STATISTICS AND DATA DIRECTORATE

Measuring Consumer Inflation in a Digital Economy

SDD WORKING PAPER No. 101

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JT03443610

Measuring Consumer Inflation in a Digital Economy

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Abstract / Résumé

The effect on the household consumption price index from possible sources of error in capturing digital products depends on the weight of the affected products. To calculate upper bounds for this effect, we apply weights based on the average structure of household consumption in OECD countries to a maximum plausible overstatement of price change for each affected or potentially affected product. The products account for about 35% of household expenditure in 2005, declining to 32% in 2015. The upper bound simulation effect on the growth rate of the consumption deflator is somewhat less than –0.6 percentage points in 2015 – large enough to improve the picture of GDP and productivity growth in advanced economies. However, this would not overturn the conclusion that productivity growth has slowed substantially compared over the past decades.

Keywords: Inflation, digitalised economy, productivity, GDP growth, digital replacements, cost of living index

JEL Classification: C43, D11, D60, E01, E31, O47

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L'effet d'une erreur potentielle de mesure de prix des produits numériques sur un indice de prix à la consommation des ménages dépend du poids par lequel les produits affectés entrent dans l'indice. Afin de calculer des limites supérieures de ce type d'effets, nous appliquons les poids moyens de la structure de consommation des ménages dans les pays de l'OCDE à des surestimations maximums de changements de prix pour chaque type de produit qui est affecté ou potentiellement affecté. Ces produits représentent environ 35% des dépenses des ménages en 2005, avec une baisse à 32% en 2015. L'effet maximum simulé sur le taux de variation du déflateur de la consommation est légèrement inférieur à -0.6 points de pourcentage en 2015 – assez large pour améliorer le bilan de croissance du PIB et de la productivité dans les économies avancées. Par contre, ce résultat ne change pas le constat d'un ralentissement substantiel de la croissance de la productivité comparé aux dernières décennies.

Mots-clés : Inflation, économie numérisée, productivité, croissance du PIB, remplacements numériques, indice du coût de la vie

Classification JEL : C43, D11, D60, E01, E31, O47

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1. Introduction and key findings

1.   Whether estimates of GDP still provide a good measure of growth in a digitalised economy has become a topic of debate. Several academic and business economists[2] have suggested that the overlooked output generated by the digital economy, including from products perceived as welfare-enhancing, could be large enough to explain the productivity slowdown that began in the mid-2000s and that growth of material living standards has far outstripped growth as measured by GDP. Possible inadequacies of GDP concepts and methods for measuring the digital economy have even been a focus of articles for instance in *The Economist*[3], *Les Echos*[4] or *Computer Weekly.*[5]

2.   On the other side of the debate, several analyses have found that many of the criticisms of GDP statistics are based on misunderstandings of the conceptual framework and purpose of GDP or on exaggerated perceptions of the likely size of the effects. Ahmad and Schreyer (2016) considered how nominal GDP measurement is affected by digitalisation and concluded that existing GDP concepts remain sound. Syverson (2017) concluded that mismeasurement is unlikely to be explanation for the productivity slowdown. Ahmad, Ribarsky and Reinsdorf (2017) developed alternative price and welfare measures for several items and found relatively small impacts on GDP growth. Byrne, Fernald and Reinsdorf (2016) found that the mismeasurement of US productivity is small compared to the magnitude of the productivity slowdown and did not grow when productivity slowed. Similarly, based on a careful assessment of sources of bias in the measurement of output, prices and productivity, Moulton (2018) found that the overstatement of the consumer price index (CPI) and of the deflator for personal consumption expenditure in the US has fallen, not risen, over the past 20 years.

3.   Welfare changes from new and free digital products are conceptually relevant for understanding consumer inflation both as measured by the CPI and as measured by household consumption deflator. However, in the case of the CPI, some of these welfare changes will have to be captured in a supplementary version of the index that is subject to revision rather than in the official index. The official CPI has some important purposes that require a conservative approach to treating subjective increases in satisfaction from the appearance of truly novel goods as price reductions, and its rapid publication timetable with no revisions limits the extent of quality adjustment that is practical. Also, lags in bringing new goods into the CPI mean that early prices changes for new goods – often downward – tend to be missed. In contrast, the household consumption deflator is well-positioned to capture most of the welfare changes. Welfare gains from the appearance of novel kinds of new goods are conceptually appropriate to include in real consumption growth even if they are not always measurable in practice, and the revision process for the household consumption deflator leaves time to implement any quality adjustment that is appropriate and to consider early price changes of new goods.

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[2] Examples include Brynjolfsson and McAfee (2014), Feldstein (2017) and Bean Review (2016).

[3]   www.economist.com/news/briefing/21697845-gross-domestic-product-gdp-increasingly-poor-measure-prosperity-it-not-even.

[4] Interview with Henri de Castries, Chief Executive AXA Assurance, *Les Echos*, 31 August 2015.

[5]   www.computerweekly.com/opinion/Why-were-measuring-the-digital-economy-in-the-wrong-way.

In this paper, we take a broad look at the possible sources of error in capturing digital products in the price and volume measures for household consumption in national accounts. While all the components of final demand could potentially play a role in mismeasurement of real GDP, household consumption represents the most important part of GDP in OECD countries (somewhat more than 60% on average) and price measures of household consumption are a key gauge of inflation, with a multitude of applications. As summarised in Table 1, the claims that prices – and, by implication, growth – of household consumption are being mis-measured largely revolve around three potential sources of distortion:

1. incomplete adjustment for quality change in products or distribution channels, i.e., the treatment of new, and often improved, varieties of existing digital products; the treatment of new digital products that replace existing non-digital products; and improved variety selection of digital and non-digital products;

2. neglected welfare gains or cost savings from truly novel digital products when these are introduced into price indexes too slowly; and

3. neglected welfare gains from free digital products when there is no imputation of shadow prices.

4.   Although digitalisation clearly poses some genuine measurement challenges, we argue in Section 2 that the welfare effects of truly novel products at their point of introduction (2) and free products (3) are best addressed as part of welfare measurement "beyond GDP" rather than within an official price index. The arguments for this are both conceptual and practical.

5.   We calculate upper-bound impacts on the deflator for household consumption arising from the various effects that are part of (1) – quality change in existing digital products, digital replacement of non-digital products and improved variety selection – by considering each effect in turn. We assume a bias in the price index for each of these categories that we view as the *maximum plausible but not necessarily as the most plausible* and apply an average weight calculated from detailed data sets on the weighting structure of household consumption in OECD countries. Using 2015 weights, the upper bound revision to the growth rate of the household consumption deflator from completely adjusting for quality change in digital products is around -0.4 percentage points per year; the upper bound adjustment from cost savings from new digital products that directly replace a non-digital product is about -0.1 percentage points; and the impact of adjusting for the widespread, but small, welfare effect from improved variety selection is -0.05 percentage points. A correction in the order of over half a percentage point to annual real consumption growth would be significant. Nonetheless more than half of the gap between the post-slowdown and pre-slowdown rates of productivity growth would remain even without considering the corrections for sources of mismeasurement in the pre-slowdown era.

