A Comparison of Deflators for Telecommunications Services Output

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Abstract – Data usage in the UK expanded by nearly 2,300% between 2010 and 2017, yet real Gross Value Added for the telecommunications services industry fell by 8% between 2010 and 2016, while the industry experienced one of the slowest rates of recorded productivity growth. The disconnect between rapid technological improvements and the measured economic performance of the industry can largely be explained by the deflators applied to nominal output. We contrast two methodologically distinct options: the first consists in strengthening the existing Services Producer Price Index for Telecommunication Services, the second in measuring price changes through the average price per unit of data for various telecommunication services. The key distinction between these options can be considered as contrasting a revenue weighted index with one that can be seen as a volume weighted index. Using these methods, we conclude that telecommunications services prices fell by between 37% and 96% from 2010 to 2017, considerably more than the current deflator. The real output of the sector will therefore have been considerably higher than indicated by current statistics.

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Users of National Accounts data usually want to analyse data in real terms for purposes such as comparison through time. This requires the deflation of nominal values. Statistical offices calculate National Accounts deflators in compliance with international guidance, but there are well-known challenges in constructing deflators, in particular how to treat new goods entering the consumption basket, quality change which may change the price as well as the nature of the product, and products reaching 'corner solutions', such as where prices fall to zero, or where consumption at a given price is without limit. These particularly affect high-tech and digital products, as engineering progress has been rapid over the last twenty years, and big increases in usage have been accompanied by large declines in unit price. This paper explores these issues with respect to telecommunications services[1], as the industry clearly manifests these challenges.[2]

This paper considers the deflation of telecommunications services as currently used in the construction of the output measure of Gross Domestic Product (GDP).[3] Telecommunication services have experienced extremely rapid technological change in recent years, and the issues debated in the literature are particularly acute here. Both Office for National Statistics (ONS) and EU-KLEMS data suggests the telecommunications sector has seen one of the slowest rates of productivity growth in recent years, and yet to a telecommunications engineer this is at odds with the extremely rapid technological progress it has experienced. The sector has also experienced rapid demand growth observed in terms of the volume of data usage, but not total industry revenues. As demonstrated in ONS (2018), the telecommunications sector has gone from being one of the two fastest growing industries in the United Kingdom in terms of productivity in the pre-Great Recession period, to being one of the two seeing the biggest decline, recording negative productivity growth in 2012-2017. This has led some (including official reports such as Bean, 2016) to suggest the official deflators understate 'true' declines in the price of such products, and therefore that real economic growth may be understated.

Our contribution is to show that both a modest improvement in the current method for constructing the output deflator for the product and a more radical alternative method deliver an estimated price decline of between 37% and 96% over an eight-year period, compared with the 3% price increase shown by the current deflator. Our alternative improvements to the current price index for telecommunications services, taking account of broadband data services suggest that the real output of telecommunications services in the UK (and likely other countries too) will have been significantly understated in recent years.

Similar issues are likely to apply to several sectors where digital technologies have driven improvements in services, but they are dramatic in the case of telecommunications services. Recent years have demonstrated exponential growth in the quantity of data transmitted via telecommunications networks. Intuitively, this huge gain in data transmission performance at constant or declining cost should represent a significant gain in real output. This paper does not venture into the complexities of new digital goods, or boundary issues concerning where they are produced (see for example Coyle, 2017), but focuses on a simpler question: the measurement of telecommunication services output in real terms and what difference alternative approaches for calculating deflators would make.

We consider both an improvement of the current methodology and an alternative data usage driven approach. These provide wide estimated bounds, so we also consider the degree to which market structure and technological change in the sector may lead to convergence between the two methods over time. At present, the price per unit of data differs significantly between services; for instance, it is more expensive to convey the same amount of data via SMS message than an 'over-the-top' service such as *WhatsApp*. This may be a transitional phenomenon. Convergence over time in the price per unit of data charged currently for different communications services can be expected, primarily through competition between differently priced close substitutes: where customers are currently charged a different

1. Telecommunication services comprises four sub-categories in the International System of Industrial Classification of All Economic Activities (ISIC) 2008 system: Wired telecommunications activities (6110), Wireless telecommunications activities (6120), Satellite telecommunications activities (6130) and Other telecommunications activities (6190). Note, however, that the deflators we are comparing in this paper are product level deflators. They are therefore informative about price changes for the product telecommunications services, rather than price changes for the industry as a whole. Whilst most telecommunications services are produced by the same industry, some of that activity also takes place in other industries.

2. In 2016 the Office for National Statistics (ONS) joined with leading economists and engineers in the Institution of Engineering and Technology (IET) to review this issue. A previous ONS article (Heys & Awano, 2016) outlined some of the key conceptual issues in scope.

3. GDP can be calculated by the Output, Expenditure or Income approaches. To ensure that the three approaches yield the same estimate in practice, National Accountants use a balancing process.

price per unit of data this should ultimately lead to the lower cost substitute becoming dominant and winning market share, as long as there is enough competition in the market. Convergence would make a data usage based unit value index a more meaningful proxy deflator. We present evidence that such convergence is under way, although for now it would be too early to recommend a switch from the current (but improved) methodology to the aggregate unit value index we calculate.

The two options exemplify a key difference between the engineering and economic approaches: economists observe a variety of products with different prices and weights in a basket of goods, delivered via the means of data transmission; engineers observe the telecommunications service sector delivering a single product – data transmitted, which has a variety of uses in delivering different services – which has experienced a clear and substantial fall in cost per bit of data through time. Our first option presents a relatively cautious updating of the current deflator in line with current international norms and standards, notably adding important components to the basket of goods in scope. The second option starts from the engineering perspective that there is a single service – data – and thus considers a data usage driven approach by translating all services into a single measure of the volume of data and using the revenue per unit of data as the deflator.

The results are striking in either case. Both approaches suggest substantially faster price decline than the present deflator. We find that prices of telecommunications services have fallen by between 37% and 96%. This is significantly lower than the current deflator suggests and implies that the real growth of telecommunications services in the national accounts has been understated. We also present some potential amendments to our two approaches that may help narrow this range.

This paper is structured as follows. First, we set out the context. Secondly, we discuss the engineering issues in terms of the differences between the various telecommunication services and how to represent the output of all services in terms of bits transported. Then we present the methodology for calculating the current deflator, and the two alternative options; and we discuss their strengths and weaknesses. Finally, we discuss the results and some potential future improvements.

1. Context

The UK fixed line telecommunications market is concentrated[4], with BT and Virgin Media having a market share of around 53% in 2017. A number of smaller providers account for the remaining 47% but these usually use the BT (Openreach) network.

Fixed line telecommunications service contracts are often bundled contracts where customers usually purchase broadband with a phone line at the minimum. However, unlike mobile phone contracts, these fixed line contracts do not always have an inclusive allowance of voice calls. As a result, we find that the revenue weights of phone calls decline significantly, as data enabled applications have emerged as substitutes. The monthly contract fee also includes line rentals but these are no longer invoiced separately and just subsumed in the bundled price. Some bundles have also evolved to include non-telecoms services, such as TV packages. However, the revenues used in this analysis exclude all non-telecommunications services revenues. This ensures that our resulting telecommunications services deflator is not biased by the inclusion of non-related revenue.

The mobile telecommunications market is equally concentrated in the UK[5] with the largest two providers controlling around 56% of the market at the end of 2015 and the largest four operators controlling around 85%. The remaining 15% of the market was served by a number of smaller virtual network operators who use the networks of the larger operators. Mobile services contracts are provided on either a pre-pay or post-pay basis. Post-pay contracts are predominately provided on a bundled tariff basis, which contain a pre-determined allowance of calls, texts and data usage. Whilst pre-pay contracts are usually based on a usage basis, these increasingly give the option of purchasing monthly bundles of calls, texts and data.

The bundling of different telecoms services into the monthly price makes it difficult to observe true revenue weights for the different mobile services. This is because the mobile operators do not break down the bundled revenue into the different components. We therefore have to apply the strong assumption that the unit

4. https://www.ofcom.org.uk/__data/assets/pdf_file/0012/110154/Q3-2017-Telecoms-Data.pdf [Data in Table 2 on page 4; retrieved: 04 December 2018].
5. https://www.ofcom.org.uk/__data/assets/pdf_file/0026/26648/uk_telecoms.pdf [Figure 4.21 on page 154; retrieved: 04 December 2018].

prices for the different services in the bundle equal the out of bundle unit prices for these services. However, voice and text services are often offered on an unlimited basis and newer bundles therefore focus on increasing the data allowance. This in turn limits the share of mobile data in the out of bundle revenue, and distorts the calculations of our revenue weights. The resulting differentials in unit prices between the different mobile services do therefore not necessarily indicate substantial differences in consumer values between the different services, particularly the conventional voice and text services compared to the newer data services.

