adjust this formula to account for the fact that some service imports are more closely related to specific cloud categories (e.g. software and SaaS):

$$(0.25 * \$4.679bn) + (0.19717 * \$4.947bn) + (0.19717 * \$1.041bn) + (0.35 * \$1.07bn) \\ = \$1.16975bn + \$0.9754bn + \$0.2053bn + \$0.3754bn = \$\mathbf{2.73bn}$$

This simple method, when applied to two entirely different sources of data gives us two comparable figures regarding the magnitude of cloud services in UK imports. Using Comtrade data we get cloud imports' of $2.86bn, as compared to $2.73bn when using data from ONS ITIS. Of course these are only as good as the figures and assumption (import values and cloud shift rates) that are used as basis for the calculation. We also made some simplifying assumptions regarding the coverage of some questions, which in some cases is much broader than what we are interested here. This applies for example to question 19, which includes software licences but also licenses for other copyrighted work.

Figure 15. Cloud shift of traditional IT spending in 2016. Source: Gartner, July 2016



However, there is a further – and potentially more significant – caveat that needs to be discussed when interpreting these figures. This is the fact that we do not know the propensity of cloud services to be traded as compared to purchased locally. Hence our figures could represent an upper bound (if cloud services are more likely to be purchased locally) or lower bound (if cloud services more likely to be imported). It is possible that with the construction of datacentres in the UK that cloud imports decrease over time. On the other hand, the general trend to shift IT expenditure to the cloud (especially SaaS) could lead to an increase in cloud imports if providers are located abroad.

In the end we believe that better data collection is necessary and would welcome a revision of the International Trade in Services (ITIS) survey to explicitly ask for services purchased via the cloud. Also international classifications in service trade – as used by Comtrade - should be refined to include a category for cloud services.

9. Discussion

Cloud computing has quickly become a significant phenomenon, quite widely used by businesses and still growing. The benefits to businesses are evident: they are paying less to access higher quality IT capital services and potentially to extend to their capabilities into new areas, compared to the counterfactual no-cloud world of investing in and operating their own IT capital. We have shown that there has been a significant decline in the price of cloud services available in the UK, especially in quality-adjusted prices, and an expansion of data centre provision. The phenomenon is notable in its own right. It also implies there may be some potential mismeasurement of real growth and total factor productivity if the switch to cloud services is not properly taken into account.

It will be hard to make progress in either constructing a less arbitrary price index or accurately estimating the impact of cloud services on productivity estimates and trade statistics without additional data. Statistical agencies could consider incorporating in their business surveys:

- Purchases of cloud services by their users, by service type, and origin
- Capital investment by cloud service providers, by type
- Revenues of cloud service providers, by type of service
- Prices charged by cloud service providers, by service type
- Data flows in and out of data centres, or installed bandwidth
- Finer detail on ICT investment in general

There is a broader question about the extent to which conventional growth accounting is a useful lens for what is essentially a business process innovation. In general, GDP captures some innovations embodied in products, albeit imperfectly as the use of hedonic price indices to deflate nominal output is limited in practice. It does not capture process innovations whose outcome is faster delivery of a service or product, greater customisation, or the capability to do something previously out of reach. Growth accounting based on measured GDP is likely to be a particularly poor indicator of the productivity improvements due to the scale of the technological transformation of the economy currently under way, as manifested by major changes in business practice. Cloud computing is one of these.

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Appendices

Appendix A. Definition of cloud computing terms

Definitions based on National Institute of Standard and Technology (2011: p.2-3) report "The NIST Definition of Cloud Computing":

Software as a Service (SaaS). The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g., web-based email), or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

Platform as a Service (PaaS). The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.

Infrastructure as a Service (IaaS). The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g., host firewalls).

Private cloud. The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may exist on or off premises.

Community cloud. The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.

Public cloud. The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider.

Hybrid cloud. The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

Appendix B. Supplementary tables and figures on use of cloud services in the UK

Figure 16. Change in proportion of businesses purchasing cloud computing services in 2013-2015, by firm size bands. Source: E-commerce Survey, ONS.

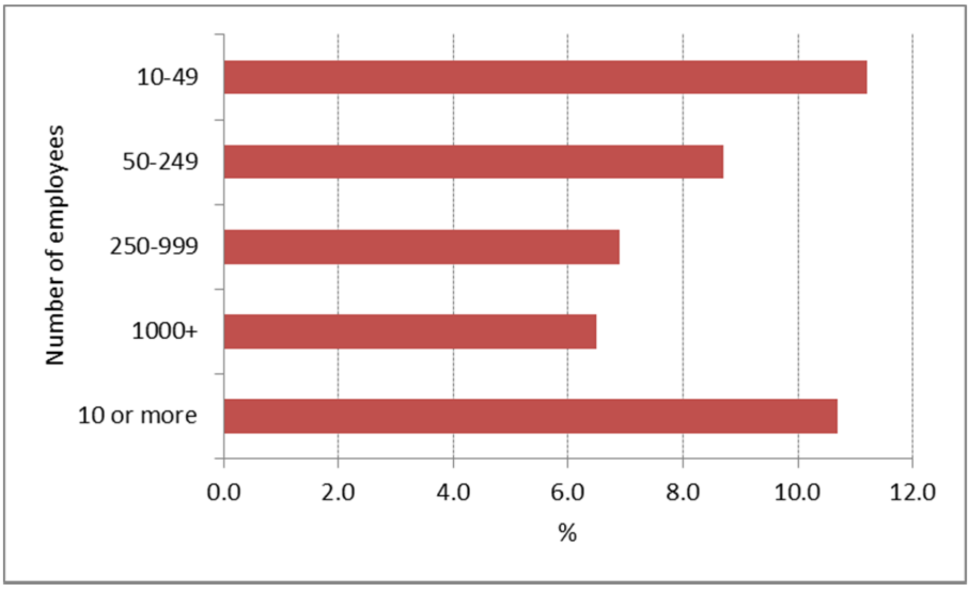


Figure 17. Change in proportion of businesses purchasing cloud computing services in 2013-2015, by industry sector. Source: E-commerce Survey, ONS.