Table 1. Sources of welfare effects

1. Quality change in existing product lines	2. Appearance of truly novel products	3. Appearance and use of free products
(a) Quality change in existing digital products through evolving characteristics embodied in new varieties of digital products (e.g. computers)	e.g. smartphones	e.g. free communication services through apps
(b) Digital replacement of non-digital products (e.g. streaming services replacing CDs)		
(c) Improved variety selection among products, digital and other (e.g. clothing, books)		

Note: This categorisation is for the present analytical purpose only and not necessarily a general classification of how industries are affected by digitalisation.

2. Quality change in existing product lines, truly novel products, and free products

2.1. Quality change in existing product lines

6.   Price indexes for aggregates like household final consumption are built from elementary price indexes that cover a single product, or narrow product stratum. The elementary indexes are compiled from micro data on individual prices of different product varieties and from different sellers.

7.   Constructing a price index for a product would be rather straightforward if the characteristics of the varieties available for purchase never changed. For products with high technological content, however, new models embodying the latest technology often appear as replacements for older models or as new varieties. Accurate measurement of real growth when technology is changing therefore requires product-level price indexes that properly adjust for the quality change implied by changes in characteristics.

8.   The basic approach used to construct elementary price indexes is to select a sample of representative varieties and sellers, and then compare prices of the same varieties and sellers over time. Because like is compared with like, such a matched-model approach produces a pure measure of price change with no risk of distortion from variation in quality. However, products' characteristics tend to evolve over time, with new models appearing in the market and existing ones disappearing. Replacement of items in the sample that disappear from the market ("forced replacements") is one of the challenges faced by price statisticians.

9.   There are four possibilities for handling a forced replacement: direct comparison, quality-adjusted comparison, linking with price changes of the continuing items used to impute the change in the missing price, and linking with overlapping prices.[6] A direct comparison of the prices of the original and replacement models is appropriate when the replacement model has similar characteristics and can be assumed to represent the same quality level. In this case, the replacement model is treated as a continuation of the original model and the entire difference between the last observed price of the original model and the first observed price of the replacement model is identified as inflation. Inflation will be overstated if the replacement model is actually of significantly higher quality.

10.   Second, the missing price may be imputed by adjusting the price of the replacement model for the quality change implied by the differences in characteristics from the original model. In effect, the quality adjustment makes it possible to treat the replacement item as a virtual continuation of the original model. The accuracy of the quality adjustment will determine whether the resulting price index suffers from an upward or downward bias.

11.   Third, if the changes in characteristics are too extensive to estimate the value of the quality change given the resources available, the index must be linked. Often collection of the replacement model's price begins only after the original model has exited. In this case, the item is left out of the price comparison in the period of the exit, the initial price of the replacement model being set aside until it can be compared to a second price of the same

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[6] For a full discussion of methods and consequences see Triplett (2006, pp. 22-23), the *International Consumer Price Index Manual* (ILO et al., 2004), and Diewert, Fox and Schreyer (2017a).

model. Leaving the item out of the index amounts to assuming that the true, quality-adjusted price of the item at hand has moved at the same rhythm as the average price change of the other items in the product line. This is, in fact, an implicit way of making a quality adjustment based on the difference between the (inflation-adjusted) final price of the exiting model and the initial price of the replacement model. Whether the method generates an upward or a downward bias in the price index depends on whether the implicit quality adjustment is less than or more than the true quality difference.

12.   A less common case is when the price of the replacement model begins to be collected while the original model is still available. Overlapping prices make it possible to include the exiting model in the price comparison for the link month. The implicit assumption in a link with overlapping prices is that the price difference between the exiting and replacement models is entirely due to quality. The direction of the bias would again depend on whether the implicit quality adjustment understates or overstates the true quality change associated with the model replacement.

13.   Whether reliance on these methods for handling changes in the sample over- or understates inflation is unclear a-priori and cannot necessarily be judged on the observation of rising or falling quality of a product alone. However, many authors have examined the overall treatment of variety entry and exit, typically finding an overstatement of inflation due to under-adjustment for quality improvements, or because the entering varieties that are linked into the index have high reservation prices. For example, Aghion et al. (2017) argue that using price changes of continuing products to approximate price changes of new varieties (method 3) leads to an over-estimation of inflation.

14.   Forced replacements are not the only way new models and new products enter an elementary index. Planned item replacements sometimes occur as part of sample refreshments. Sample refreshments help to keep the sample representative and are also occasions for bringing in *new products and product varieties*. In a sample refreshment, a newly selected sample is "linked in", and the old sample is "linked out". The first period the new sample comes in is also the last period for which the old sample is used. Any quality difference between them that is not fully reflected in their relative prices will not be captured, as the linking procedure assumes that the market is always in a state of perfect equilibrium in which apparent price dispersion really stems from quality differences. In the case of a product undergoing significant quality improvement, the failure to adjust for the higher average quality of the items in the sample being linked in may cause the index to overstate the product's price change (Moulton and Moses, 1997).

15.   An important question concerns the frequency of sample refreshment and how quickly new products are brought into the price index. Late introduction can lead to price declines early in the life cycle being missed, a problem that is particularly relevant for digital products. Goolsbee and Klenow (2018) constructed a digital price index as an alternative to the CPI for products sold online. They emulate the basic CPI matched-model methodology, where price changes are assessed as the weighted average of those models whose prices can be observed in consecutive comparison periods (method 3 above). The Adobe data set used by Goolsbee and Klenow (2018) allows for a much speedier and finer identification of entering and exiting products than standard CPI sampling procedures and Goolsbee and Klenow (2018) find a significantly lower rate of inflation in their digital price index (-1.6% per year for 2014-17) than in the corresponding categories of the CPI (-0.3%). Thus, the rapid inclusion of new products and the timely exclusion of exiting products appear to be an important factor in matched-model price indexes.

16.   Sample refreshments are also an occasion for bringing new outlets into the sample for an elementary index. Reinsdorf (1993) investigated sample refreshments to update the outlet sample to reflect current shopping patterns for food and gasoline. The outlets in the newly selected samples had systematically lower prices, but the linking procedure prevented the index from reflecting consumers' savings from substitution to lower-priced outlets, a problem known as outlet substitution bias. Digitalisation has again raised the question of outlet substitution bias as consumers have substituted online shopping for shopping in physical stores. The evidence on whether prices are lower online is mixed. On the one hand, retailers with both an online and offline presence tend to offer the same price both places (Cavallo and Rigobon, 2016). But on the other hand, Cavallo (2017) finds that Amazon's online prices are, on average, 5% lower than offline prices. If a product is 5% cheaper online, gains in the online market share at the rate of 2 percentage points per year would cause an overstatement of 0.1 percentage points in the growth rate of the product's price index.