1.1. What are Telecommunications Services?

Users primarily perceive that they are buying digital products and services of many kinds, from movies to banking services, rather than buying their transportation per se. However, in engineering terms communications, whether traditional telephony, TV/video, banking or social/text networking, is essentially a bit-transport service. An analogy would be that the domestic user may use water to wash, clean, cook and a variety of other purposes, but the water supplier sees only the quantity of water being piped to each home, with charges being driven by the volume of water consumed and the fixed costs of the network. For ordinary physical products they would expect that any transportation necessary to cost an amount relating to specific characteristics such as the product's size and weight, rather than the intrinsic value of the product itself (with some exceptions). Data services in the UK are provided by data bits transmitted to consumers via either fibre or wireless connections. These are weightless and essentially non-physical, but otherwise the analogy remains.

The cost of a fibre network is typically dominated by the fixed costs of installation[6], which has not changed much in recent years. However, the data rate achieved on a single installed fibre has risen by some 10^{10} times (from 0.1 MBit/s to 1 Petabit/s) for 'champion' results[7] between 1960 and 2015. Similarly, the data rate for widely installed systems rose 10^{6} times between 1980 and 2015 (from about 1Mbit/s to about 1Terabit/s).[8] These improvements each broadly equate to a fairly steady log growth gradient of 150% per annum or 5,000-6,000% per decade.[9] Although there has been some levelling off in the champion rates in recent years, these are considerably higher than the installed rates. This means that large further gains in the installed rates remain possible.

1.2. Measuring Price Change

The key question in this market is therefore how to conceptualise and measure the fundamental communications product, 'data', encapsulating broadband (fixed and mobile) data and all other telecommunications services (phone calls, text messages, etc.). The question concerns the appropriate volume units of measurement, taking into account quality change and hence the appropriate price deflator to apply to nominal output to permit volume estimation to occur.

This question sits within a family of similar recent questions concerning measurement of the digital economy. These however only re-open, in a particularly acute manner, older debates. Innovation is the defining characteristic of the digital economy, either in the form of new products and services, improved quality and variety, or new business models (such as digital platforms), and can be clearly observed in the changes described above in recent years in the telecommunications sector. Innovation in general has long posed a challenge to the construction of price indices, as elegantly summarised by Diewert (1998): "The basic problem is that traditional index number theory assumes that the set of commodities is fixed and unchanging from period to period, so that like can be compared to like."

Considerable attention has therefore been paid to how innovation should be treated in price indices, and the extent to which this diverges from normal practice in statistical offices.

The naïve approach is to use a unit value index, calculated using total revenue and total volume for a particular service. Unit value indices are both dependent on the choice of units deployed, and need the goods to be broadly homogenous as otherwise the price series might be biased. This is because the unit price captures both price and quantity changes. Only

6. Meaning civil engineering (construction) for the most part.
7. Champion results are those achieved in best case experimental systems. See Ellis et al. *(2016).*
8. These gains in volume for similar or falling cost should deliver equivalent gains in productivity. Indeed if we were producing bags of sugar instead of digital bits it would. Today's annual sugar consumption in the UK would, if spread evenly across the national surface area amount to barely more than the thickness of an oil film on water (4 microns or about 1/30 the diameter of a human hair or optical fibre). However, if the gains since 1980 in installed fibre systems were applied to sugar the UK would now be covered by an extra depth of four metres of sugar each year.
9. Interestingly, similar to Moore's Law.

if the products are completely homogeneous, and a shift in consumption therefore occurs for some reason other than substitution for product characteristics, is there no bias.[10] Statistical offices sometimes use unit value indices for pragmatic reasons but economic theory favours other methods to generate required indices. The traditional Laspeyres index is one such, and answers the question: How much would a given consumer with given preferences need today to make her as well off as she was yesterday still consuming yesterday's basket of goods? It therefore forms an upper bound because it does not take into account consumer substitution when the relative prices of goods change.[11]

From the perspective of economic theory, the price index should preferably answer a subtly different question: How would a hypothetical consumer evaluate the two different sets of prices and goods? What is the compensating variation that keeps the consumer on the same indifference curve, given price changes and substitutions? For instance, suppose a laptop cost £1,000 in both 2012 and 2017 but the 2017 laptop had much better performance characteristics such as speed and memory. It is possible that a given consumer would be equally satisfied in 2012 and 2017, given what is available on the market and her (socially influenced) expectations (and hence the intuitive appeal of unit value comparisons). However, to reflect the real growth through innovation, the price ought to record a decline; there has been an increase in value received as consumer surplus. Hence economists prefer a superlative index such as the Fisher index, which approximates the theoretical cost of living index that keeps consumers' utility constant. However, such superlative indices require expenditure data for the current period that is usually unavailable when price indices are being calculated. The Laspeyres (or Lowe[12]) index is therefore typically used in practice (either with fixed weights or annually updated weights).

Given standard practice, there are several ways of reducing the potential bias from new goods and quality change, employed to differing degrees by statistical offices, particularly after the Boskin Commission Report (1996). One is to update the index weights frequently. Another is to introduce new goods into price indices more swiftly than had previously been the practice, to better capture the rapid price declines that often occur in the early years of the product lifecycle. A third, often seen as the gold-standard solution to the problem of adjusting for rapid quality change, is hedonic adjustment based on regressions on definable characteristics, in order to link prices per unit "to a yardstick more nearly relevant to its intrinsic utility".[13] For instance, hedonic regressions for computer prices might include processor speed, RAM, hard drive capacity, screen resolution, presence of a built-in camera and so on. In effect, products become bundles of more fundamental characteristics, allowing comparison of the price of comparable bundles of these characteristics. However, hedonic adjustment is typically applied to a few goods experiencing rapid change in their quality or characteristics, accounting for a small proportion of the consumption basket (0.39% in the UK[14]), in part because of the significant data requirements. To be a solution to the bias, hedonic adjustment also requires the assumption that the price contribution of different components equals their marginal contribution to consumers' valuation of the product.

There is an extensive literature on both the new goods problem and the hedonic approach. On the topic of new goods, the introduction of broadband as a product has attracted noticeable interest. The common approach in these studies is to evaluate quality-adjusted prices using hedonic regressions (Griliches, 1961). Williams (2008) considers internet access prices in the United States for the period December 2004 to January 2007. The study uses 135 price quotes from the BLS' CPI database and constructs hedonic functions where the main quality characteristic is bandwidth. Williams finds that quality adjusting the internet access price index makes little difference. Greenstein & McDevitt (2010) use a sample of over 1,500 price quotes for the period 2004 to 2009 obtained from a private consultancy. They use this to construct a hedonic model where the main quality characteristic is the download and upload speed. They find that quality adjusted prices fell by around 3%-10% in the period. This was a steeper decline than the official measure but still much smaller than the quality-adjusted price changes for other products such as computers.

10. Equally, there is not really an index number problem in that case.
11. Conversely, the Paasche will form a lower bound, looking back from today's basket of goods.
12. The Lowe will exceed the Laspeyres in a period when there are long-term trends in relative prices and consumers are substituting to lower priced items.
13. Adelman & Griliches (1961).
14. This figure relates to the Consumer Price Index.

However, hedonic studies have limitations, which is why in this instance we have not followed this approach. Hausman (2003) discusses some limitations of hedonic regressions in general. He argues that prices in imperfectly competitive markets are determined by demand, cost and the degree of competition in the market, and that hedonic regressions often fail to separate out these factors. In addition, even in the case where a hedonic regression might be acceptable, Hausman argues that it is difficult to identify all the product characteristics that are needed. This is especially relevant where the product characteristics are changing rapidly.

More fundamental, in terms of practical application, there is also a question about the completeness of product characteristics used in the hedonic regression. Bandwidth and upload/download speeds, while important, are not individually sufficient to explain price and quality changes of broadband. Other factors such as data caps, speed limitations ('throttling') at peak times, latency (the degree of time delay between the person transmitting and the person receiving), and geographical coverage are important quality considerations of the broadband service itself. In addition, even the bandwidth needs to be treated carefully as there is a difference between advertised and actual bandwidth. Advertised speeds can remain static whilst actual download and upload speeds improve, and vice versa. Furthermore, actual bandwidth cannot be captured in hedonic functions, as the actual speeds cannot be observed on an individual service contract level. These shortcomings of the hedonic approach can be overcome by the unit value approach under certain circumstances which could apply to the telecoms services industry.

It is also difficult to construct representative baskets of broadband service contracts, given the complexity of pricing in the industry and the wide range of available tariffs and options available and their dynamic nature. The use of a basket of goods approach in constructing a price index is therefore questionable in this case.