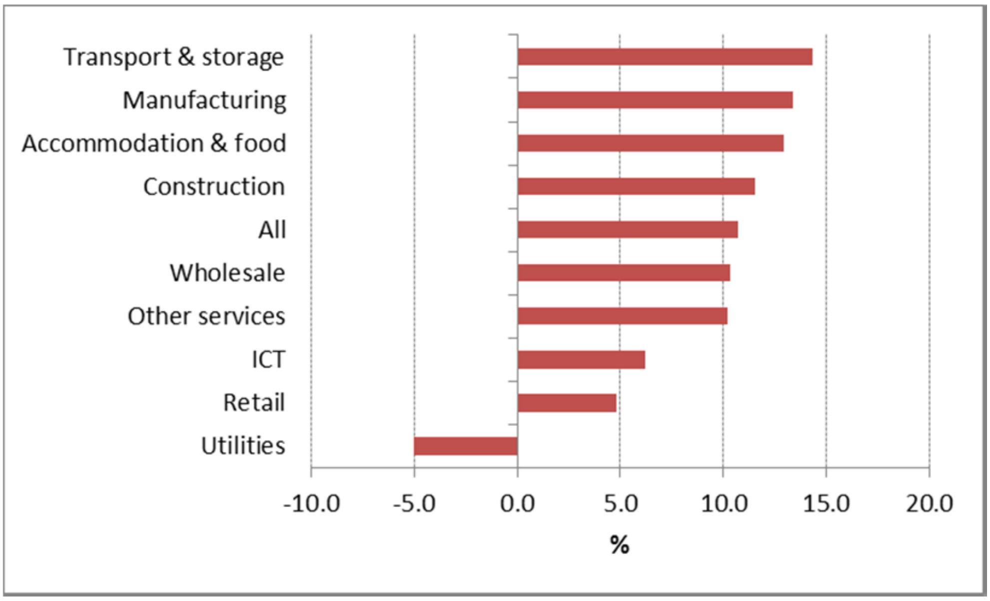
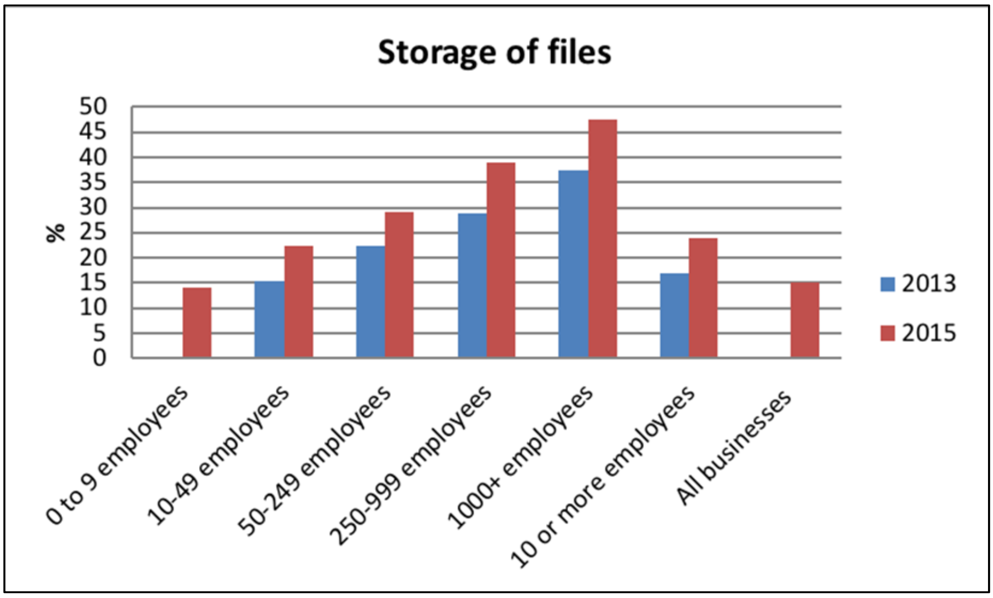
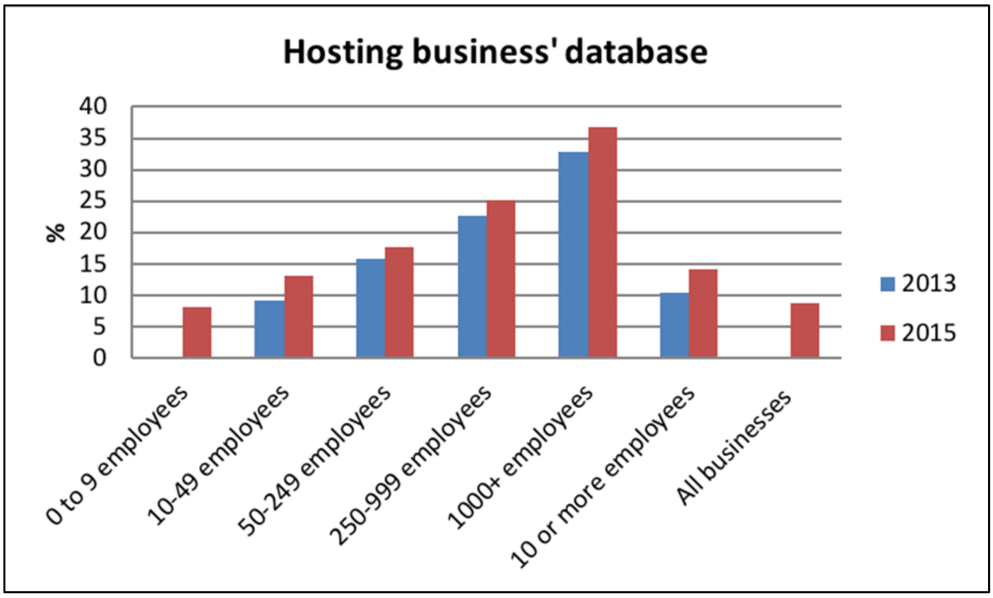


Figure 18. Proportion of businesses purchasing cloud computing services in 2013 and 2015, by type of cloud service. Source: E-commerce Survey, ONS.

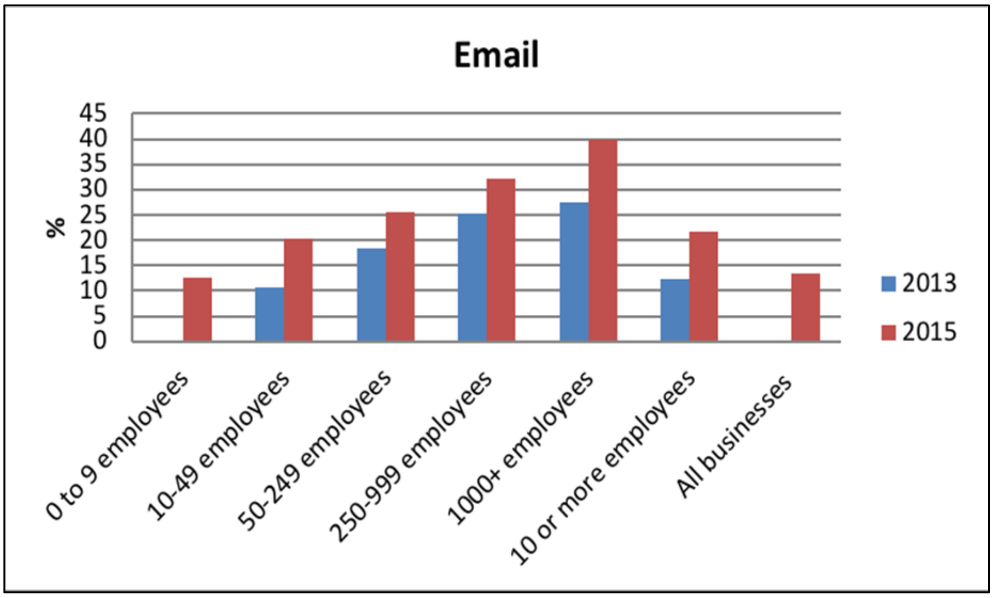
(a)



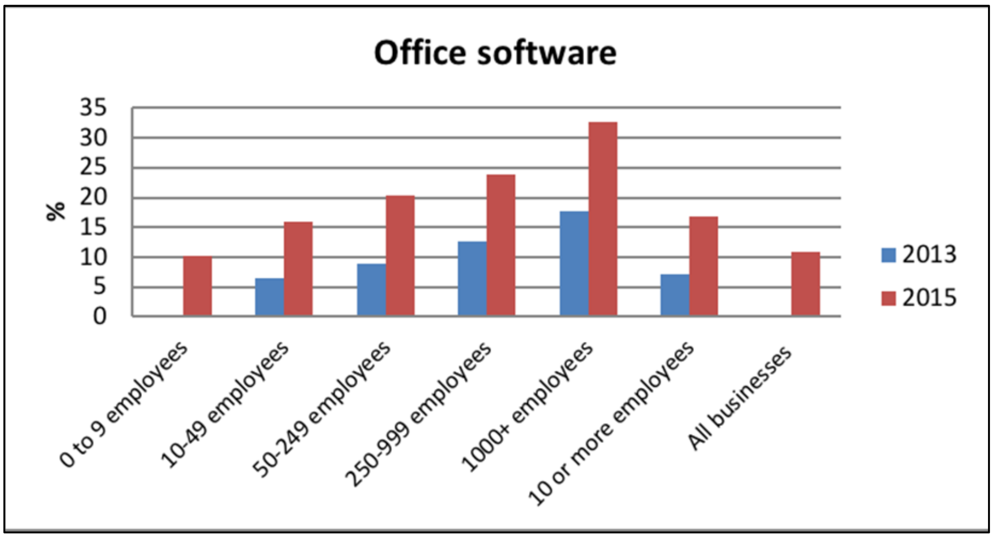
(b)