17.   Much less investigated, but not to be overlooked, is whether quality change of some digital products may systematically be ***overstated***. Examples of quality declines that are not captured in price measures include programmed obsolescence of certain consumer products, after-sales services that are purely machine-based, or the requirement to purchase new models of mobile phones and computers in the absence of backwards compatibility of new software with older hardware. There is also the case of digitally-enabled services where the consumer must supply a labor input as part of the transaction; for instance, self-checkout in stores or self-check in on airports. Whether these constitute quality improvements or declines is a matter of debate and personal perception, but it is clear that these changes to self-service are not accounted for in official price indexes.

18.   To summarise, quality adjustment of replacements for existing products within a sample, and of new products coming in during sample refreshments, may miss some quality change. The overlooked quality change and cost of living effects could be in either direction, but for digital products benefitting from new technology, insufficient capture of quality improvements is more likely. The consequences of possible biases can be significantly attenuated by bringing new products into the sample early in their life through frequent sample updates.

2.2. Truly novel products

19.   In addition to the new products and varieties that replace existing products and varieties, truly novel products are occasionally invented. Such goods and services are recognizable by the entirely new characteristics and service flows that they offer, or by the entirely new way – and typically much more efficient way – by which service flows are generated; historical examples are the introduction of electricity, automobiles or air conditioning ("tectonic shifts", in the terminology of Nordhaus, 1996). These entirely new products (or associated services) are too different from any existing product to estimate the quality adjustment needed for a comparison to an existing product. They must therefore enter as an "added line" in the structure of product strata of the top-level index. This entails adjusting the weights to make room for the new elementary index and linking the new elementary index into the top-level index as part of a general updating of the item strata definitions and weights. The delay in bringing them into the index until the next update of the basket structure and weights poses a risk of bias because, depending on the pricing strategy and market conditions, novel products may initially exhibit distinctive price change behavior. The most common pattern is for prices of truly novel products to decline

quickly at first, so the bias is upward. A key issue with entirely new products is then, again, avoiding a delay in getting them into the price index.

20.   There is another, more basic issue with new goods. Their standard treatment in price index compilation links them into the index basket in a way that prevents any immediate effect on the index. But from a conceptual point of view, consumer welfare in the period prior to introduction of the new good is the same as if a price existed that was just high enough to drive demand for that good to zero (Hicks, 1940). The difference between this unobserved "reservation price" and the observed price at the moment of entry is not captured in traditional price indexes. From a welfare perspective, the standard treatment misses part of the effect of new products on consumers' living standards.[7]

21.   There is no agreed methodology for imputing reservation prices of new goods, and, in practice, no attempts have been made to include them in official price indexes.[8] There is thus a question of whether the unmeasured consumer welfare effects generated by the appearance of truly new digital products are significant. The answer is likely to be yes, but even rather large absolute welfare effects do not automatically entail large corresponding adjustments to aggregate deflators, and aggregate real growth. The reason is the small weight that typically attaches to recently introduced products.

2.3. Free products

22.   Many empirical studies of the value of new and free products have found that important gains for consumers are insufficiently picked up by consumption price indexes. For instance, Brynjolfsson and Oh investigate welfare gains from the Internet and conclude:

> Our key findings are as follows: the average incremental welfare gain from the Internet between the years 2002 and 2011 is about $38 billion per year [for the United States]. Of that amount, we estimate that about $25 billion accounts for the consumer surplus from the free digital services on the Internet. This corresponds to about 0.19% of annual GDP. In contrast, the welfare estimates are significantly lower when we estimate it in a traditional way, relying only on money-based expenditures. The best estimate of the annual incremental welfare gain is only about $2.7 billion when we do not consider the value of time. This is about 7% of the estimate derived from our preferred model. (Brynjolfsson and Oh, 2012)

23.   In addition, Varian (2011) puts a USD 65 billion figure on the value to US consumers of time savings from Google's search engine, and Bughin (2011) estimates the consumer surplus from the Internet to be about USD 64 billion based on a survey where users stated their preferences. However, multiplying the USD 17 530 median willingness-to-accept to forego access to Internet search engines found by Brynjolfsson, Gannamaneni, and Eggers (2018) by the number of adult Internet users in the US would imply a surplus of almost USD 3.8 trillion, or 30% of personal consumption expenditures in the US national accounts.

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[7] For reasons of symmetry, a reservation price should also be imputed for disappearing products. In the disappearing product case, the effect on the index of the imputation would be upward.

[8] For a discussion of the COGI approach, see National Research Council (2002). Methodologies reservation prices here put forward by Hausman (1996), Diewert and Feenstra (2017), de Haan and Krsinich (2014).

24.   Often, the digital goods examined in these studies are available free of charge to consumers. This increases consumer choice and consumer welfare. The question is whether, and if so, how and when, free goods should be reflected in consumption price indexes.

25.   From a cost-of-living perspective, with all observed prices unchanged but new kinds of free digital services becoming available, the price index should decline to reflect the rise in living standards. This would occur by introducing free products into the price index and assigning shadow prices to them. Consider a situation where households' utility depends on a vector of products $q \equiv [q_1, q_2, \ldots q_N]$ with a positive price $p \equiv [p_1, p_2, \ldots p_N]$ and a set of "environmental variables" $z \equiv [z_1, z_2, \ldots z_M]$ for which there is no market price. This could be environmental variables in the sense of the term such as clean air or free digital products. Consumer utility is then given by $u = f(q,z)$[9] and the corresponding *variable or conditional cost function* (McFadden 1978) is:

$$C(u,p,z) = \min_q(p \cdot q : f(q,z) \geqslant u). \qquad (1)$$

26. $C(u,p,z)$ thus indicates the minimum expenditure consumers incur on market products q given p and z. It can be shown that C is linearly homogenous and non-decreasing in p and non-increasing in z. A cost of living price index (Konüs, 1939) conditioned on environmental variables z is then given by:

$$P(u,p^1,p^0,z) = C(u,p^1,z)/C(u,p^0,z). \qquad (2)$$

By holding z constant, equation (2) reflects the standard approach of defining the COLI as conditional on a fixed level of the environmental variables and considering only priced goods in constructing price indexes that estimate the COLI. Although it is generally necessary to hold the environmental variables constant – a point emphasised by the National Research Council (2002) panel – researchers have considered models in which the free products supplied by digital platforms are treated as an environmental variable that could change. To compute a price index that estimates equation (2) from just market prices and quantities, the usual assumption is thus that the "free" goods z remain unchanged. This is, however, a strong assumption in an environment of rapidly emerging free digital products. Another possibility is to follow Diewert (2000), who shows that under the assumption that the effects of the changes in z on the consumption basket are monotonic, the changes in z can be accommodated using a superlative price index number formula,[10] in the sense that the superlative index corresponds to some average level of z between the periods of comparison.