1.3. Alternative Methods to Deal with New Goods and Quality Change

One of the results of the rapid technological change in the telecoms services industry is that the volume weights for the different services differ significantly from their respective revenue weights. For example, while data services are weighted very highly in volume (as measured by bits for all services), the weight of data services in revenue is much lower. A similar problem is observable in the price of drugs. When generic versions of a drug enter the market, the price index is hardly affected, even though the price of generic drugs is much lower (Griliches, 1994). This is because the price index usually uses revenue weights. The incumbents often maintain a large share in the revenue while generics account for the bulk of volume.[15] Griliches & Cockburn (1993) note that the revenue-weighted official prices are a poor measure of the prices actually paid for goods which consumers regard as near-perfect substitutes, but the index treats as distinct goods even as the consumer substitution occurs over time. In the standard index for price change between periods 1 and 0, the revenue weight used for the old good is:

$$\frac{Q_{old}^{1}.P_{old}^{1}}{Q_{old}^{1}.P_{old}^{0} + Q_{new}^{1}.P_{new}^{0}}$$

This amount by which this will overstate the contribution of the old good is related to the change in quantity purchased of the new good and its average reservation price, as the 'true' weight is:

$$\frac{Q_{old}^{1}.P_{old}^{1}}{Q_{old}^{1}.P_{old}^{0} + Q_{new}^{1}.P_{new}^{0} + \left(Q_{new}^{1} - Q_{new}^{0}\right).p^{r}}$$

where p^r is the average reservation price for the new good. Clearly as the quantity substitution by consumers from old to new occurs, the revenue weight on the old good declines and the problem eventually disappears. However, even in the approach proposed in Griliches & Cockburn (1993) does not disregard revenue weights. Instead, the data usage approach in this paper is more closely aligned with Nordhaus (1994, 2007).

Price indices, even hedonically adjusted, will anyway fail to capture the consumer surplus due to the introduction of a new good into the market. Feldstein (2017) argues that the failure to consider new products and their impact on consumer value is an even greater source of bias than the failure to account for quality changes. It is difficult to time the inclusion of new goods in a price index and estimate the impact on consumer value using conventional methods. In theory, and in practice in a few instances, it is possible to estimate the demand curve and hence the reservation price at which demand is zero,

15. Although a key question is why the incumbent products are able to maintain this price differential; is this because of some unobserved characteristic or because of a poorly functioning market where consumers are not reacting fully to new price signals.

when the good is first introduced (Hicks, 1940; Hausman, 1996, 2003). Hausman also shows this reservation price can be approximated using an estimate of the own-price elasticity of demand. This approach requires current expenditure data, and imposes significant data requirements.

An alternative approach is to measure the cost of the service characteristic directly. This approach has been applied to lighting (lumen hours) and computer processing (computations per second) by Nordhaus (1994, 2007), who constructed long run series of directly observed engineering measures of performance and estimated corresponding supply costs per unit of light or computation. To the extent that mark-ups remain constant, changes in prices charged should be closely linked to cost changes. By measuring the price of the fundamental service characteristic (light or computations), instead of measuring the price of the goods delivering the characteristic, this approach should capture quality changes and the value of new goods, as long as mark-ups do not change much for reasons such as varying degrees of competition, for instance. The analogy in our case would be the engineering costs of transmitting a unit of data. However, it is usually much more difficult to collect the costs of such supply-side characteristics over time rather than market prices of goods, particularly for complex network services such as communications.

The alternatives to the hedonic approach also indicate substantial upward bias in conventional price indices. However, both involve painstaking statistical and econometric work and are not practicable for the regular calculation of official price indices. A key question we consider here is whether a reliable service characteristic – bits of data transported – can be measured in a way which is both conceptually useful and relatively easy to construct. However, there seems to be no completely satisfactory practical solution to the potential upward bias in price indices in the case of goods and services where there is significant innovation.

This issue remains a live one: see for example Bean (2016), and work in the US such as Byrne & Corrado (2017) and Groshen *et al.* (2017). Ahmad *et al.* (2017) attempt to gauge the scale of the problem by applying different countries' deflators to other countries to see if the magnitude of the resultant volume change is large enough to merit further work. They find that the impacts are relatively small. The weakness of this approach is that comparing a variety of upwardly biased deflators may not expose any commonly shared bias from a more correctly specified deflator.

1.4. New Methodological Challenges in Telecommunications

Importantly, in telecommunications services technological change means there is convergence between services both from a network perspective and from the perspective of users. For example, voice calling (once called telephony) is still distinct in terms of how it is handled and charged for by the network (and also, mostly, by regulators), but from a user perspective it is increasingly equivalent to services like *Skype* and *WhatsApp* that provide voice calls on the 'data' network, which is subject to a different pricing regime. The same is true of texting; indeed the word once meant SMS but now covers any of a wide range of text-chat services that in fact use the data network, but have the same (or better) functionality for the user. This means there are significant price differences for similar services, particularly when converted into price per data bit. There can still be major cost differentials between similar bit rates carried on different network services and at different ranges.[16] It is likely that the kind of service people use on their devices, fixed or mobile, will continue to shift rapidly in ways that are generally hard to predict.

This therefore leads to some key questions for our construction below of an index based on units of data:

- How long will different products (telephony, texting, data usage), all of which are essentially end-presentations of the same product (data), continue to be regarded as different services by users?

- How long will price differentials exist for these products?

- As cheaper substitutes become available, how long will providers continue to supply these services in the old mode; in other words,

16. *Use of the data network is generally cheaper and normally distance-price-insensitive. There can be other differences that are important to the user such as the use of encryption and the blending with video and picture transmission, but the overall effect is to make all services look like bit transport from a network perspective. The phone network has clear guidelines on the maximum latency allowed, to avoid the sort of difficulty that makes voice 'calls' using geostationary satellites as often seen on TV so unsatisfactory. Data network based voice calling services like* Skype *once had similar problems, but overall improvements in networks have largely solved these to the extent that broadcasters sometimes prefer them to traditional telephones.*

how long will telephony providers deliver telephony distinct from data rather than port across to using a IP protocol technology delivering the same user service using less data and at lower cost?

- Is it therefore appropriate or not to consider, for example, *Skype* and telephony as substitutes?

Boiling these down, therefore, presents a new challenge to price indices methods, namely, what happens when, rather than an old good being replaced by a new good, multiple old goods converge into a single new good? For example, if *Skype* and telephony increasingly converge which price does one take as the relevant one for the base period, or indeed does one weight these together? If one does, should this be weighted by revenue or volume? The following section considers both of these in the options presented. Option A is an improved Services Producer Price Index (SPPI), using the same methodology as at present (which employs unit value indices), and uses revenue weights. Option B is a unit value index based on data usage. In assuming perfect substitutability, this latter data usage approach is fundamentally driven by volume weights and would in theory reflect pure cost-based changes. Given the caveats about this assumption, discussed above, it should be interpreted as a downwardly biased estimate of the change in prices that would keep consumer utility constant.

Our two options can be considered respectively as upper and lower bounds to some ideal constant utility index, perhaps a hedonically-adjusted superlative index. Before exploring these new methods, however, we first discuss the current method in the UK for constructing the output deflator for telecommunication services.

1.5. Current Method

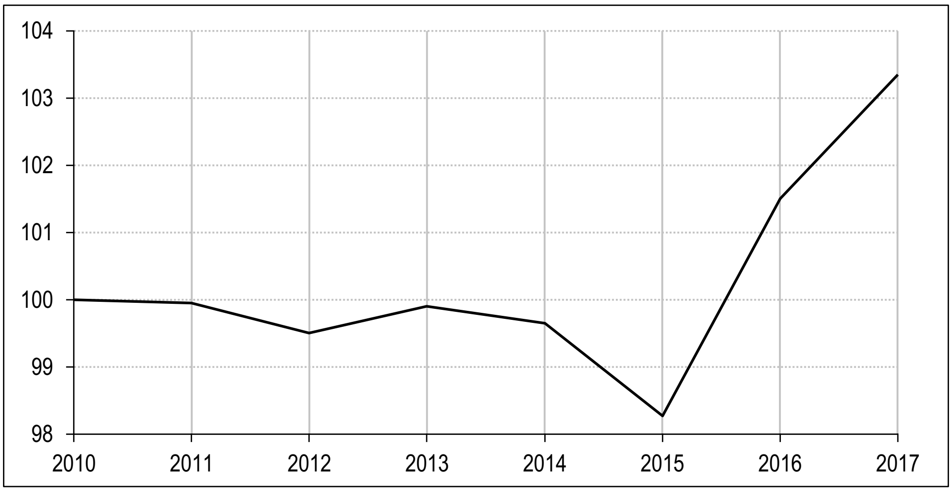
In the UK, the ONS currently deflates telecommunications services output at the domestic aggregate level[17] using an index which comprises two components: the product level index of the Consumer Price Index (CPI) covering Telecommunications Services and Equipment; and the product level index of the Services Producer Price Index (SPPI) covering Telecommunications Services. These are weighted around two-thirds CPI and one-third SPPI in the current deflator.

Between 2010 and 2017, the overall product deflator for telecommunications services in the UK has increased by around 3% (Figure I), despite substantial technological advances in that period (such as the shift from 3G to 4G technology).