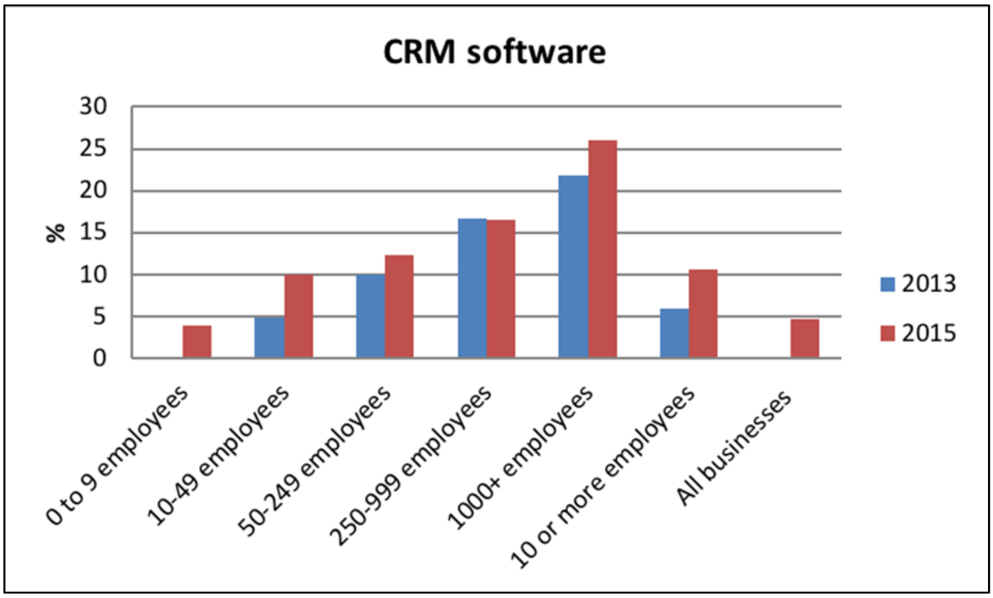
(c)


Email
45
40
35
30
25
20
15
10
5
0
%
0 to 9 employees
10-49 employees
50-249 employees
250-999 employees
1000+ employees
10 or more employees
All businesses
2013
2015

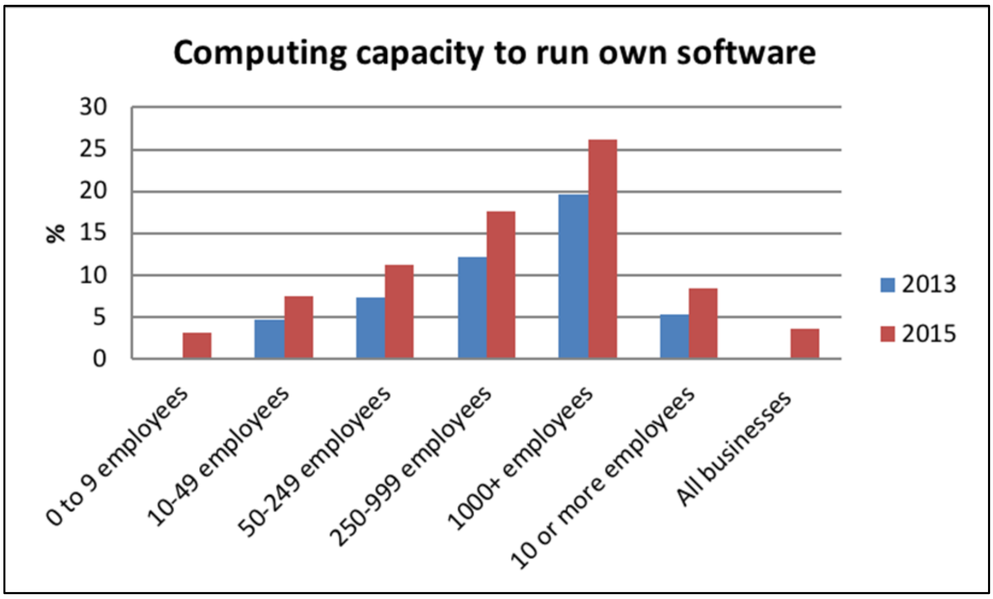
(d)


Office software
35
30
25
20
15
10
5
0
%
0 to 9 employees
10-49 employees
50-249 employees
250-999 employees
1000+ employees
10 or more employees
All businesses
2013
2015

(e)


CRM software
30
25
20
15
10
5
0
%
0 to 9 employees
10-49 employees
50-249 employees
250-999 employees
1000+ employees
10 or more employees
All businesses
2013
2015

(f)


Computing capacity to run own software
30
25
20
15
10
5
0
%
0 to 9 employees
10-49 employees
50-249 employees
250-999 employees
1000+ employees
10 or more employees
All businesses
2013
2015

(g)

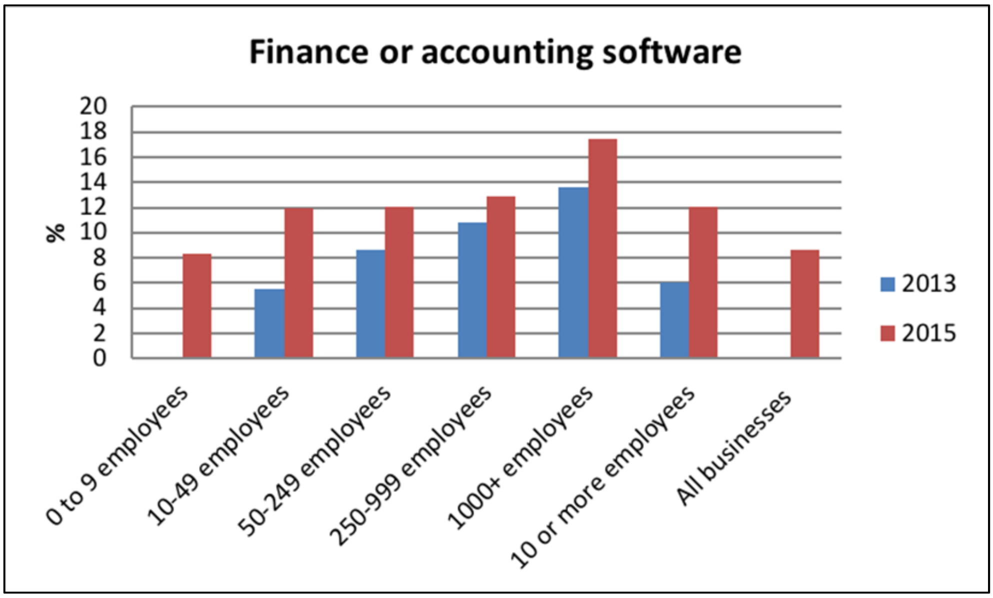


Figure 19. Personal use of the cloud to store data in the UK, by gender, 2015-2017. Source: E-commerce Survey, ONS

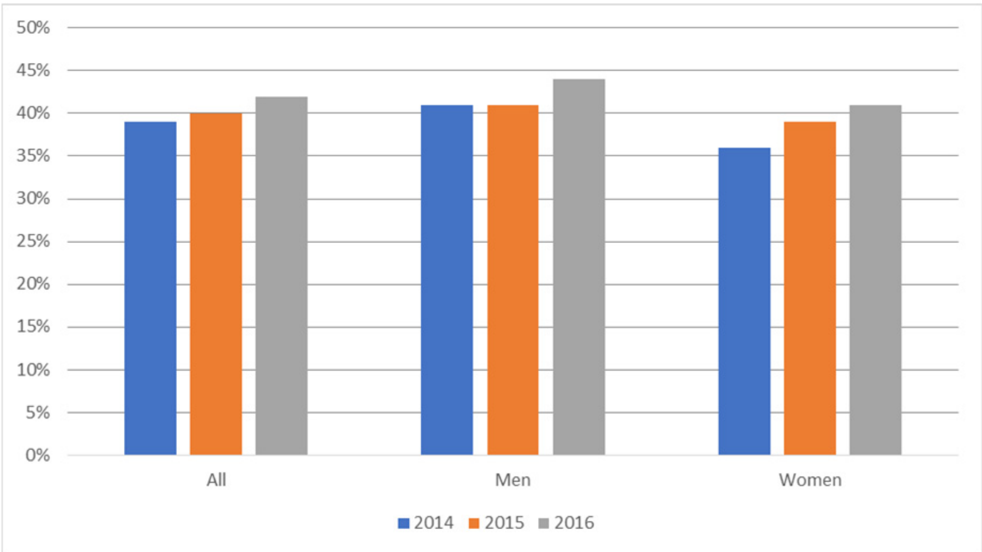
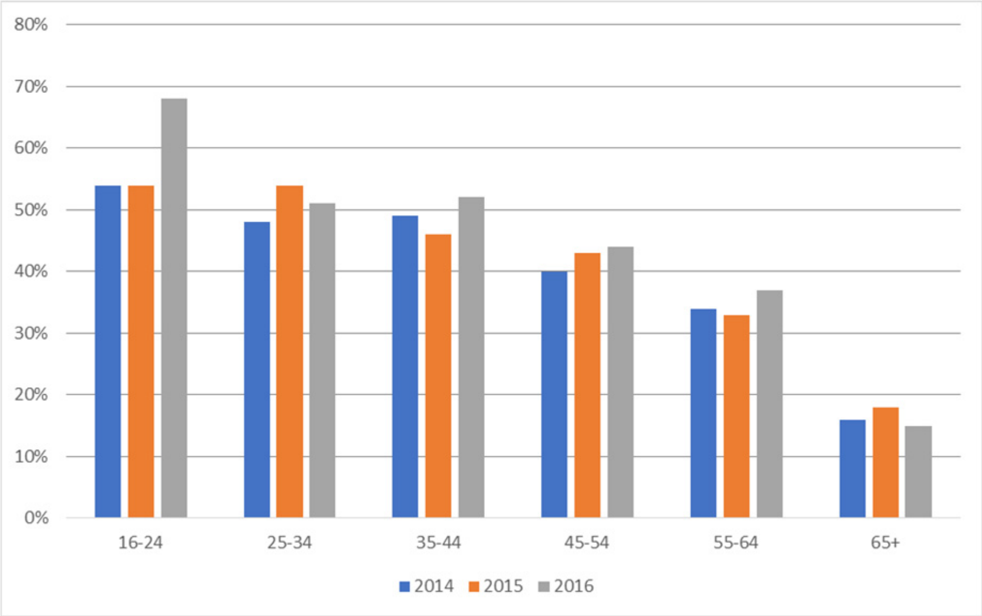