27.   While the assumption of monotonic effects is a less stringent requirement than an unchanged z, it still makes the COLI *conditional on environmental variables*, including the free products, and therefore does not reflect cost-of-living decreases due to the introduction of free digital products. What would a price index that makes explicit allowance for such free products look like? Diewert and Fox (2016) demonstrate that the inclusion of free products into the consumers' cost minimisation leads to a cost function of

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[9] The utility function u(q,z) is continuous and quasi-concave, and increasing in q and z.

[10] Diewert (1976) defined a price index (quantity index) to be superlative if it is exact for a unit cost function capable of providing a second-order differential approximation to an arbitrary twice-differentiable linearly homogeneous function. The Fisher index number formula used in the U.S. national accounts is an example of a superlative form.

the form C(u,p,w), where w represents shadow prices for each free product. Under cost minimisation, it holds that $w \equiv -\nabla z \, c(u,p,z)$, i.e., shadow prices correspond to the marginal change in total costs to consumers due to the use of one additional unit of a free product. As Diewert and Fox (2016, p.11) point out: "[these are]…the appropriate prices to use when valuing the services of free goods in order to construct cost of living indexes or measures of money metric utility change". Given shadow prices and quantities of free products, these would be introduced into the price index number formula just like any market product.

28.   Unfortunately, there are two issues here. First, where would shadow prices to value the change in z come from? Another, more fundamental question is whether shadow prices should be introduced in a consumption price index in the first place. We consider these questions in turn.

29.   If the free products are available in unlimited quantities, under the assumptions of cost minimisation, consumption will expand to the point where $\nabla z \, c(u,p,z) = 0$, making the post-entry shadow price equal to 0. However, the pre-entry reservation price is not zero, and the consumer surplus from the change in z from its pre-entry quantity of zero to the quantity consumed when it is freely available equals the area under the demand curve from the reservation price down to the post-entry shadow price of zero. Quality improvements in existing free products also generate consumer surplus.

30.   Concerning the measurement of the consumer surplus, one option is assessing the consumer's willingness to accept a payment to give up free products via surveys or indirect measurement tools. One such indirect tool has been tried: Brynjolfsson, Eggers and Gannamaneni (2018) designed a sequence of discrete choice experiments to elicit US consumers' willingness-to-accept to forego access to various kinds of free Internet services. As mentioned above, the results imply large valuations for some of these free services.

31.   Another option is to expand the model of consumer behavior to include the consumer's time budget as a second constraint alongside the normal monetary budget constraint. The opportunity cost of the time involved would then act to limit the consumption of free products. After all, the value of consumers' time constitutes the main impediment to increasing marginal use of free Internet and smartphone app products. The prices of the ICT equipment and services required to access the free products are, of course, relevant for the decision of whether or not to consume the package of services, but once those prices have been paid, the only constraint on marginal consumption of more services comes from the time budget (though quality improvements may increase real consumption with time held constant). Of course, given the need to pay for the services out of the time budget, the marginal willingness-to-pay from the monetary budget is zero, but the total consumer surplus from the appearance of the new free products and their subsequent quality improvements should have some relationship to the time budget expenditures.

32.   A third consideration is that many "free" digital products are not, in fact free. Even ignoring the cost of the devices and telecommunication services needed to access these products, they generally involve an implicit payment through the consumer's acceptance of advertisements while using the free product (an app, for instance), or her acceptance to share personal data with the provider of free product. However, neither the valuation of time, nor the valuation of implicit payments in exchange for viewing the free product, is

straightforward in practice, and these approaches also raise theoretical issues.[11] While extremely valuable as a research project, the implementation of shadow prices in an official price index may raise questions of transparency, reproducibility, and, ultimately, credibility of the price index.

33. Concerning the more basic question of whether these free products should be part of the COLI in the first place, much depends on the purpose of measurement. If the purpose is to measure production, it would be difficult to justify including "free" digital products in the COLI while at the same time excluding other non-market products that also command a shadow price in terms of the value of time: child care, care of the elderly, or gardening, to name just a few examples. In contrast to the time spent using free digital products, which may fall under leisure, households' nonmarket work clearly involves production. But if the purpose is simply to measure welfare itself, the exclusion of important environmental variables such as life expectancy would be difficult to justify. The steady rise of life expectancy in many parts of the world has also raised consumer welfare for a given market consumption bundle (Deaton, 2013). Rising life expectancy has a massive welfare effect not captured in the consumption of market products. Full inclusion of non-market products and environmental variables would fundamentally change the character of the consumption deflator.

34. A COLI also might be used for CPI purposes. For some of these purposes, the answer to the question "Would the CPI be a better tool for policymaking if the welfare from free goods and services were captured?" seems to be "no". For example, monetary policy targets to maintain the purchasing power of money should consider the prices of things that money is used to buy rather than a rate of inflation that reflects imputations for free products produced by households or for environmental variables. Also, pensions and other payments are often escalated by the CPI. Downward adjustments to the CPI for increases in welfare from truly novel inventions and improvements to the external environment would leave the recipients of the escalated payments no better off than if these gains had never happened, in effect excluding them from sharing in the benefits of progress. There is also a conceptual consideration: it is impossible to include every aspect of the external environment in the COLI calculations, but including a selective set of free goods or other aspects of the external environment in an ad hoc way could leave the index with an unclear or confusing interpretation.

35. Nevertheless, measures of shadow values of free products, the associated full income including the time budget endowment are needed for purposes of a full understanding of growth and productivity in the digital era regardless of their treatment in the consumption deflator and CPI. Their inclusion in an extended COLI would be an important step towards broader measures of consumer welfare.

In summary, quality change in existing products, the emergence of new products, and free goods are not new issues, but the digital economy, with its fast pace of innovation, has brought them to the fore. Rapid change in available products and in product characteristics has increased the potential for price measurement shortcomings. Indeed, there is evidence of understatement of some price changes due to insufficient quality adjustment and long

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[11] See for example Nakamura and Soloveichik (2015) for valuing free media or Diewert, Fox and Schreyer (2017b) for a discussion of the conceptual and econometric issues in valuing consumer time for non-market activities and leisure. A simpler version with cross-country comparisons of full consumption (monetary consumption expenditure plus value of time) and the derivation of an associated consumer price index can be found in Schreyer and Diewert (2014).

lags in bringing new products into the index. The failure of the official price and volume indexes to capture the welfare gains at the moment of entry of truly novel new products, and the welfare effects of free products is well noted but practical – and, to some extent, conceptual – considerations support these omissions. Nevertheless, broader welfare effects are important to measure. This can be done as part of statistics "Beyond GDP", as will be discussed below in Section 4.