An explanation for the trend in the overall deflator can be found by looking at the trend in its two component indices (Figure II). While the SPPI shows a general downward trend, the CPI declines until around 2008 and then rises. Since CPI is more heavily weighted in the output deflator, this has driven the composite deflator

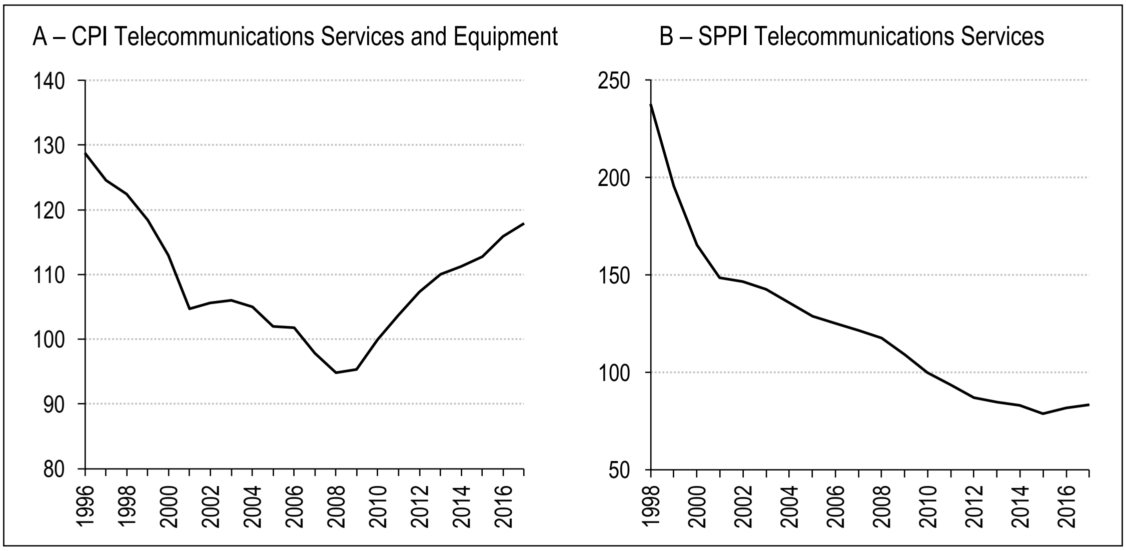
17. Import and exports are treated separately.

Figure I – **UK telecommunications deflator**



Note: 2010=100. Current product deflator for telecommunications services (CPA 61) in the UK.
Sources: ONS.

Figure II – **Components of GDP(output) deflator in the UK**



Note: 2010=100. The CPI Telecommunications Services and Equipment weight in deflator is 66%; the SPPI Telecommunications Services weight in deflator is 34%.
Sources: ONS.

(Figure I) to be broadly flat and then began to rise after 2015.

While this approach meets international standards, it is a methodology borne out of pragmatic decisions needed to deliver an appropriate deflator for the sale of telecommunications services to both businesses and consumers in the UK. These are:

1) The shares of the CPI (reflecting business-to-consumer sales) and SPPI (reflecting business-to-business sales) reflect broad usage patterns in the UK economy, but may not be reflective at the product level. For example, the shares of business and consumer usage may differ for different call types, messaging services and data usage.

2) The inclusion of the CPI is necessary because the SPPI conceptually captures only business-to-business transactions and therefore excludes consumer sales. However, output should be deflated in basic prices, and whilst the CPI reflects business-to-consumer transactions, it does so on a purchaser's[18] (rather than basic[19]) prices basis. This does not strictly map to the price of interest, the basic price of telecommunications services output before logistics, retail and margins.

3) The CPI product level index is a Laspeyres type index which captures both telecommunications services and equipment goods, despite the product group to be deflated including only services. The CPI and the product group that is deflated are also classified using different systems that do not easily map to each other.[20] This pragmatic compromise may introduce potential biases.

4) Whilst many of the CPI item level[21] indices are constructed using the traditional 'basket of goods' approach, a notable exception to this is the item level index for mobile phone charges, which includes Pay As You Go and contract charges. Due to the complex pricing structures and range of tariffs in the market, it is difficult to construct a representative basket of tariffs. Instead, this item is constructed using a "basket of consumers" approach recommended by Eurostat.[22] The ONS obtains representative consumer usage profiles from the UK's telecommunications regulator, the Office of Communications (Ofcom). For each consumer profile, the ONS identifies the price for the cheapest available tariff from the main service

18. That is, after non-deductible taxes, subsidies and relevant wholesale and retail margins and separately invoiced insurance and transport charges.
19. Also referred to as 'factory-gate' prices. That is the price before taxes, subsidies, margins and transport costs.
20. The CPI is based on the Classification of Individual Consumption According to Purpose (COICOP) while the national accounts product classification is based on the Classification of Products by Activity (CPA). The SPPI classification is based on CPA.
21. Item level indices are below product levels indices. For example, the item level index for Smartphones would form part of the product level index for Telecommunications Services and Equipment.
22. http://ec.europa.eu/eurostat/documents/272892/7048317/HICP+recommendation+on+telecoms+-+June+2015

providers. These are then weighted together using expenditure shares which are also supplied by Ofcom.[23] This approach has problems, particularly when quality change of more expensive contracts needs to be taken into account. The cheapest tariff is often based on old technology while the price of the new technology declines and the old technology is phased out. In this case, significant price movements in tariffs based on new technologies are missed, even if most people are using the new technology.[24] Likewise, other quality aspects such as coverage would also be omitted since these cannot be determined on an individual tariff basis as they depend on network and geographical region. As a result, actual quality changes might not be reflected in the price index, even when using hedonic methods.

5) With the exception of smartphones, none of the item level indices in the CPI: Telecommunications Equipment and Services are hedonically adjusted to control for quality change within the twelve month life of the basket of goods before new products are selected. In a fast-moving sector where contract design can change significantly and quickly this is a major weakness.

6) There are methodological differences in the way ONS constructs the product level CPI and SPPI, as well as differences in the construction of item level indices within the CPI. While the CPI: Telecommunication Services and Equipment is constructed as a price index, the SPPI: Telecoms Services is a unit value index. The ONS obtains administrative data sets from Ofcom. This includes volume and revenue of calls (by type) and text messages. A unit value (or average price) is then calculated for each item and aggregated up, based on revenue weights. The data for fixed line telecommunications only captures business telephony but the mobile data captures the entire market. Since the SPPI at present only attempts to cover business-to-business transactions, an assumption is made about the proportion of the total mobile phone revenue that is due to business use.

7) The SPPI has not been kept fully up to date with the pace of change in the sector. A notable absence from the SPPI is mobile and broadband data.

2. Alternative Deflators

Irrespective of the two options we present in this paper, the ONS is committed to reviewing and updating the current deflator, not only stimulated by the work described here and the digital economy agenda, but also by mandated changes through the implementation of the European Union's Framework Regulation Integrating Business Statistics (FRIBS). The FRIBS agenda requires expanding the scope of the SPPI to cover business-to-all transactions, not just business-to-business. This suggests that the ONS, alongside the two options presented below has a *de minimis* alternative of moving to exclusively using a business-to-all SPPI and dropping the CPI component from the output deflator. This would resolve issues 1-6, but would still leave issue 7 unresolved, which would be unsatisfactory.

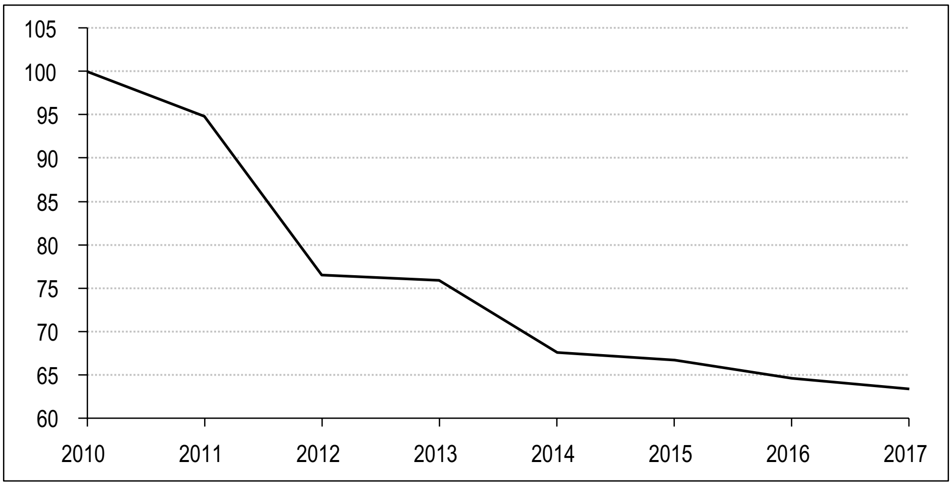
2.1. Option A: An Improved SPPI

The current SPPI treats voice and text as distinct services, and does not include data services. Adding data into the basket presents one immediate route for improving this deflator and meeting issue 7. Therefore, under this option broadband and mobile data are added to voice and text in the current SPPI. To reflect the potentially large difference in consumer values, we construct granular unit value indices and aggregate them together using revenue weights. This is largely based on the current SPPI but with major differences: the index includes mobile and broadband data, uses a business-to-all transactions basis, and is annually chain linked. Removing the CPI component from the deflator and using the improved SPPI produces an index showing that telecommunications services prices have declined by around 37% between 2010 and 2017 (Figure III).