Figure 20. Personal use of the cloud to store data in the UK, by age group, 2015-2017. Source: E-commerce Survey, ONS



Appendix C. Definition of GFCF components used by ONS

Published Asset	Includes	Definition	Examples (N.B. not exhaustive)
Dwellings	Dwellings	Dwellings are buildings, or designated parts of buildings, that are used entirely or primarily as residences, including any associated structures, such as garages, and all permanent fixtures customarily installed in residences	Houses, mobile homes and caravans. However, it should be noted that dwellings does not include prisons, boarding schools or hospitals
Transport	Transport equipment	Transport equipment consists of any equipment used to move people and objects.	Motor vehicles, trailers, ships, trains, trams, aircraft, motorcycles, and bicycles
Intellectual property products (IPP)	Research and development	This is the value of expenditure on creative work to increase the stock of knowledge, which developers can market or use for their own benefit when producing goods and services.	Development of software programs or design for a new aircraft
	Mineral exploration	This is the value of expenditure on exploration for petroleum and natural gas and for non-petroleum deposit and the subsequent evaluation of the discoveries made.	License and acquisition costs, appraisal costs, costs of test drilling and boring
	Software and Databases	Software consists of computer programs and supporting systems for both systems and application software.	Packages such as Microsoft Office and VLC Media Player
	Entertainment	This consists of the original films, recordings, manuscripts, tapes, etc which drama performances, radio, television programmes, sporting events and etc are recorded and embodied.	Films, tapes, recordings, radio and television programmes and books
Other buildings and structures and transfer costs	Other buildings	Other buildings are buildings that are not dwellings, industrial buildings, commercial buildings, educational buildings and health buildings.	Schools, hospitals, prisons, religious, sport, amusement and community buildings
	Transfer costs	Transfer costs, sometimes known as cost of ownership transfer, are the costs associated with buying or selling an asset	Transportation costs, legal fees and stamp duty.
Information and communication technology equipment (ICT) and other machinery and equipment	ICT	This mainly consists of computer hardware and telecommunications equipment such as computers and mobile phones	Computers, laptops, mobile phones and gaming consoles
	Other machinery and equipment including weapons	Other machinery and equipment consists of all equipment and machinery that is for general or special use. General use machinery includes engines, turbines, ovens, etc. Special use machinery includes machinery for mining, domestic appliances, agricultural equipment, etc	Typically large electronic equipment (e.g. equipment used in the production of goods and services)
	Cultivated	Cultivated assets are livestock for breeding (including fish and poultry)	Livestock not for slaughter, orchards, vineyards, dairy draught

Appendix D. AWS price reductions for computing and storage products

AWS price reductions	
6. Nov. 2007	Introduction price for S3 products in Europe/Ireland is announced at $0.18 per GB/month.
10. Dec. 2008	Introduction of EC2 computing product in Europe/Ireland.
1. Nov. 2009	Prices for all EC2 (on-demand) products in Europe/Ireland are reduced by up to 15%.
8. Dec. 2009	Prices for all S3 products in Europe/Ireland are reduced by 15% to $0.15 per GB/month. [This has since decreased to $0.023]
8. Dec. 2009	Prices for EC2 Windows and SQL server instances in Europe/Ireland by more than 5%, e.g. to $0.12 for small instances. [This has since decreased to $0.0352]
1. Nov. 2010	Prices for S3 products in Europe/Ireland are reduced to $0.14 (up to 1 TB), $0.125 (1-49 TB), $0.1 (50-500 TB), $0.095 (501-1,000 TB), $0.08 (1,000-5,000 TB), and $0.055 (over 5,000 TB).
1. Feb. 2012	Prices for S3 products globally reduced by 12% (up to 50 TB) and 13.5% (up to 500 TB)
1. Mar. 2012	Prices for EC2 compute products globally reduced by 10% (on-demand instances) and 37% (reserved instances).
1. Mar. 2012	Prices for RDS database products up to 42% (reserved instances) or 10% (on-demand instances).
21. Aug. 2012	Glacier storage introduced at $0.01, also in Dublin.
	28. Nov. 2012: Prices for S3 storage products globally reduced by 24-28%.
1. Feb 2013	Prices for EC2 compute products in Europe/Ireland reduced by 9-23% (M1 – 23.5%; M2 – 9.1%; c1.medium & c1.xlarge – 11.3%).
1. April 2013	Prices for EC2 (Windows, on-demand) prices are reduced by up to 26%, depending on region and product.
1. Nov. 2013	Prices for EC2 (m2, on-demand) reduced by 10% or 15% (reserved instances).
1. April 2014	Prices for S3 and EC2 reduced by 10-60%.
1. June 2015	Prices for EC2 (m3, c3, on-demand) reduced by 5% in Dublin and Frankfurt.
1. Sep. 2015	Prices for Glacier storage reduced by 30% from $0.01 to $0.007.
1. Jan. 2016	Prices for EC2 (on-demand, reserved instance, dedicated host) products c4 and m4 and r3 reduced by 5% in Dublin and Frankfurt.
1. Dec. 2016	Prices for EC2 (on-demand, reserved instance, dedicated host) products reduced by 5% for c4 in Dublin, and 10% for m4 in Dublin and Frankfurt.
1. Dec. 2016	Prices for S3 by 23% in Dublin to $0.023 (0-50 TB), $0.022 (51-500 TB), and $0.021 (500+ TB). Prices for Frankfurt are always 0.0015 cents higher. Glacier storage reduced by 43% to $0.004.

Source: Press releases and blog entries by AWS

Microsoft price reductions	
Jan. 2013	Prices for storage were dropped by 20-28% across all regions (effective April 2013) (link)
Apr. 2013	Microsoft pledged that it will match AWS prices and reduced prices for some services by 21-33% (link)
Apr. 2014	Price reductions of 20-28% are realised
Jan. 2016	VM prices (D-series v2) reduced by 10-17%.
Oct. 2016	VM prices lowered by 11% (F-series, D-series v2) to 50% (A1, A2) (link)
Nov. 2016	New A-series v2 at 36% lower costs than standard A-series (link)
Feb. 2017	Prices for storage reduced by 26% (hot) to 8% (cold), while prices for VM dropped by 18-51% depending on the instance type (link)
Apr. 2017	Price reduction for VM (L-series) by 60-69% to match AWS (link)
May 2017	Announcement that prices for General Purpose VM (D-series v2) will be reduced by 4-7% (link)

Source: Press releases and blog entries by Microsoft

Figure 21. AWS quarterly prices for large General Purpose EC2 Instances (m1/m3/m4/m5), Dublin, Linux, 2010–2018. Source: Calculations based on AWS data.