3. What's the potential impact?

36.   The next task is assessing the potential bias in consumption deflators that may arise in conjunction with digital products. The discussion in Section 2 has identified some reasons why current price index compilation practices may not reflect the welfare effects from quality change and from novel and free products:

    a. Less-than-complete quality adjustment when new varieties of existing products and new products with similar functions to an existing product enter the sample, and lags in bringing in them into the index;

    b. Lags in bringing truly novel new products into the price index, and no imputation of a reservation price; and

    c. No imputation of shadow prices for free products.

37.   Section 2 also argued that some of the omitted welfare effects are not appropriate to include in official indexes of consumption prices for reasons of transparency and credibility. In what follows, we shall therefore focus on issue a) because there is a consensus that quality change should be reflected in price index practice; indeed, this is recommended in international guidelines for price and volume measures. Therefore, no quantification will be provided for the absence of reservation prices for truly novel products and for shadow prices of free services, or more generally for effects of environmental variables. These are, however, good candidates for broader welfare measures.

38.   It is sometimes forgotten that even significant biases in individual product strata only affect the aggregate picture in proportion to their weight. This oversight leads to what could be called "anecdotal fallacy", whereby the bias in the price change of one particular product is extrapolated to the index as a whole. To avoid this fallacy, we consider the question: "if prices of the affected products were corrected for the bias that could potentially be present, what would be the implications for the aggregate price index?"

39.   Our approach to quantifying the potential inadequacies in quality adjustment techniques proceeds by examining "pessimistic" scenarios that assume that the official procedures largely overlook the quality changes in digital products (some of the relevant evidence has been summarised in Section 2). The main tool for our analysis is a detailed set of 145 household consumption expenditure weights from the *OECD Purchasing Power Parities database* covering 34 OECD countries in recent years. Expenditure weights are not affected by the price measurement biases mentioned above, but they provide the link to translate measurement errors in price changes of individual products to aggregate price index. Our illustration of the plausible upper bound of the effects will be based on averages of the weights for each OECD member as of 2005 and 2015.

40.   We proceed in two steps. First, we classify all expenditure items into three groups based on the degree to which the price measures are likely to be affected by difficulties in measuring digital products:

    1. *Affected products:* products that clearly fall under the label of "digital" and whose price measures are most prone to difficulties due to digitalisation, such as information technology goods or communication services;

2. ***Unaffected products:*** products whose prices are very unlikely to suffer from a measurement problem associated with the digital economy, such as food, tobacco or housing;

3. ***Possibly affected products:*** products that are in-between, such as cars or other consumer durables where digital features may have gone unnoticed in price measurement.

41.   The second step is to further break down the categories 1) Affected and 3) Possibly Affected by the type of effect identified earlier (Table 1). This breakdown is judgmental and ad-hoc and in no way constitutes an official categorisation of digital economy products. But we consider the three categories as fit-for-use for the problem at hand of determining an upper bound of the plausible range for the mismeasurement of the deflator for household consumption. Three kinds of effects were distinguished under the category Quality Adjustment in Table 1:

*   ***Quality adjustments in deflators of existing digital products:*** for digital products where ***advances in technology*** are causing rapid quality improvement, it is plausible that official price indexes under-adjust for quality change. Affected products include telephone equipment, telephone services, and computers and software. A full list is shown in the top four rows of Table A 1 in Annex A.

*   Byrne and Corrado (2015, 2017a, 2017b) construct alternative price indexes for communication equipment, computer and peripheral equipment and computer software. They base their estimates on the existing literature on high-tech price change and on their own price indexes for detailed products of the relevant US industries which they construct using a broad variety of statistical and industry sources. For communications equipment, the authors' price index declines at close to 10% per year between 2010-15, or 8 percentage points faster than the official price index (Byrne and Corrado 2017b, Table 2). For computers and peripheral equipment, the authors incorporate indicators of price-performance trends in constructing their price index and find a downward difference from the official BEA index of 11 percentage points per year between 2010-15 (Byrne and Corrado, 2017b, Table 5). For software, Byrne and Corrado (2017b) construct an index using a refined version of the basic BEA approach (e.g., more granular structure for software products and more differentiated input cost measure). Overall, the alternative price index for ICT investment shows a rate of price change of -8% between 2004 and 2015, 5.9 percentage points below the official US price index.

*   Greenstein and McDevitt (2010) quality adjust the broadband price index but find that this makes only a small difference to the official measures (2 percentage points per year). The quality characteristics in their hedonic approach are upload and download speed.

*   Abdirahman et al. (2017) construct alternative communication services deflators for the UK with an economic perspective in one case and an engineering perspective in another case. At the core of both approaches are unit value measures based on the price per unit of data transported. The economic approach treats data transportation associated with different services (text, voice, etc.) as different products, the engineering approach treats them as a single product, assuming perfect substitutability of a unit of data transported between any type of usage. Given the exponential growth in the number of bytes transported, the resulting indexes decline rather steeply – about 8% annually in real terms between 2010 and

2015 for the economic approach and around 35% per year in real terms for the engineering approach. Both figures are considerably larger in absolute terms than the 0.4% per year rate of decline of the official price index. The authors are very explicit about the fact that their engineering approach overstates the true fall in prices, which they suggest lies somewhere between the two estimates. The use of unit values as the basis for price indexes, especially when computed over heterogeneous categories of products, is, indeed, not recommended by international statistical standards.

- Byrne and Corrado (2017c) develop a measure of household consumption of digital services that "[…] reflects the intensity with which households use their ICT equipment and software, along with the intensity with which consumers use purchased digital services, internet access, cellular and cable TV services as well as cloud services (via gaming or other entertainment services, and computing or storage)". Intensity of the consumer use of ICT capital services is captured in terms of Petabytes of Internet Protocol Traffic. Byrne and Corrado (2017c) develop their argument as part of an extension of the production boundary where households deliver large volumes of own-account digital services (akin to owner occupied housing) that gives rise to a new digital access service price index, essentially a use-adjusted price index of subscription costs. This use-adjusted adjusted price index declines by 11% per year, as compared to the official price index that is essentially unchanged (Byrne and Corrado, 2017c, Table 4, p.18).[12]

- Goolsbee and Klenow (2018) use online prices to estimate alternative indexes for several product categories in the US CPI. For information technology products, they derive a measure of annual inflation of -6.1% for the years 2014-17. This compares with a decline in the corresponding CPI category of -3.7%, suggesting an upward bias of 2.4 percentage points per year.

- The Boskin Commission (Boskin et al., 1996) estimated the missing quality adjustment for consumer durables in the US CPI in 1995 at around 0.6 percentage points per year. Bils (2009) found twice this estimate. Moulton (2018) updated some of the estimates and assessed the quality adjustment bias for the US personal consumption expenditure deflator at 0.34 percentage points per year.