This method presents key benefits, as it is readily comparable to other deflators and represents a cautious improvement to the existing methodological framework. By constructing granular item level indices and aggregating them up, this method also accommodates the possibility that the different telecoms services remain heterogeneous products rather than perfect substitutes. However, the key weakness of this deflator is that it does not reflect the significant technical and quality improvements in the industry from

23. *For details, see the CPI Technical Guide (page 58-60): https://www.ons.gov.uk/ons/guide-method/user-guidance/prices/cpi-and-rpi/cpi-technical-manual/consumer-price-indices-technical-manual--2014.pdf*
24. *It should be noted that even when a representative basket of tariffs can be constructed, hedonic adjustments would still raise some issues. For example, the headline speed for a tariff (which is often used in the hedonic adjustment) might remain constant while actual achieved speed increases (or indeed decreases, for example due to increased contention).*

Figure III – **Improved SPPI deflator**



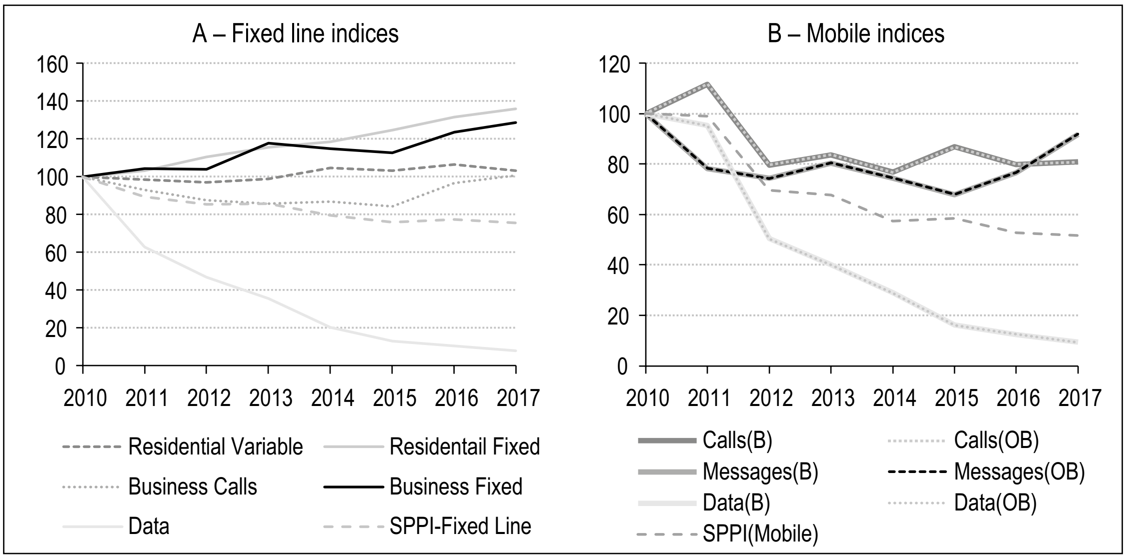
Note: 2010=100.
Sources: Authors' calculations.

an engineering perspective. This is because the deflator uses revenue weights which results in data services having a limited impact on the overall index movement. This is at odds with the engineering perspective, which regards data services as driving technical progress in the industry.

The breakdown of this deflator into the item level indices shows a significant difference in the price movement of the data elements and the voice and texts indices for both fixed line and mobile services (Figure IV). The data items thereby show substantial price decreases but are lower weighted and thus only have a limited impact on this overall SPPI index.

A particular challenge is the treatment of fixed line access charges. While the revenue from voice, texts and data can be divided by the volume of minutes, texts and bits, the denominator to construct unit values for access charges is the number of subscribers as this is the closest to a quantity measure for the access charges. As a result, the item indices for access charges show an increase in prices but different patterns for residential and business subscribers. For residential subscribers, the revenue of line

Figure IV – **Breakdown of improved SPPI deflator**



Note: 2010=100. In the breakdown of the Mobile Index, OB refers to out-of-bundle charges and B refers to bundled charges. The two indices are thereby the same as we assume that bundled and out-of-bundle charges are the same.
Sources: Authors' calculations.

rental has increased much faster than the number of subscribers. For businesses, the number of subscribers declined substantially but the corresponding revenue decline from access charges was less pronounced.

While access charges and the treatment of bundled items are areas that warrant further attention (see Online Appendix C2 for technical details; link to the Online appendices at the end of the article), a general feature of option A is that compared to option B below it places a lower weight on the contributions of broadband and mobile data. This is due to the impact of substantial price differences between the different services through the revenue weights; access, voice and text charges currently contribute a higher share of telecoms revenue. A raw increase in data consumption therefore has a limited impact on the Option A deflator, whereas substitution away from voice and text services toward data-driven alternatives such as *Skype* and *WhatsApp* manifest as a price increase.

2.2. Option B: Data Usage Approach

An alternative approach is to incorporate the engineering perspective on the industry's output, seeing the primary service of the industry as the transfer of data, and as such converting different services into comparable measures of units of data, that is bits or bytes[25], used to deliver the service itself. From a network perspective, there is little difference between a voice call and, say, a *Skype* or *WhatsApp* call, beyond the differences in bit/s that they use. We have accessed sectoral expertise to identify the factors to convert voice and text services into generic data services, using a number of simplifying assumptions[26] (Table):

- for text, we ignore shorter/longer messages and 'emoticons' for simplicity and assume all texts are 140 characters long, although many modern text systems will use more characters;

- a traditional voice call can reduce the data rate to a 'holding' level if both ends happen to be silent, and many systems exploit the relative tendency for both ends not to be speaking together, but we do not adjust for this;

- similar arguments apply to picture and video compression, which will depend upon the characteristics of the particular images involved, and will also likely change over time with technical developments.

Whilst for most services the total number of bits moved within the service period is the dominant consideration, other characteristics also matter. For example, latency (the total end-to-end transmission delay) is important in voice calls and some other services, as is coverage – i.e. whether or not you are in range of a transmission point. However, in most cases, these considerations are modest compared to the basic cost-per-bit-moved. This can be seen, for example, through the frequent use of satellite systems with extremely long latency. We do not therefore consider other characteristics, besides the cost-per-bit-moved, at present. Other traditional cost factors, such as transport range, are much less significant in modern digital communications.[27]

This conversion of voice, texts and data services into a common volume measure (petabytes of data) reveals that broadband and mobile data account for the vast majority of volume. It also shows that output, as measured by data transmitted, has increased 2,300% between 2010 and 2017, primarily driven by the increase in broadband and mobile data volumes. The volume of voice calls and text messages has been decreasing since 2010. This is either due to a drop in demand or, more likely, due to a substitution away from traditional telephony toward data-driven applications.

25. One byte equals eight bits.
26. Differences due to these simplifications are modest compared to the scales involved.
27. Although this was always true to an extent disguised by the relative pricing of, for example, international telephone calls.

Table – **Data conversions**

Medium	Bytes / kBytes rate	Other factors	Aggregate Bytes/ kBytes required
Voice	32 kBit/s each way	×2 for a two-way call /8 to convert kBits to kBytes ×60 to convert seconds to minutes	480 kBytes per minute
Text	1 byte/character	×140 as maximum of 140 characters per text.	140 Bytes per text

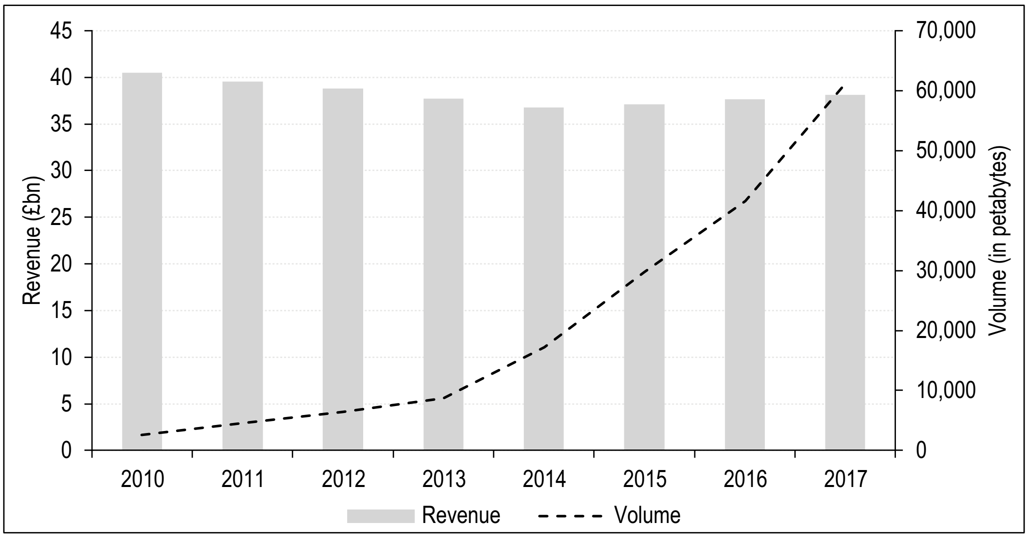
Notes: Authors' assumptions.