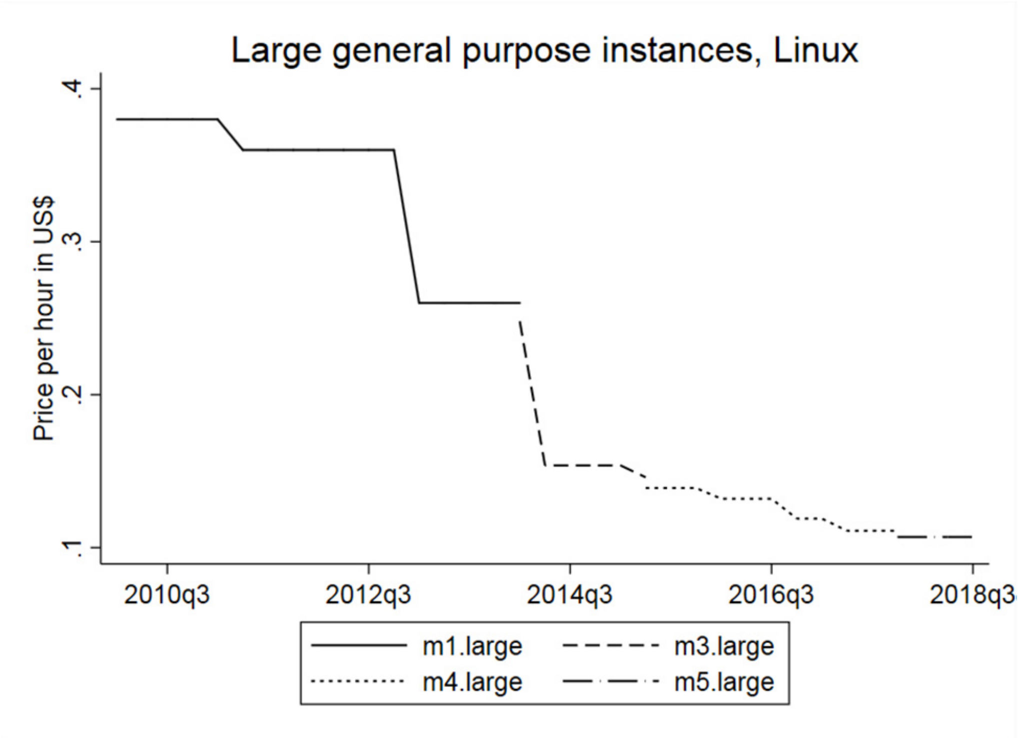


Figure 22. AWS quarterly prices for xlarge General Purpose EC2 Instances (m1/m3/m4/m5), Dublin, Linux, 2010–2018. Source: Calculations based on AWS data.

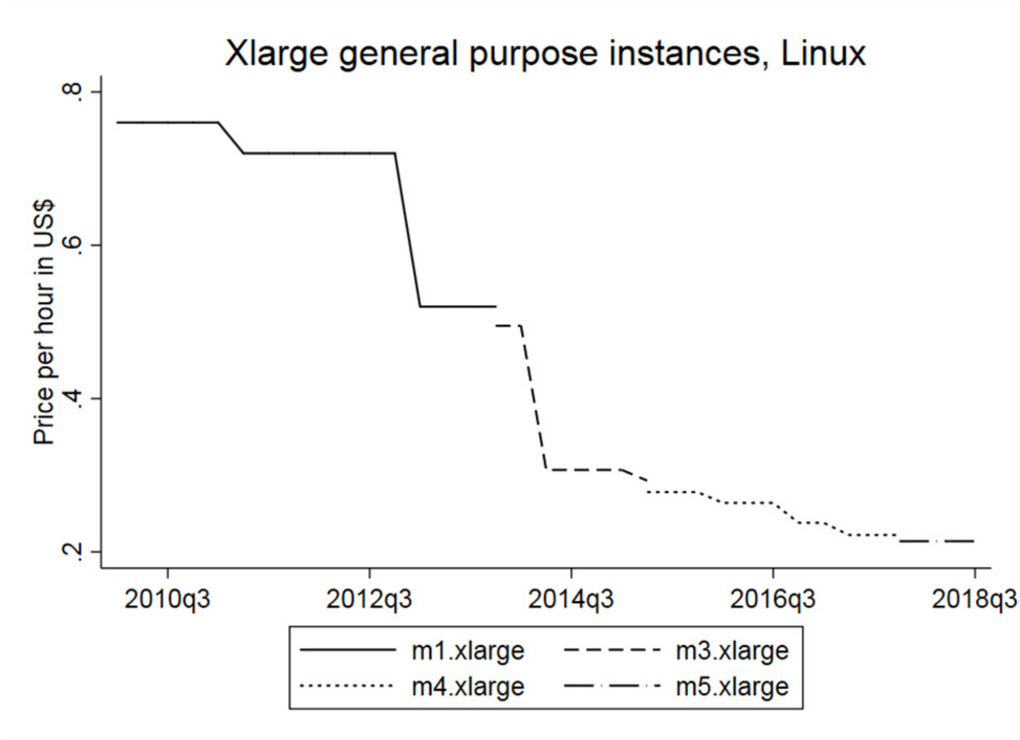
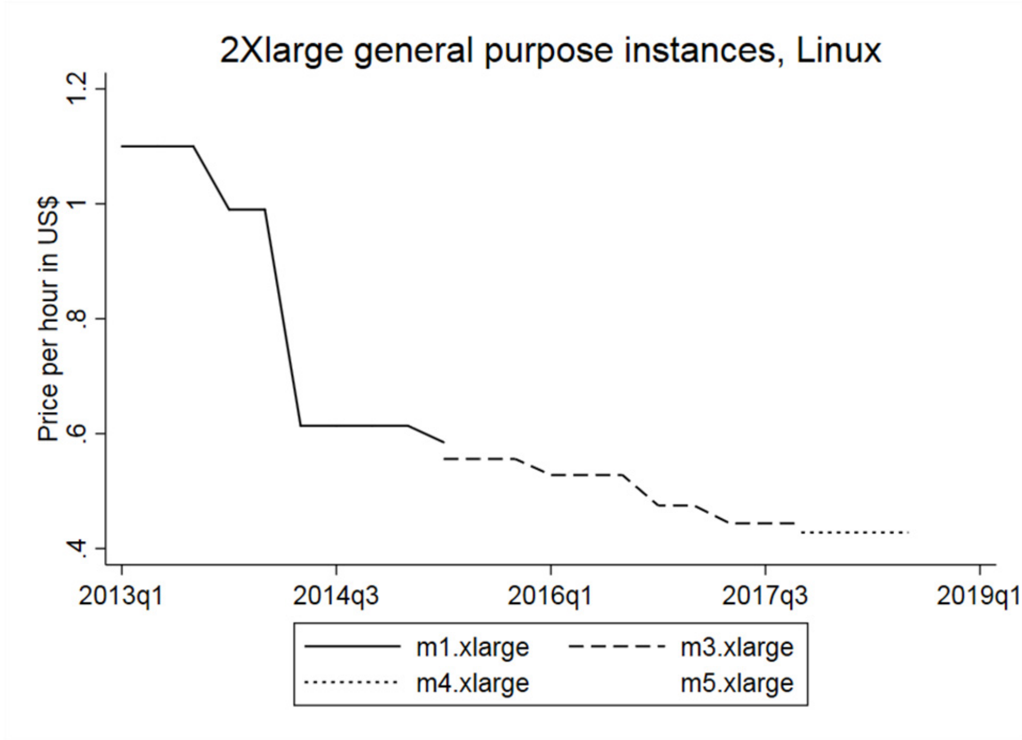


Figure 23. AWS quarterly prices for 2xlarge General Purpose EC2 Instances (m1/m3/m4/m5), Dublin, Linux, 2010–2018. Source: Calculations based on AWS data.