42.   In light of the evidence above, we assume a *5-percentage point per year over-estimation of the price change* in the affected categories of *ICT equipment and communication services*. As communication services are also a product group where digital replacement occurs (see below) we add another *5 percentage points of possible upward bias*. Bearing in mind that most countries have procedures in place to capture at least some of the quality change, and that the large declines in experimental communication services prices reflect debatable adjustments in proportion to the volume of data transported, this figure is clearly an upper bound.

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[12] Byrne and Corrado's (2017c) approach raises a more general question, namely whether price indexes should reflect the actual intensity of use of a product by consumers (provided it can easily be measured). With rising importance of flat subscription fees for digital services, this is particularly relevant for the ICT area: while there is no doubt that changes in capacity or speed constitute quality criteria that should be reflected in price indexes, it is less clear whether the intensity of use of such capacity should make its way into the price index – this is not common practice for other products (car prices are not adjusted for average mileage). Nevertheless, adjustments for use intensity have been made for capital service flows, which is indeed the setting used by Byrne and Corrado (2017c).

43.   In addition, we assume a ***2-percentage point per year over-estimation of the price change*** in the possibly-affected categories (next four rows of Table A 1). Motor vehicles are the largest of possibly-affected categories, and for them the existing procedures appear likely to capture most of the quality change. The composition of the other possibly-affected categories gives a relatively low weight to digital items with quality changes.

Digital replacements: Some digital products provide a free or inexpensive replacement for a more expensive item that used to be the only option available. For example, in some places Uber services are cheaper than a taxi. Or digital cameras made photo processing services unnecessary, only to become largely unnecessary themselves as smartphones replaced separate digital cameras in many use cases. Official price indexes only partially capture the cost-of-living declines from lower-cost or free digital replacements. For the item categories that have been extensively replaced by digital alternatives (shown in the top five rows of Table A 2), we assume that the cost of living index declines by 5% per year relative to a conventional price index over the ten years from 2005 to 2015. In some cases, digital replacements require some increases in spending elsewhere – one must first purchase a smartphone, or at least a computer and internet access services to benefit from the replacement. Also, there is an upper limit to this kind of bias, because once everyone has switched to the digital replacement, there are no further gains to be made. For categories in the possibly-affected group (in which items not replaced by a digital alternative predominate) we assume a ***1 percentage point decline in the cost of living.***

44.   ***Access and information enabling better selection of varieties:*** E-commerce has expanded consumers' access to varieties, and online sources of information have reduced search costs for finding the best match for one's individual needs and tastes. Brynjolfsson, Hu and Smith (2003) provide some evidence on the welfare gains from increased access to variety for books, finding that "obscure" titles accessible only through online bookstores accounted for 2.35% of total book sales. With a plausible value of 4 for the elasticity of substitution, the Feenstra (1994) formula for the effect of new varieties on a cost of living index implies a decline of about 0.8 percentage points from newly accessible books (Byrne, Fernald and Reinsdorf, 2017). If the expansion in the selection of books available online took four years, the average annual impact would be 0.2 percentage points. Second, better information that allows better selection of varieties affects almost any kind of differentiated product consumed by households. These welfare gains are part of Hulten and Nakamura's (2017) concept of "output-saving technological change" (which they capture in a complementary welfare measured that they call EGDP). Table A 3 identifies the product categories that are relevant for the effects of online information or for both effects and finds that they had a budget share of almost 17% in 2005. In absence of much direct evidence, we will assume ***0.3-percentage points per year*** over-estimation of the relevant prices as the upper bound for the variety effects. At least for recent years, this is probably too high as the gains from variety access and better information are concentrated in the early days of the Internet: once the variety set is already large, additional varieties have little marginal impact on welfare, and information is also subject to decreasing returns.

45.   Table 2 shows the corrections to a household consumption price index whose purpose is assumed to be to estimate a broad cost-of-living index that accounts for welfare gains from quality change, digital replacements, and expanded and improved selection of varieties. The first observation here is that the categories of affected and potentially affected products account for 31.5% of consumer expenditure in 2015 (unweighted average across 34 OECD countries). In other words, over two-thirds of household consumption expenditure is unlikely to be subject to a measurement bias linked to the digital economy. The second observation is for each kind of effect (quality adjustment, digital replacement,

better choice of varieties) the expenditure share has declined between 2005 and 2015. This may reflect declining relative prices of the products (or transition to free products), possibly coupled with an elasticity of substitution below unity. Whatever the precise cause, the consequence is that the sensitivity of aggregate inflation to measurement errors in prices of digital products has declined.

46.   In terms of the simulated effects of possible measurement errors, the upper bound correction to the index's growth rate for overlooked quality change is -0.41 percentage point in 2015, largely driven by the assumed 10% overestimation of the deflator for telecommunication services. The potentially unmeasured savings from digital replacements declines from about -0.18 percentage points based on 2005 weights to -0.11 percentage points based on the 2015 weights. Our upper bound correction for improved variety selection is -0.05 percentage point. Combining all the effects, we end up with an upper bound for the potential mismeasurement of digital products of -0.68 percentage point in 2005 and -0.57 percentage point in 2015. A correction in the order of half a percentage point to recent annual real consumption growth would not be insignificant. Nonetheless more than half of the gap between the post-slowdown and pre-slowdown rates of productivity growth would remain. And some upward corrections for sources of mismeasurement are also likely be needed in the pre-slowdown era.

Table 2. Corrections to growth rate of the consumption deflator if the goal is to estimate a broad cost-of-living index

	Assumed measurement error in growth rate of prices (percentage points per year)	2005 weight (unweighted average across 34 OECD countries - percent)	2015 weight (unweighted average across 34 OECD countries - (percent)	Correction to growth rate of the consumption deflator, 2005 weights (percentage points)	Correction to growth rate of the consumption deflator, 2015 weights (percentage points)
Significant potential for under adjustment for quality change ("*affected product*") except communication services	5	0.79	0.99	-0.04	-0.05
Significant potential for under adjustment for quality change ("*affected products*") - communication services	10	2.71	2.38	-0.27	-0.24
Some potential for under adjustment for quality change ("*potentially affected products*")	2	7.38	6.16	-0.15	-0.12
Significant replacement by alternative product from the digital economy ("*affected products*")	5	2.36	0.98	-0.12	-0.05
Some replacement by alternative product from the digital economy ("*potentially affected products*")	1	5.79	6.06	-0.06	-0.06
Significant potential for improved variety selection ("*affected and potentially affected products*")	0.3	16.83	15.55	-0.05	-0.05
All potential effects on aggregate deflator		**35.86**	**32.12**	**-0.68**	**-0.57**

Source: Authors' calculations based on the *OECD Purchasing Power Parities database*, https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm.