By 2017, around 99.8% of total volume was estimated to be broadband and mobile data. This is in stark contrast to the revenue weights, where broadband and mobile data account for around 40% of the total in 2017. In contrast to the exponential increase in volumes, total industry revenue fell by around 6% between 2010 and 2017 (Figure V). This is mainly due to a 47% decrease in wholesale revenues. Retail revenues increased by around 9% in the same period.[28]

Option B uses an aggregate unit value, which divides total revenue[29] in the industry by the total data volume.[30] This unit value index represents the average price per bit transported. Between 2010 and 2017 this measure suggests that telecommunications services prices decreased by around 96% (Figure VI). The increase in data volume, with revenue broadly staying flat, is seen as a volume increase and a price decrease. Likewise, a substitution away from more expensive voice calls and text messages towards cheaper services such as *Skype* and *WhatsApp* is also seen as a volume increase and a price decrease.

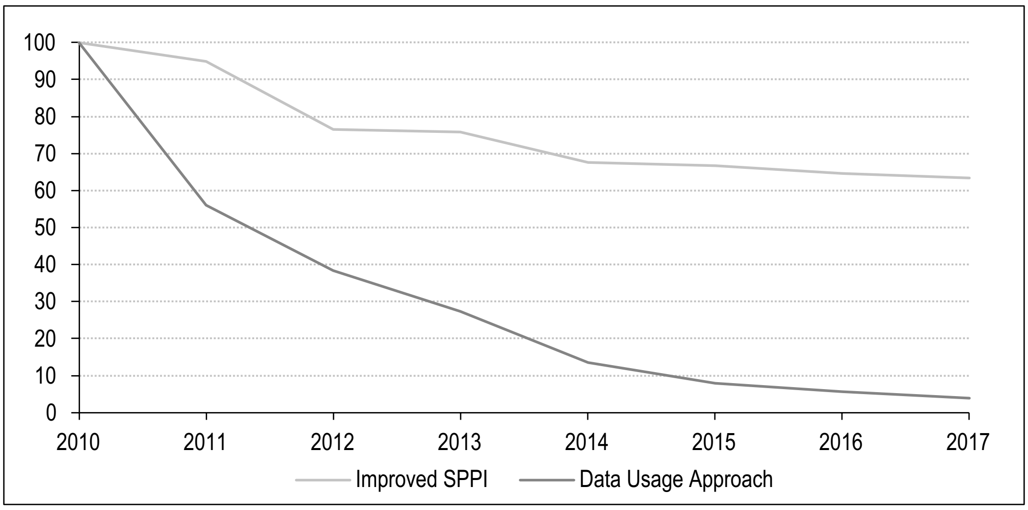
28. See Appendix A1 for details.
29. The total revenue figures exclude non-communications revenue such as TV bundles.
30. See Online Appendix C1 for details. The total volume excludes wholesale and corporate volumes. This does not impact on the main results; see Appendix A2 for details.

Figure V – **Revenue and volume in telecommunications services industry**



Sources: Ofcom and Authors' own calculations

Figure VI – **Comparing improved SPPI (Option A) and data usage (Option B) deflators**



Note: 2010=100.
Sources: Authors' calculations.

The merit of Option B is that it better reflects the significant technical advances and quality improvements observed in telecoms services, and is capable of capturing in a simple measure a variety of quality aspects without further adjustment: increased coverage, for example, allows more people to get access to telecommunications services and thus increases data traffic. Likewise, an increase in speed increases volume as users can consume more data in any given time period. Finally, future changes in technology may be more easily reflected in a data usage based deflator. This is because, as long as the service is defined as the transport of data, any new technology or service will be adding to the volume of data. The impact that the new service will have on prices is then determined by its impact on total revenue relative to its impact on total volume.

The key weakness with this option is that it takes no account of the differential prices currently paid for different communication services. This is vital as consumers do appear to assign different values to the different services, reflected in the differences in prices. However, whether the prices truly reflect consumer utility from different telecoms services can be questioned. Our initial analysis indicates that phone calls cost many multiples per data unit of the equivalent data service, for example by looking at out of bundle charges. While there could be a stronger preference for traditional call and text services, it seems unlikely that the strength of preferences alone could explain the observed magnitude of the difference in prices.

3. Discussion

Our results show a substantial difference between Option A, the improved SPPI, and Option B, the data usage approach, although both reveal a large decline in prices compared to the current methodology. While both deflators are improvements compared to the current method, their incremental impact on real output growth in the sector would differ significantly in terms of magnitude. The key question is whether it is possible to narrow this wide range and so deliver a method that might be applied with confidence in the national accounts.

Two possible extensions to narrow the range are: first, to consider quality adjustment of the SPPI Index, using some of the characteristics of telecommunications not captured presently, such as coverage and latency; secondly, to consider whether the data usage approach can be improved by making an allowance for the fixed infrastructure element in both the delivery and the pricing, which has been increasing in recent years. The index presented here attributes all the costs to the data transmitted. These improvements might help to narrow the gap between these two approaches, but we may need to start with a more basic question, namely why they show such different results in the first place?

The market for communication services is in a period of rapid innovation, resulting in changes both in pricing and consumer behaviour (including significant growth in data usage), thanks to the remarkable engineering advances. The use of an aggregate unit value measure such as the data usage approach, for all that it is not a true price index without the assumption of homogeneity, is probably closer than the Laspeyres to many people's intuition about the effect of advances in communication services on their economic welfare; but to the degree these advances are not reflected in the narrowing of price differentials, we must ask if there may be other reasons for these price differentials which we need to take into account.

3.1. Explaining Price Differentials

In practice, when there are new or improved goods, there will be a period of gradual consumer substitution away from the old goods. The diffusion of digital hardware is typically rapid, with reasonably short replacement cycles, but consumer habits and know-how may take time to catch up. The Boskin Report noted that in a typical product cycle, a new version enters the market at a higher price than old models. When they nevertheless gain market share, "we can conclude that it was superior in quality to the old model by more than the differential in price between the two". This is not the situation across the board in communications, where there is a mix of:

- higher quality and higher price in some services (such as 4G versus 3G for mobile calls and data);

- new, lower prices services substituting for existing ones (such as VOIP versus fixed or mobile telephony, or Rich Internet Applications such as *WhatsApp* versus SMS);

- bundling of different services, and 'convergence' of services, making price and quality comparisons difficult for consumers (and statisticians).

A possible explanation for the price difference therefore lies in product differentiation in a less than perfectly competitive market. Some specific services may additionally benefit from network effects that would not be captured in market prices. One conceivable unobserved characteristic is the degree to which voice calls and text messaging applications act as platforms, benefiting from significant network effects. While special software or apps might be needed to make a phone call using the data service, the network's own platforms allow the consumer to immediately reach a greater number of people. Once alternative platforms achieve significant market penetration, they become viable alternatives with their own network effects. This, for example, is the case for *WhatsApp*, which reached over a billion users in 2016.[31] However, to get to this stage, consumers need to know about the existence of cheaper and better platforms. We could therefore be experiencing a disequilibrium situation where consumers need time to learn about these alternative platforms.

Furthermore, traditional platforms can be bundled with the equipment. For example, all smartphones come bundled with a telephone and text messaging app which uses the more expensive services of the telecoms provider. Tariffs too come in bundles usually including an allowance of minutes, texts and data. Since consumers cannot opt out of the voice and text elements, they might continue to use these traditional services. Consumers may also have difficulty in comparing prices across differently structured bundles. There are surely large information asymmetries.

The data usage approach clearly presents a lower bound estimate. This is particularly the case if consumers are substituting traditional voice and text services for data driven ones because they feel poorer and so are switching to cheaper and (by assumption) lower quality alternatives. However, the alternative platforms can be superior in that they provide users with additional information and functionality. *WhatsApp* (and other messaging apps) for example indicate if a message has been read and allow users to set up status messages that help their peers know whether someone is available to be contacted. Likewise, if consumers attached lower values to general data usage, such as streaming videos or browsing the internet, then these too should have lower weight in the deflator. However, it is not clear that consumers do indeed attach lower values to data services. For after all, data consumption, along with the usage of data based alternatives to traditional phone calls and text messaging, has been increasing substantially.