Appendix E. Prices and price indices for Google Cloud Platform

Figure 24. Price index Google based on nominal prices for Europe, standard computing machine, Q1.2013 – Q1.2018. Source: Calculations based on GCP prices on website

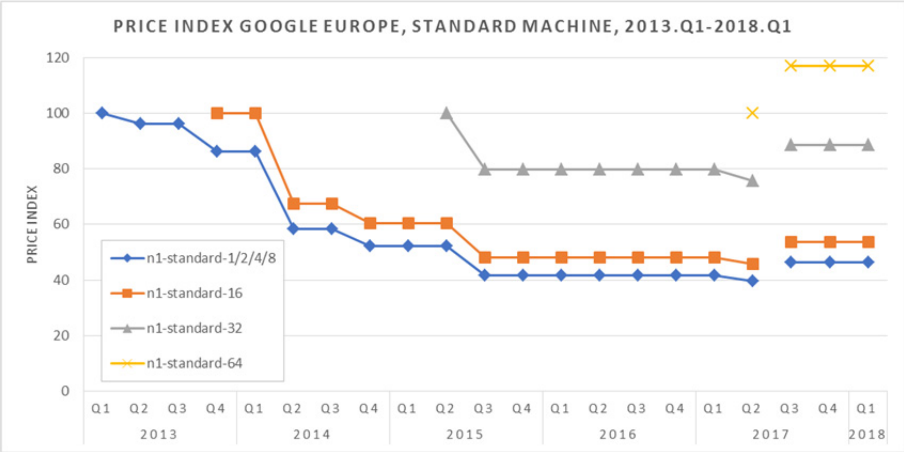


Figure 25. Price index Google based on nominal prices for Europe, high-memory computing machine, Q1.2013 – Q1.2018. Source: Calculations based on GCP prices on website

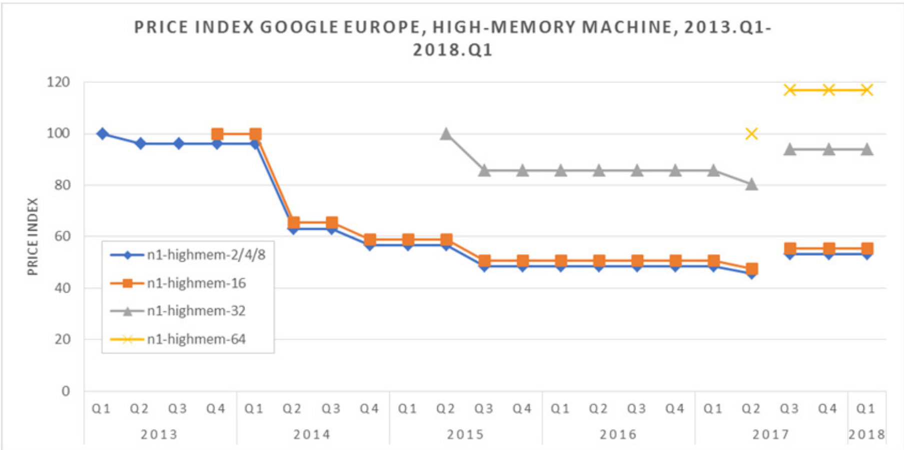


Figure 26. Price index Google based on nominal prices for Europe, high-CPU computing machine, Q1.2013 – Q1.2018. Source: Calculations based on GCP prices on website

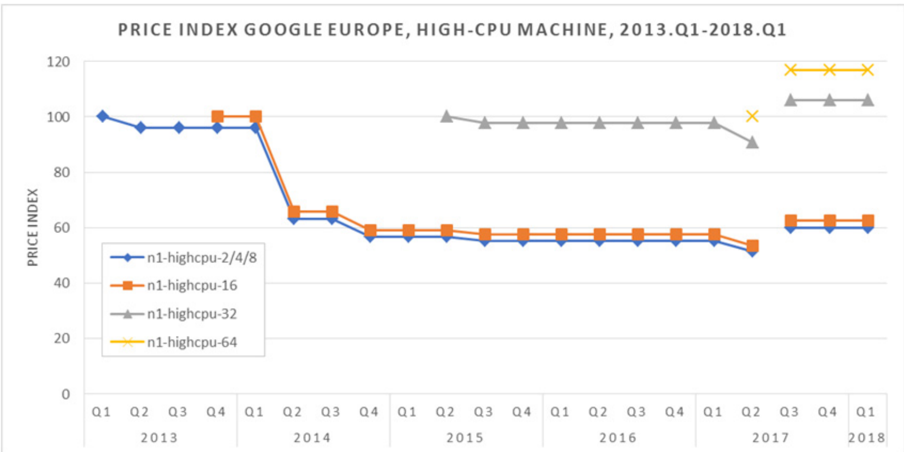


Figure 27. Price index Google based on nominal prices for the US, standard computing machine, Q1.2013 – Q1.2018. Source: Calculations based on GCP prices on website

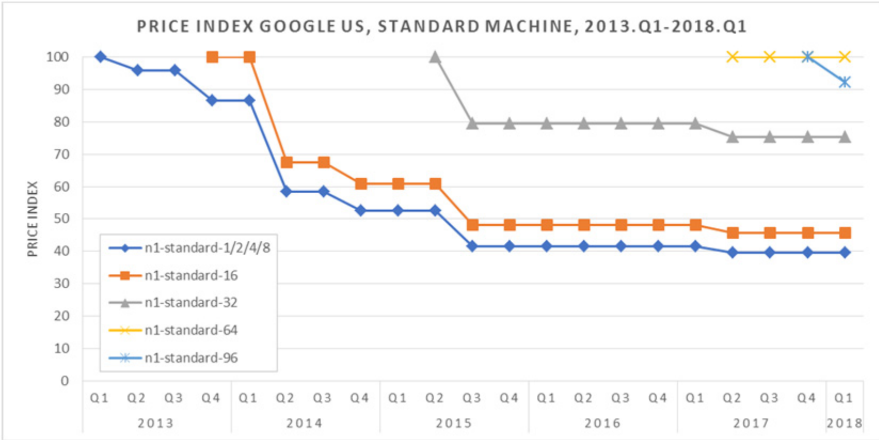


Figure 28. Price index Google based on nominal prices for the US, high-memory computing machine, Q1.2013 – Q1.2018. Source: Calculations based on GCP prices on website

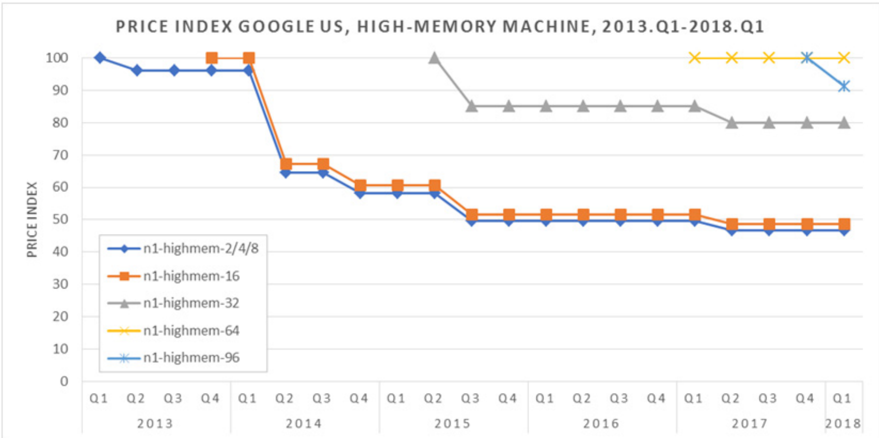


Figure 29. Price index Google based on nominal prices for the US, high-CPU computing machine, Q1.2013 – Q1.2018. Source: Calculations based on GCP prices on website

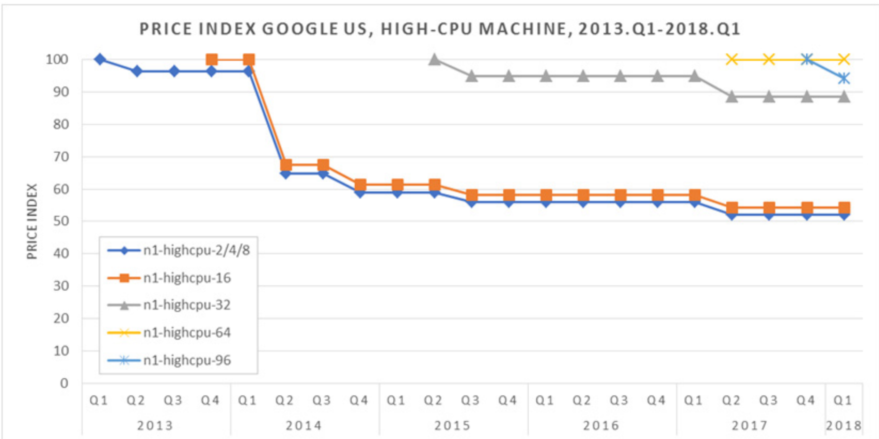


Table 9. List of nominal prices in USD for Google compute products in Europe, Q1.2013 – Q1.2018. Source: Calculations based on Google website using archive.org

	2013				2014				2015				2016				2017				2018
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
n1-standard-1	0.132	0.127	0.127	0.114	0.114	0.077	0.077	0.069	0.069	0.069	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.052	0.061	0.061	0.061
n1-standard-2	0.264	0.253	0.253	0.228	0.228	0.154	0.154	0.138	0.138	0.138	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.105	0.122	0.122	0.122
n1-standard-4	0.528	0.507	0.507	0.456	0.456	0.308	0.308	0.276	0.276	0.276	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.209	0.245	0.245	0.245
n1-standard-8	1.056	1.014	1.014	0.912	0.912	0.616	0.616	0.552	0.552	0.552	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.418	0.490	0.490	0.490
n1-standard-16				1.825	1.825	1.232	1.232	1.104	1.104	1.104	0.880	0.880	0.880	0.880	0.880	0.880	0.880	0.837	0.979	0.979	0.979
n1-standard-32										2.208	1.760	1.760	1.760	1.760	1.760	1.760	1.760	1.674	1.958	1.958	1.958
n1-standard-64																		3.347	3.917	3.917	3.917
n1-standard-96																				N/A	N/A
n1-highmem-2	0.286	0.275	0.275	0.275	0.275	0.180	0.180	0.162	0.162	0.162	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.130	0.152	0.152	0.152
n1-highmem-4	0.572	0.549	0.549	0.549	0.549	0.360	0.360	0.324	0.324	0.324	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.260	0.305	0.305	0.305
n1-highmem-8	1.144	1.098	1.098	1.098	1.098	0.720	0.720	0.648	0.648	0.648	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.521	0.609	0.609	0.609
n1-highmem-16				2.196	2.196	1.440	1.440	1.296	1.296	1.296	1.112	1.112	1.112	1.112	1.112	1.112	1.112	1.042	1.218	1.218	1.218
n1-highmem-32										2.592	2.224	2.224	2.224	2.224	2.224	2.224	2.224	2.083	2.437	2.437	2.437
n1-highmem-64																		4.166	4.874	4.874	4.874
n1-highmem-96																				N/A	N/A
n1-highcpu-2	0.152	0.146	0.146	0.146	0.146	0.096	0.096	0.086	0.086	0.086	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.078	0.091	0.091	0.091
n1-highcpu-4	0.304	0.292	0.292	0.292	0.292	0.192	0.192	0.172	0.172	0.172	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.156	0.182	0.182	0.182
n1-highcpu-8	0.608	0.584	0.584	0.584	0.584	0.384	0.384	0.344	0.344	0.344	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.312	0.365	0.365	0.365
n1-highcpu-16				1.167	1.167	0.768	0.768	0.688	0.688	0.688	0.672	0.672	0.672	0.672	0.672	0.672	0.672	0.624	0.730	0.730	0.730
n1-highcpu-32										1.376	1.344	1.344	1.344	1.344	1.344	1.344	1.344	1.248	1.459	1.459	1.459
n1-highcpu-64																		2.496	2.918	2.918	2.918
n1-highcpu-96																				N/A	N/A
f1-micro			0.021	0.021	0.021	0.014	0.014	0.013	0.013	0.013	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.010	0.010	0.010
g1-small			0.059	0.059	0.059	0.039	0.039	0.035	0.035	0.035	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.029	0.032	0.032	0.032
n1-megamem-96																					N/A

Table 10. List of nominal prices in USD for Google compute products in the US, Q1.2013 – Q1.2018. Source: Calculations based on Google website using archive.org

	2013				2014				2015				2016				2017				2018
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
n1-standard-1	0.120	0.115	0.115	0.104	0.104	0.070	0.070	0.063	0.063	0.063	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.048	0.048	0.048	0.048
n1-standard-2	0.240	0.230	0.230	0.207	0.207	0.140	0.140	0.126	0.126	0.126	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.095	0.095	0.095	0.095
n1-standard-4	0.480	0.461	0.461	0.415	0.415	0.280	0.280	0.252	0.252	0.252	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.190	0.190	0.190	0.190
n1-standard-8	0.960	0.922	0.922	0.829	0.829	0.560	0.560	0.504	0.504	0.504	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.380	0.380	0.380	0.380
n1-standard-16				1.659	1.659	1.120	1.120	1.008	1.008	1.008	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.760	0.760	0.760	0.760
n1-standard-32										2.016	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.520	1.520	1.520	1.520
n1-standard-64																		3.040	3.040	3.040	3.040
n1-standard-96																				4.941	4.560
n1-highmem-2	0.254	0.244	0.244	0.244	0.244	0.164	0.164	0.148	0.148	0.148	0.126	0.126	0.126	0.126	0.126	0.126	0.126	0.118	0.118	0.118	0.118
n1-highmem-4	0.508	0.488	0.488	0.488	0.488	0.328	0.328	0.296	0.296	0.296	0.252	0.252	0.252	0.252	0.252	0.252	0.252	0.237	0.237	0.237	0.237
n1-highmem-8	1.016	0.975	0.975	0.975	0.975	0.656	0.656	0.592	0.592	0.592	0.504	0.504	0.504	0.504	0.504	0.504	0.504	0.474	0.474	0.474	0.474
n1-highmem-16				1.951	1.951	1.312	1.312	1.184	1.184	1.184	1.008	1.008	1.008	1.008	1.008	1.008	1.008	0.947	0.947	0.947	0.947
n1-highmem-32										2.368	2.016	2.016	2.016	2.016	2.016	2.016	2.016	1.894	1.894	1.894	1.894
n1-highmem-64																		3.789	3.789	3.789	3.789
n1-highmem-96																				6.232	5.683
n1-highcpu-2	0.136	0.131	0.131	0.131	0.131	0.088	0.088	0.080	0.080	0.080	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.071	0.071	0.071	0.071
n1-highcpu-4	0.272	0.261	0.261	0.261	0.261	0.176	0.176	0.160	0.160	0.160	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.142	0.142	0.142	0.142
n1-highcpu-8	0.544	0.522	0.522	0.522	0.522	0.352	0.352	0.320	0.320	0.320	0.304	0.304	0.304	0.304	0.304	0.304	0.304	0.284	0.284	0.284	0.284
n1-highcpu-16				1.044	1.044	0.704	0.704	0.640	0.640	0.640	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.567	0.567	0.567	0.567
n1-highcpu-32										1.280	1.216	1.216	1.216	1.216	1.216	1.216	1.216	1.134	1.134	1.134	1.134
n1-highcpu-64																		2.269	2.269	2.269	2.269
n1-highcpu-96																				3.610	3.402
f1-micro			0.019	0.019	0.019	0.013	0.013	0.012	0.012	0.012	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
g1-small			0.054	0.054	0.054	0.035	0.035	0.032	0.032	0.032	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.026	0.026	0.026	0.026
n1-megamem-96																					10.674

Appendix F. Supplementary tables and figures relating to trade

Table 11. Top 10 exporters of good HS 847150 in 2017. Source: UN Comtrade

Country	Value (bn$)	Share (%)
Mexico	12.2	31.8
USA	6.5	16.8
Czech Republic	4.3	11.1
China, Hong Kong SAR	3.5	9.2
Singapore	3.5	9.1
Germany	2.7	7.2
Hungary	1.1	2.9
Ireland	0.9	2.3
United Kingdom	0.7	1.9
Malaysia	0.5	1.4
Other	2.4	6.2
World	38.3	100.0

Table 12. Top 10 importers of good HS 847150 in 2017. Source: UN Comtrade

Country	Value (bn$)	Share (%)
USA	23.5	42.3
Japan	3.9	7.1
China, Hong Kong SAR	3.2	5.8
Germany	3.2	5.8
Canada	2.0	3.6
United Kingdom	2.0	3.6
India	1.4	2.5
Rep. of Korea	1.3	2.3
Singapore	1.3	2.3
Australia	1.1	2.0
Other	12.5	22.5
World	55.5	100.0

Figure 30. UK imports in servers (HS 847149). Number of units and average unit price, 2000-2017. Source: UN Comtrade

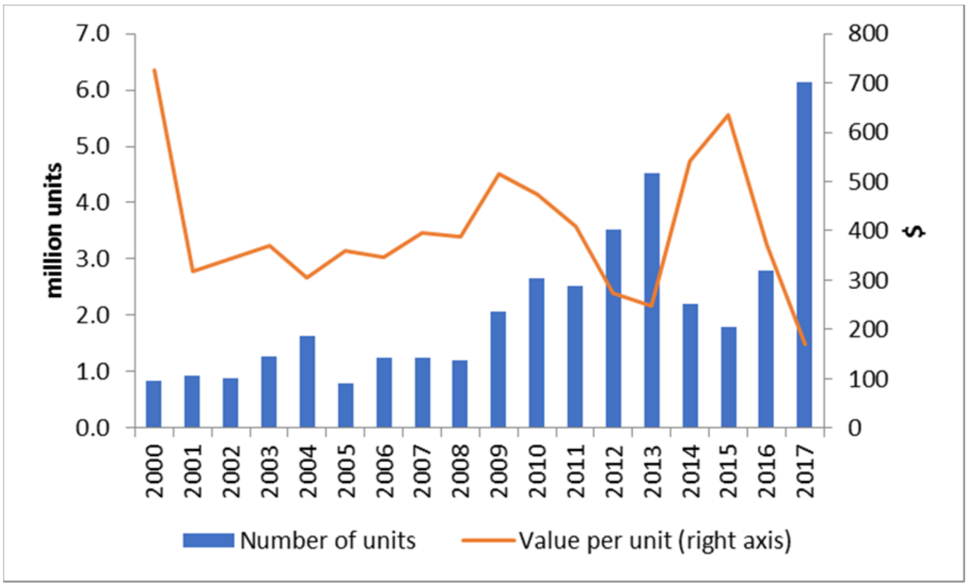


Figure 31. UK imports in servers (HS 847149). Total value in $bn, 2000-2017. Source: UN Comtrade

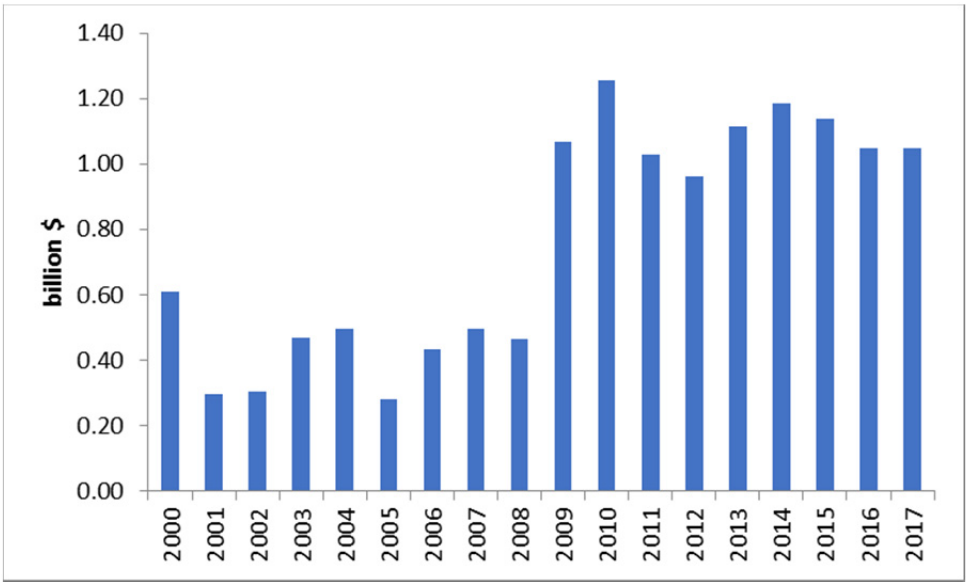


Figure 32. UK imports in servers (HS 847141). Number of units and average unit price, 2000-2017. Source: UN Comtrade

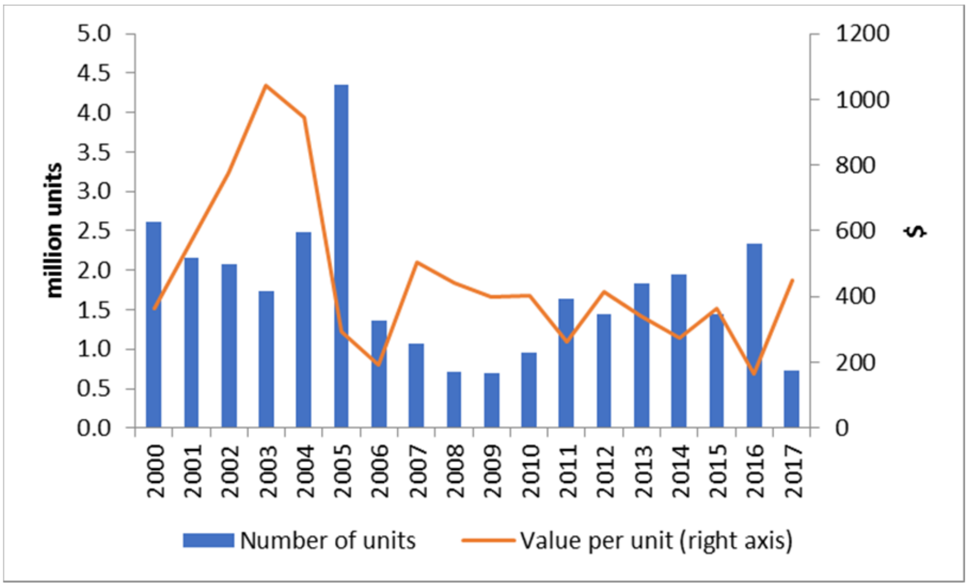


Figure 33. UK imports in servers (HS 847141). Total value in $bn, 2000-2017. Source: UN Comtrade

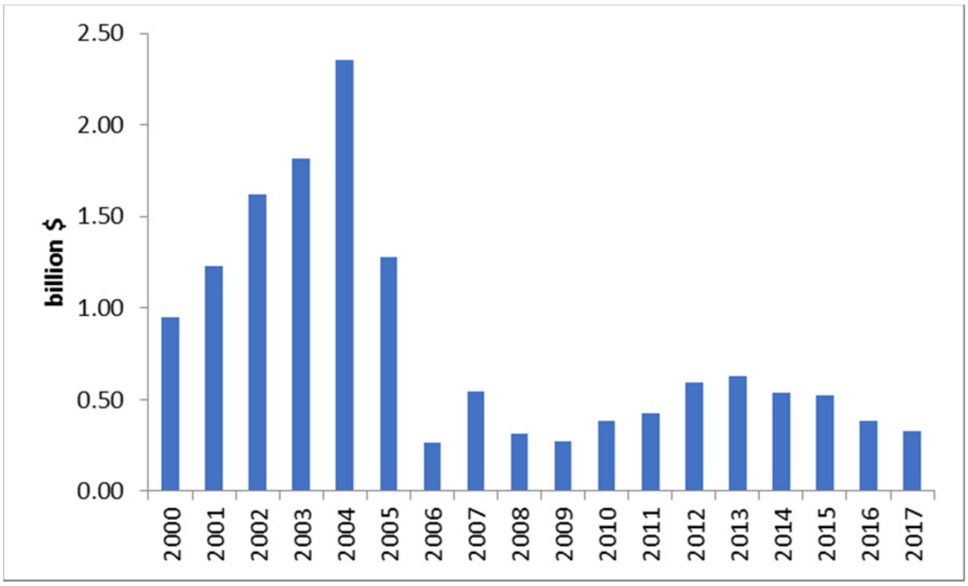


Figure 34. Imports in servers (HS 847141), Netherlands. Number of units, 1998-2017. Source: UN Comtrade