4. Two unorthodox points and "Beyond GDP"

4.1. Hulten Paradox

47.   Hulten (1996) – in a discussion of the estimates of the price of light and potential measurement biases in long-term real income in Nordhaus (1996) – concluded that our ancestors would have suffered from an implausibly low standard of living had there been a long-term upward bias in price measures of the magnitude suggested by Nordhaus. Here, we transpose Hulten's thought experiment to a shorter and more recent period, but its basic spirit is unchanged.

48.   The household consumption deflator in the US national accounts rose by 3.3% per year between 1959 and 2016. As shown in Table 15.3, in 1959, median household income was USD 5 400 at then-current prices. In today's prices, and given the 3.3% annual price increase, this 1959 income translates into USD 34 636/household. Compared with today's income of USD 59 039 at current 2016 prices, there has thus been a 70% rise of real income over the past six decades.

49.   Now assume that the annual growth rate of the household consumption deflator was biased upwards by 1 percentage point, so that "true" inflation was only 2.3% per year. This yields a 1959 income of USD 9 588 in 2016 prices, implying a tripling of material living standards over the six decades. And the 1959 median income, expressed in 2016 prices, would only be USD 11 077 if a 2 percentage points upward bias is assumed, implying a *four-fold* rise in living standards in less than a lifetime (59039/11077=4.33). This seems implausibly high.

50.   There is another telling comparison: By today's poverty threshold, the 1959 *median* income expressed in 2016 prices would lie just above the poverty line (1% bias scenario), or markedly below it in the 2% bias scenario. To be sure, none of this is hard evidence, and the Hulten Paradox rests on a hypothetical scenario. Nevertheless, it puts some plausibility limits on any *persistent and significant* bias in overall inflation measurement.[13]

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[13] A persistent bias may be less probable than a bias for shorter periods of time, as statisticians usually take measures to address known issues. For instance, hedonic quality adjustment methods for computers were introduced in the US as early as 1986, and their use spread to other countries following the Boskin Commission.

**Table 3. Median income per household under alternative inflation assumptions (United States)**

Year	Price basis	USD
2016	2016	59 039
1959	1959	5 400
1959	2016 with official PCE deflator	34 636
1959	2016 prices with assumed bias 1%	19 588
1960	2016 prices with assumed bias 2%	11 077
	Poverty threshold	
2016	2016, for HH size 2	15 569
2016	2016, for HH size 3	19 105
	Real income change 2016/1959	70.5%
	Real income change 2016/1959, 1% bias	201.4%
	Real income change 2016/1959, 2% bias	433.0%

Source: US Bureau of Economic Analysis and US Census Bureau.

4.2. Perceived inflation

51.   Central Banks, the European Commission, and other institutions have systematically monitored peoples' perceptions and expectations about consumer inflation. Expected inflation is obviously an important piece of information for central banks, given the role of expectations as a transmission channel of monetary policy. Yet, for the question at hand – whether there is a systematic upward bias in aggregate consumer inflation due to mismeasured prices of digital products – it is less the expectation of inflation than the gap between perceived inflation and measured inflation that is of interest. We take the European data, recently analysed by Arioli et al. (2017) as representative of a finding that seems to hold broadly: despite differences between countries and over time, the level of perceived inflation is nearly always above the level of inflation as measured by consumer price indexes (Figure 1).

Figure 1. EU consumers' inflation perceptions and expectations
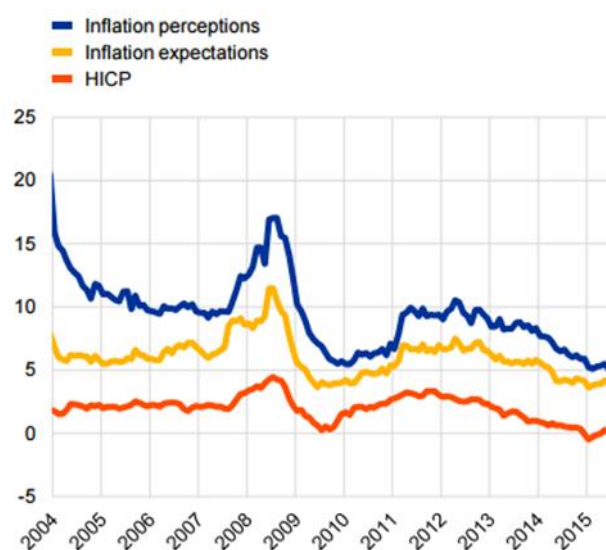
Note: HICP = harmonised consumer price index in the European Union.
Source: Chart 4a in Arioli et al. (2017).

52.   There are explanations for such a discrepancy: incorrect weighting of price changes by consumers (small, frequently purchased items tend to get disproportionate weight in perceptions), other psychological reasons (price rises are better remembered than price drops) and, often-quoted, the fact that consumers do not account for quality change, whereas statisticians do. Thus, the USD 500 cost of a new laptop today is registered as no price change over the USD 500 laptop purchased three years ago, even if the new model offers vastly improved performance and weighs less than the old model. Another factor that may play out here is inequality. Households at different points of the income distribution may face different inflation rates and the survey results may summarise the experience of individual households differently from the aggregate consumer price index.

53.   The implications of these observations for the question at hand are of a qualitative nature. First, we simply note that consumers tend to believe that their own cost of living has risen by *more* than is shown by aggregate official price indexes. Thus, if the official deflator is upward biased because it overlooks the welfare gains from digital products, correcting for such a bias will widen the gap between perceived and measured inflation. Perceived, rather than official, inflation is what drives many elements of consumer behavior, so a wider gap may pose some issues both from a policy perspective and from a perspective of credibility of statistics.

54.   Second, an observation of a more philosophical nature is that our theory of quality adjustment of consumer prices is firmly rooted in the picture of a utility-maximising, well-informed representative consumer. The measurement of welfare gains that come with new products, free products and digitally-enabled products relies on the same consumer theory. However, as the discussion of perceived inflation shows, consumers do not appear to make rational and well-informed judgements on the rate of inflation. Are consumers increasingly well off even if this is contrary to their own judgement? Or are consumers indeed rational but equipped with a more elaborate intuitive perception of their net welfare gains than the economic models underlying price measurement? For instance, people might intuitively

factor in certain disadvantages that come with digital products (24/7 connectedness, extended working hours, loss of privacy, cybersecurity incidents, etc.), or might attribute less of a quality improvement to their new computer than statisticians do because the higher-performing computer is simply necessary to accommodate more-demanding software that essentially performs the same tasks.

55.   Any answer to this question is beyond the scope of the present paper, but a potentially wide gap between perceived and measured inflation is an issue that cannot be ignored as a matter of credibility and perceived quality of official statistics.