3.2. Convergence

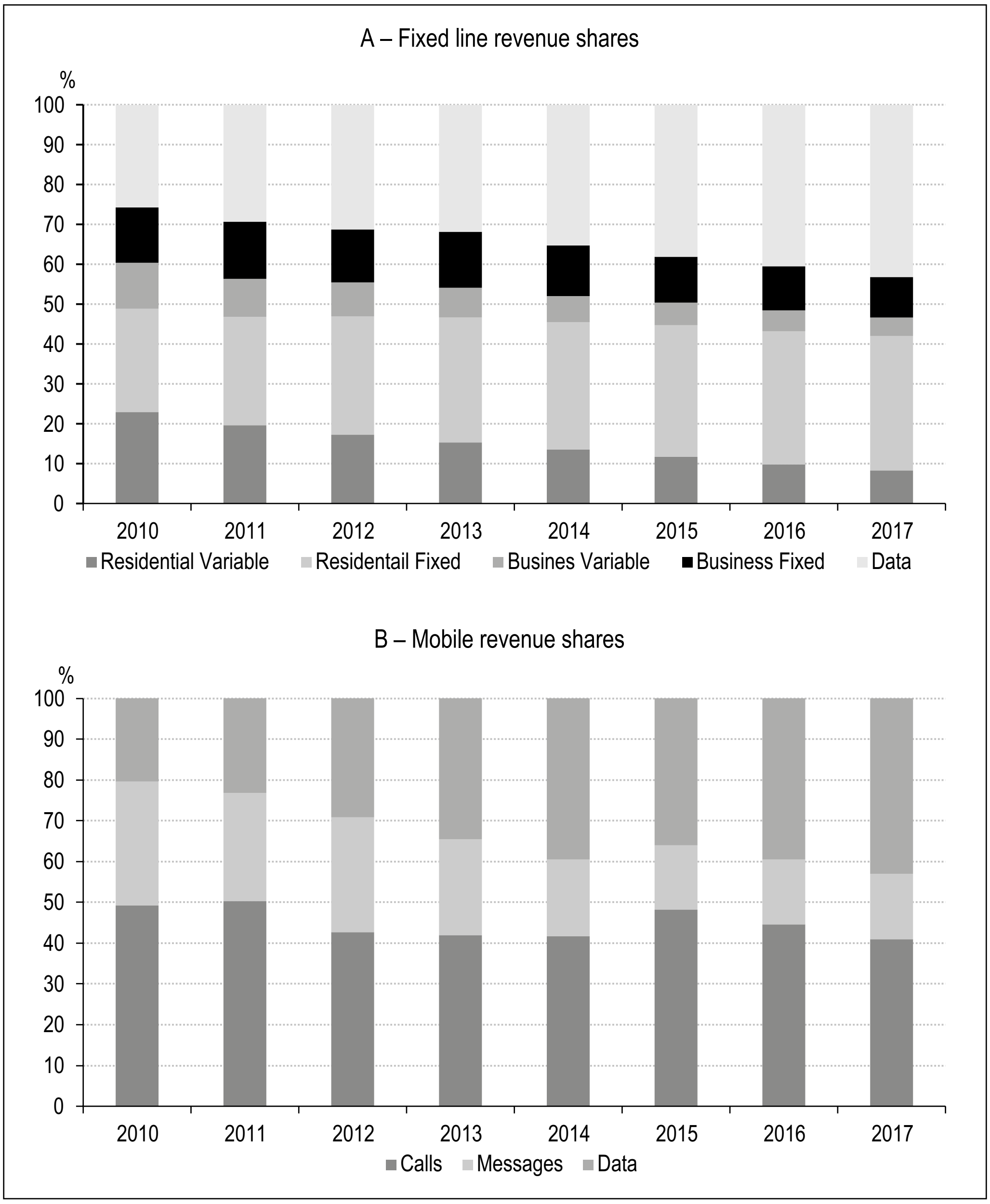
Despite these caveats, it does not seem unreasonable to assume a high and rising degree of substitutability between different forms of telecommunication services as users' behaviour adapts, rather than assuming none – which is the alternative given that we do not have both prices and quantities. In this context, the question is then the degree of homogeneity of voice, text, and data services. Price differentials between these suggest substantial differences from a consumer value perspective. However, from a network perspective, the different services are broadly similar in that they all involve the transportation of data, using the same transmission lines and networks. Having said that, it is clear that this is a transitional phase, both in technology and in consumer behaviour; and in addition that there might be heterogeneous characteristics of voice telephony that some people will continue to buy, such as reliability or coverage.

While the improved SPPI and the data usage approach appear substantially different at present, in future they might converge. The share of total revenue due to data usage increased between 2010 and 2017 for both fixed line and mobile telecommunications (Figure VII). For example, we estimate that broadband data accounted for around 26% of total fixed line revenue in 2010, but by 2017 this had increased to 43%. Similarly, we estimate that mobile data accounted for around 20% of total mobile revenue in 2010, increasing to 43% by 2017, whilst in both mobile and fixed line telecommunications, the share accounted for by voice calls and text messaging decreased. If this trend continues, the revenue and volume weights for the different services could converge. This would mean that the (revenue weighted) improved SPPI and the (volume weighted) data usage approach would converge.

On the face of it, this could favour option A over option B. Since the improved SPPI is chain linked, it could become equivalent to the data usage approach, although this would require further work to establish how to chain link when existing products are converging to become a single, new product. However, until the movements in the two deflators converge, there would continue to be a question of which provides the most unbiased 'true' value of the deflator and hence real volume in the industry.

31. http://www.bbc.co.uk/news/technology-35459812 [Retrieved: 21 July 2017].

Figure VII – **Fixed line and mobile revenue shares (weights for the indices)**



Sources: Authors' calculations.

At the moment, a specific obstacle to convergence is the existence of access charges, now incorporated into bundled prices. While the share of call charges for businesses and residential households decreased from around 35% in 2010 to 13% of total fixed line revenue in 2017, the share of residential and business access charges increased from around 40% to 44% in the same time period (Figure VII). If this trend does not reverse, the two deflators as presently modelled will continue to diverge, as we have no effective way to apportion access charges beyond using the number of subscribers, suggesting the need to incorporate access charges into the data usage model as a cautious way forward.

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*

The constant utility approach that informs price theory sits uncomfortably with the practical use of price indices based on specific products to calculate real output and productivity for the national accounts. In the early debate about hedonic prices, Milton Gilbert observed that if quality adjustments fully reflected utility, resulting in lower price indices, a bikini would represent equivalent output to a voluminous Victorian bathing costume, "And should this trend reach its limit of no costumes at all, we would have to say that swimsuit production had not fallen, even though the industry was out of business.” Zvi Griliches replied that the concept of goods made no sense independent of a utility framework, and one would not say the Victorians were better off because they had bulkier swimsuits (quoted in Stapleford, 2009, p. 322). Both perspectives have their appeal, which suggests that the choice of approach and index might depend on whether they are the answer to a question about production or whether in fact the question does not concern output and productivity at all but is instead an aspect of economic welfare.

Our contribution in this paper has been to show that a sensible improvement to the current method for calculating a price index for telecommunications services, taking account of broadband data services, results in an index that has declined substantially more in recent years than the current index. However, this will still be an upward-biased deflator, as it does not sufficiently take account of increasing consumer utility due to new goods. An alternative unit value methodology inspired by the engineering improvements and price declines for data transmission results in an index that declines dramatically more. This understates the ‘true’ price of the communications services concerned to the extent it does not reflect either consumer attributions of value for service characteristics or attributes such as market structure and price differentiation. It is nevertheless informative about the supply-side efficiency of the services.

Improvements to the current price index for telecommunications services, taking account of broadband data services in both options analysed suggest that the real output of telecommunications services will have been significantly understated in recent years. As these are an intermediate input into other sectors, there will be consequential implications for the sector distribution of output, but potentially also for real GDP. We have focused on telecommunications services but similar considerations may apply to other service sectors experiencing rapid digital innovations. ☐

Link to Online Appendices: https://www.insee.fr/en/statistiques/fichier/4770156/ES-517-518-519_Abdirahman-etal_Online_Appendices.pdf

BIBLIOGRAPHY

Adelman, I. & Griliches, Z. (1961). On An Index of Quality Change. *Journal of the American Statistical Association*, 56(295), 535–548. https://doi.org/10.1080/01621459.1961.10480643

Ahmad, N., Ribarsky, J. & Marshall, R. (2017). Can potential mismeasurement of the digital economy explain the post-crisis slowdown in GDP and productivity growth? *OECD Statistics Working Papers,* 2017/09. https://doi.org/10.1787/a8e751b7-en

Bean, C. (2016). *Independent Review of UK Economic Statistics*. https://www.gov.uk/government/publications/independent-review-of-uk-economic-statistics-final-report

Boskin Commission (1996). *Final Report of the Commission to Study The Consumer Price Index*. Washington D.C: U.S. Government Printing Office. https://www.finance.senate.gov/imo/media/doc/Prt104-72.pdf

Byrne, D. & Corrado, C. (2017). ICT Prices and ICT Services: What do they tell us about Productivity and Technology? *Finance and Economics Discussion Series* 2017-015. Washington: Board of Governors of the Federal Reserve System. https://doi.org/10.17016/FEDS.2017.015r1

Coyle, D. (2017). Do-it-yourself digital: Searching for clues to solve the productivity puzzle. *Economic Statistics Centre of Excellence Discussion Paper*. Number 2017-1. https://www.escoe.ac.uk/wp-content/uploads/2017/02/ESCoE-DP-2017-01.pdf

Diewert, W. (1998). Index Number Issues in the Consumer Price Index. *Journal of Economic Perspectives,* 12(1), 47–58. https://doi.org/10.1257/jep.12.1.47

Ellis, A., Suibhne, N., Saad, D. & Payne, D. (2016). Communication Networks Beyond the Capacity Crunch. *Philosophical Transactions of the Royal Society* A374: 20150191. http://dx.doi.org/10.1098/rsta.2015.0191

Feldstein, M. (2017). Underestimating the Real Growth of GDP, Personal Income, and Productivity. *Journal of Economic Perspectives,* 31(2), 145–164. https://doi.org/10.1257/jep.31.2.145

Greenstein, S. & McDevitt, R. (2010). Evidence of a Modest Price Decline in US Broadband Services. *NBER Working Papers* 16166, National Bureau of Economic Research. https://doi.org/10.3386/w16166

Griliches, Z. & Cockburn, I. (1993). Generics and New Goods in Pharmaceutical Price Indexes. *NBER Working Papers* 4272, National Bureau of Economic Research. https://doi.org/10.3386/w4272

Griliches, Z. (1961). Hedonic Price Indexes for Automobiles: An Econometric Analysis of Quality Change. *The Price Statistics of the Federal Governement*, 173–196. National Bureau of Economic Research. http://www.nber.org/chapters/c6492.pdf

Griliches, Z. (1994). Productivity, R&D, and the Data Constraint. *American Economic Review,* 84(1), 1–23.

Groshen, E., Moyer, B., Aizcorbe, R. & Friedman, D. (2017). How Government Statistics Adjust for Potential Biases from Quality Change and New Goods in an Age of Digital Technologies: A View from the Trenches. *Journal of Economic Perspectives*, 31(2), 187–210. https://doi.org/10.1257/jep.31.2.187

Heys, R. & Awano, G. (2016). Measuring output in the Information Communication and Telecommunications industries, ONS. https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/articles/measuringoutputintheinformationcommunicationandtelecommunicationsindustries/2016

Hausman, J. (1996). The Valuation of New Goods under Perfect and Imperfect Competition. *In:* eds Bresnahan, T., F. & Gordon, R., J., *The Economics of New Goods,* pp. 207–248. NBER. http://www.nber.org/chapters/c6068.pdf

Hausman, J. (2003). Sources of Bias and Solutions to Bias in the Consumer Price Index. *Journal of Economic Perspectives*, 17(1), 23–44. https://doi.org/10.1257/089533003321164930

Hicks, J. (1940). The Valuation of Social Income, *Economica*, 7(26), 105–124. https://doi.org/10.2307/2548691

Nordhaus, W. (1994). Do Real Output and Real Wage Measures Capture Reality? The History of Lighting Suggests Not. *Cowles Foundation Discussion Papers* 1078, Cowles Foundation for Research in Economics.

Nordhaus, W. (2007). Two Centuries of Productivity Growth in Computing. *The Journal of Economic History*, 67(1), 128–159. https://doi.org/10.1017/S0022050707000058

Office for National Statistics (2018). Division level labour productivity estimates: February 2018'. ONS, Available at https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/articles/divisionlevellabourproductivityestimates/january2018#the-effect-of-reallocation-on-output-per-hour-growth

Stapleford, T. (2009). *The Cost of Living in America*. Cambridge University Press. https://doi.org/10.1086/ahr.117.2.565

Williams, B. (2008). A Hedonic Model for Internet Access Service in the Consumer Price Index. *Monthly Labor Review*, 131(7), 33–48. https://www.bls.gov/opub/mlr/2008/article/hedonic-model-for-internet-access-service-in-the-consumer-price-index.htm

APPENDIX 1

BREAKDOWN OF REVENUE AND VOLUME IN THE TELECOMMUNICATIONS INDUSTRY

Table A1-1 – **Revenue breakdown (in £bn)**

	2010	2011	2012	2013	2014	2015	2016	2017
Wholesale services	10.1	8.9	7.8	7.0	6.0	5.9	5.4	5.4
Retail fixed	12.6	12.4	12.4	12.6	13.0	13.5	14.3	14.7
Retail mobile	15.1	15.4	15.8	15.5	15.2	15.2	15.4	15.6
Corporate data services	2.7	2.8	2.7	2.6	2.5	2.5	2.5	2.5
Total	40.5	39.5	38.8	37.7	36.7	37.1	37.6	38.1

Notes: ‘Corporate data services’ comprises web hosting, Ethernet, IP VPN, digital leased line, corporate VoIP and frame relay/ATM services; wholesale mobile comprises wholesale mobile voice, messaging and data services, mobile voice and SMS termination revenue and wholesale inbound roaming revenue (i.e. revenue from overseas operators when their subscribers use UK networks).
Sources: Ofcom Communications Market Reports 2016, 2017 and 2018.

Table A1-2 – **Volume breakdown (in Petabytes)**

	2010	2011	2012	2013	2014	2015	2016	2017
Total Voice	122	116	113	109	105	104	104	97
Texts	0.018	0.021	0.021	0.018	0.015	0.014	0.013	0.011
Fixed Line Broadband	2,352	4,223	6,017	8,208	16,495	28,751	40,234	59,280
Mobile Data	79	99	239	347	542	880	1,270	1,877
Total	2,553	4,438	6,369	8,664	17,142	29,735	41,607	61,254

Notes: Fixed line Broadband and Mobile Data figures are extrapolated for 2010.
Source: Authors’ calculations.

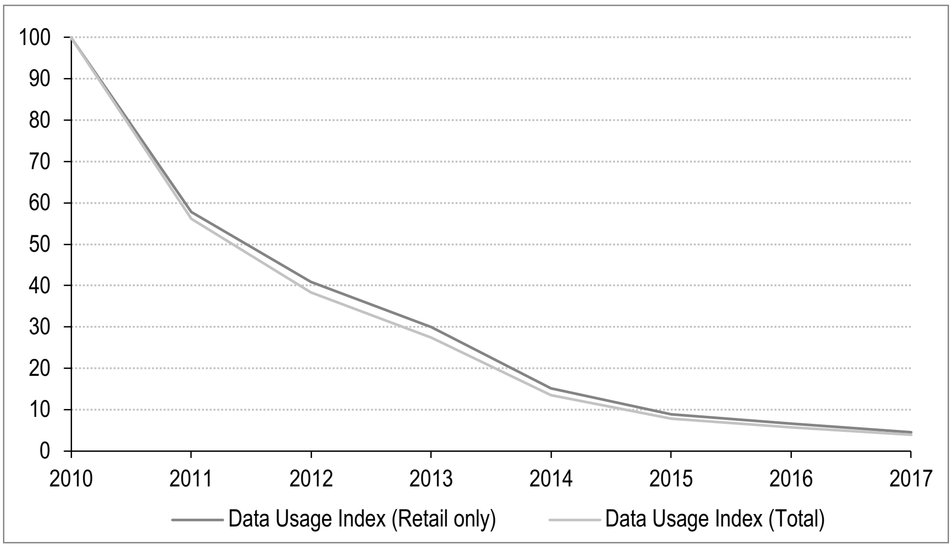
DATA USAGE APPROACH USING RETAIL REVENUES ONLY

Some of the volume data for the data usage approach is limited to retail volumes. Whilst we capture revenue from wholesale and corporate data services, the corresponding volumes are more difficult to identify.

Corporate Data Services for example are often delivered through digital lease lines and the volume of usage is often not measured. Likewise, wholesale volumes, i.e. services that telecoms services providers buy from each other, often have different billing arrangements from the retail market and the volumes are not always readily available.

However, this limitation does not have a substantial impact on our results. When comparing the data usage approach that we use in this paper to an adjusted deflator that only uses retail revenue, we find that there is a minimal difference between the two, with the retail only version of the data usage approach being 1-2.5 index points higher (Figure A2). This is because, while the retail revenues constitute the bulk of telecommunications services revenue, wholesale revenues have been declining at a much faster rate. The inclusion of wholesale and corporate revenues could however bias our results if their corresponding volumes have a significantly different trend from the retail volumes. Further work is required to ascertain these trends and identify suitable datasets for wholesale and corporate data volumes.

Figure A2 – **Data usage approach with different revenue bases**



Note: 2010=100. The Retail index only excludes Wholesale and Corporate Data Services revenue.
Sources: Authors' calculations.