4.3. "Beyond GDP"

56.   The welfare gains from digital products are, undoubtedly, large. But from a statistical perspective, the question is, how many of these welfare effects should be packed into our core macro-economic measures – consumption, real income, and GDP? Or should these welfare effects instead be identified in data designed to gauge quality of life "Beyond GDP"? One consideration is whether the macroeconomic measures would remain fit for key macro-economic policymaking purposes. While a consensus on this criterion will likely remain elusive, it can at least help with drawing the boundaries. For instance, a consumer price index that partly depends on shadow prices is unlikely to pass the criterion of being fit for interest rate targeting and may be hard to accept as a reference for escalating pensions and other payments. Reproducibility of results, objectivity, and transparency of methods are important criteria, along with purely practical considerations. For example, even if we set aside the conceptual problems, developing an estimate of a reservation price for a truly novel product is a major research project that would be impossible to conduct within the normal timeliness and resource constraints of statistical offices. At the same time, there are good reasons to go further in incorporating quality adjustments to the greatest extent possible, and in capturing new products early in their life cycle.

57.   Another promising avenue is to attempt to systematically capture important dimensions of welfare and well-being in data sets that complement macro-economic aggregates. On the one hand, some elements of this work are conceptually tied to the *System of National Accounts* and provide additional depth to existing data, such as introducing distributional information into measures of household consumption or real income (Jorgenson and Schreyer, 2017; Zwijnenburg, Bournot and Giovannelli, 2017). In the area of price statistics, an analogous complement would be an investigation of whether the implied price changes from new goods disproportionally affect certain income groups. This sort of analysis could also be relevant for free services from digital platforms, and platform-enabled services and rentals.

58.   On the other hand, the "Beyond GDP" agenda clearly requires indicators on well-being and welfare that cover broader dimensions of life, economic and otherwise. The agenda has been set by Stiglitz, Sen and Fitoussi (2009) and work undertaken at national and international levels (for instance OECD, 2017). Current and more specific research in the context of the OECD's *Going Digital* Strategy (www.oecd.org/going-digital/) concerns the link between digitalisation and well-being. It aims at assessing the effects of digitalisation across major dimensions of the quality of life. These are highly relevant welfare effects, but none of them will be reflected in consumer price indexes, nor should they be.

5. Conclusion

59.   We divide the potential sources of distortion in the price index for household consumption into three categories: (1) neglected welfare gains from new and free goods, and from improved matching of variety characteristics with consumer tastes; (2) the cost savings from new free or low-cost digital products that directly replace existing non-digital products; and (3) incomplete adjustment for changes in the quality of products embodying digital technology. We argue that welfare effects that require estimation of reservation prices or shadow values are relevant for a complementary welfare account but less suitable for the measurement in official GDP and consumer price statistics. With the help of detailed data on the weighting structure of household consumption in OECD countries, we calibrate upper bounds for the impact on the deflator for household consumption of incorporating the remaining welfare gains (though their inclusion in GDP is also debatable), the cost savings, and complete adjustments for quality change. We find that the products concerned account for about 35% of household expenditure in 2005, declining to 32% in 2015. Total plausible (but not necessarily most plausible) upper bound effects on the growth rate of the consumption deflator amount to somewhat less than -0.6 percentage points in 2015, down from just under -0.7 in 2005. The implied upper bound adjustment to real household consumption growth would result in a more optimistic picture of growth and productivity change, but would not overturn the conclusion that productivity has slowed substantially compared to the its performance in the early 2000s and late 1990s, particularly if the adjustments to the productivity growth also needed in the earlier years are also considered.

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ANNEX A. Weights in household consumption basket of product categories potentially affected by measurement errors in deflators

Table A 1. Weights in household consumption of products with potentially overlooked quality improvements

Unweighted averages across 34 OECD countries

Product category	Potential source of measurement error	2005 weight (per mil)	2015 weight (per mil)
Telecommunication equipment	Overlooked quality change	2.1	4.1
Telecommunication services	Overlooked quality change and replacement by digital alternatives	27.1	23.8
Information processing equipment and software	Overlooked quality change	4.5	4.9
Photographic/cinematographic equipment	Overlooked quality change and replacement by the smartphone	1.3	0.9
Major and small HH appliances	Possibly/partially affected by overlooked quality change	11.2	9.5
Equipment for the reception and recording of sound and vision	Possibly/partially affected by overlooked quality change and replacement by online services	7.0	5.3
Motor vehicles and parts	Possibly/partially affected by overlooked quality change	50.8	42.6
Games, toys and hobbies	Possibly/partially affected by overlooked quality change	4.8	4.2
Total		**108.8**	**95.3**

Note: Thirty-three countries used in 2005 because of missing values.
Source: Authors' calculations based on the *OECD Purchasing Power Parities database*,
https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm.

Table A 2. Weights in household final consumption of products subject to replacement by digital alternatives[1]

Unweighted averages across 34 OECD countries

Product category	Digital alternative providing replacement	2005 weight (per mil)	2015 weight (per mil)
Passenger transport, taxi or hired car with driver	Platform-enabled ridesharing	3.1	3.0
Pre-recorded recording media	Digital media, downloads and streaming	2.2	1.2
Unrecorded recording media	Digital downloads and streaming	1.1	0.4
Newspapers and periodicals	Online media	6.8	4.5
Category containing film developing and printing	Digital cameras and storage media	10.4	0.7
Books[2]	e-books and used books bought online	4.7	3.3
Passenger transport by air[2]	Internet enables households to be their own travel agent	6.8	8.9
Package holidays[2]	Digital replacement for travel agents	8.1	9.3
Accommodation services[2]	Sharing economy replacement for hotels	14.1	15.6
Services for maintenance and repair of dwelling[2]	YouTube enables do-it-yourself repairs	4.6	4.1
Postal services[2]	Online billing paying (and quality improvement from online tracking of packages)	1.1	0.9
Jewellery, clocks and watches[2]	Smartphone replaces watches and clocks	4.3	3.9
FISIM[2]	Better rates of online banks and peer-to-peer lenders	14.2	14.6
Total		**81.5**	**70.4**

Notes: [1] The adjustment for quality change in communication services and photographic instruments and equipment for reception and recording of sound and vision is assumed to include effect of digital replacements, so they are omitted here.
[2] Replacement by digital alternative limited in scope.
Source: Authors' calculations based on the *OECD Purchasing Power Parities database*,
https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm.

Table A 3. Weights in consumption of products where digitalisation may have enabled improved variety selection

Unweighted averages across 34 OECD countries

Product category	2005 weight (per mil)	2015 weight (per mil)
Cloth and clothing	51.6	44.5
Furniture, floor coverings, HH textiles, and repairs thereof	25.0	19.8
Games, toys and hobbies	4.8	4.2
Newspapers and periodicals	6.8	4.5
Books	4.7	3.3
Other durable and nondurable HH goods	18.3	16.9
Restaurants, cafes and dancing establishments	38.4	42.6
Accommodation services	14.1	15.6
Services for maintenance and repair of dwelling	4.6	4.1
Total	**168.3**	**155.5**

Source: Authors' calculations based on the *OECD Purchasing Power Parities database*,
https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm.