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*Keywords*: National Accounts, Digital services, welfare, official statistics, economic measurement, modern economy, capital, time use

*JEL classification:* A13, I31, E01, E21, E22

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# GDP and Welfare: Empirical Estimates of a Spectrum of Opportunity

**Robert Bucknall, Stephen Christie, Richard Heys, and Cliodhna Taylor[1]**

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In Heys, Martin, and Mkandawire (2019), a conceptual process was laid out to utilise existing economic statistics to tell a more complete story about economic welfare than can be delivered solely by Gross Domestic Product (GDP) alone. This paper takes this theoretical work and delivers i) further thoughts on the method and how it complies with current statistical frameworks, ii) a summary of the data which already exists in the UK for immediate use, iii) methodological steps which have been taken to fill data gaps and derive estimates, iv) empirical estimates of the different measures developed in the 'Spectrum' as a proof of concept, and v) areas of further development identified in developing these estimates, both empirically and conceptually.

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## 1. Introduction

Many policymakers globally are unsatisfied with the present state of statistical information about the economy and the society, in particular the effective treatment by many of Gross Domestic Product (GDP) as the sole indicator of welfare. Despite having attractive qualities in terms of international comparability, regularity and frequency of publication, accuracy in terms of measuring the volume of output produced in the market, and the ability to be broken down into its component parts, GDP is widely recognised as a poor indicator of a society's standard of living because it is partial and focused primarily on those areas traditionally considered part of the market. GDP does not directly account for many activities conducted outside the market, such as unpaid work in the home or community, leisure, and the value that society may place on services provided 'free at the point of delivery' and therefore does not portray a complete picture of household consumption. It equally tells us little about the distribution of income or the impact of increases in variety and technology. GDP also measures the outcomes of public services poorly and as a result, excludes (or is a poor measure of) environmental quality and levels of health and education. These are just a few examples of goods and services which affect people's welfare, whether or not they are bought and sold in the market and whose social value is not fully captured in their price even when they are transacted in the market.

Attempting to address this challenge, Heys, Martin, and Mkandawire (2019) (hereafter HMM19) outlined initial proposals for a spectrum of economic and social measures to meet a range of user needs, which in a sufficiently advanced statistical system, could be built from pre-existing datasources. GDP is itself defined on the basis of a number of boundary definitions which can be considered, to a degree, artificial – seemingly based on the dual principles of a) minimising (not eliminating) imputations where market values are not available, and b) setting up frameworks and standards, based on the broadest common denominator, to enable international comparisons to be made[2]. HMM19 noted that if one is willing to move past these constraints there is little to prevent the utilisation of common national accounts methods to wider data to develop new metrics with a wider scope which may better meet policy needs.

In other words, whilst GDP will continue to be needed for monetary and fiscal policy (and to maintain international consistency), by utilising existing data new measures of welfare on the same monetisable, exchange value basis as the national accounts (i.e. excluding consumer surplus and externalities[3]) could be readily produced. This paper delivers a first set of empirical estimates of these measures first proposed in HMM19. It is hoped these will help policy-makers and other users better evaluate policies and economic events by making explicit the trade-offs inherent in economic activity, and providing a better barometer for long-run standard of living increases. These could then be reviewed alongside proposals and

[2] The two most important of which are the inclusion of the public sector, recognising the scope of this varies from country to country, and the imputed rental from owner-occupied housing where excluding this would negatively impact the GDP of countries with small residential housing markets relative to those with large rental sectors.

[3] Noting that when we come to consider the flow of benefits received from natural assets, such as carbon sequestration these could be considered as externalities because of the absence of a market. In this work we look to capture this because of the general trend in the measurement and policy communities to recognise that the environmental impact of economic and other human activity is an essential component of understanding the economy.

experimental work from many other authors (for example, Stiglitz et al, 2009) in terms of whether they provide users with sufficient informational content to be of value.

This paper provides an update on progress towards developing this new set of measures, in both current price (CP) and real chained linked volume terms (CVMs) in line with existing national accounts aggregates. The paper is structured into five components: i) a brief recap of the issues with GDP, alongside the proposed Spectrum framework from HMM19, ii) a summary of the data which already exists in the UK for immediate use in the Spectrum framework, as well as methodological steps which have been taken to fill data gaps and derive estimates, iii) empirical estimates of the different measures developed in the Spectrum framework, and iv) areas of further development identified, both empirically and conceptually.

## 2. The Spectrum Framework – further reflections

As has been recognised by many authors (see HMM19 for a short review), a number of factors that contribute to welfare are not bought and sold, and lie outside of the limited non-market sector covered in GDP – and therefore GDP is a limited tool for measuring standards of living. To understand the limitations of using GDP as a measure of welfare it is useful to highlight the things that GDP does not cover:

- Under the 2008 System of National Accounts (SNA08) (United Nations 2008), the production boundary for GDP is generally defined as "*activity carried out under the control and responsibility of an institutional unit that uses inputs of labour, capital, and goods and services to produce outputs of goods or services. There must be an institutional unit that assumes responsibility for the process of production and owns any resulting goods or knowledge-capturing products or is entitled to be paid, or otherwise compensated, for the change-effecting or margin services provided*." Production of services undertaken by households for their own use is, therefore, not included.

  For example, hiring a gardener or cleaner is part of GDP, but doing these tasks yourself is not part of GDP. Since these activities contribute to living standards, any indicator of welfare would be incomplete without them. It is a peculiarity that shifts in the nature of the producer between the household and the market could affect GDP – while in theory the same production is being undertaken. This clearly has the ability to significantly distort our picture both of welfare and economic growth.[4]

- Being *Gross* Domestic Product, GDP does not deduct production which is required to replace depreciated/consumed capital. This captures a key criticism of GDP – that, for example, following a natural disaster, the process of rebuilding destroyed buildings could perversely mean the disaster leads to an *increase* in GDP. In less disastrous times, it is an essential feature of economies that a certain portion of production must go towards replacing depreciated capital, but obviously this replacement only maintains existing productive capacity and hence standards of living. From a welfare perspective, this production cannot be seen as *improving* welfare. For this reason, *net*

[4] GDP does not account for leisure time, which has varied significantly over time and between countries, and is something that people are likely to put a high value on when considering their standard of living, but which we also do not address.

measures of production – which subtract depreciation of capital – are preferable for measuring economic welfare.

- GDP includes what is spent on environmental protection, healthcare, and education, but it does not include the flow of benefits we all receive from environmental cleanliness, improved life expectancy, and the future returns to human capital investment. GDP includes the cost of buying pollution-control equipment, but it does not address the flow of benefits we receive or lose if air and water are cleaner or dirtier. GDP includes spending on medical care, but it does not address whether life expectancy or infant mortality have risen or fallen. Similarly, GDP counts spending on education, but the national accounts do not address directly how much of the population is educated, or the change in the value of the stock of human capital.

- GDP does not consider the range of varieties available or which technology and products are available. No matter how much money somebody had 50 years ago, one could not have purchased an iPad or various medicines[5], items which can be assumed to have improved their standard of living if available at the time. The economy is becoming increasingly digital and has therefore demanded new insights into the role of technology in the economy. It is argued that a growing fraction of innovation is not being measured in GDP because sections of the sharing economy, free digital services, benefits of new products, and volunteer-produced content and software are omitted. To the extent that this is true, the wedge between welfare and GDP may be widening.

  However, it is also important to note that certain economic and cultural developments over the past several decades may have narrowed the gap between GDP and welfare. For example, to the extent that more women have joined the labour force since the 1950s – with an accompanying shift from domestic labour to waged labour – the production of a substantial portion of the population (and its resulting benefits for welfare) has shifted from outside to inside the GDP production boundary.

- When there are large changes in the income distribution, GDP per capita may not provide an accurate assessment of the situation in which many people find themselves. If inequality increases enough relative to the increase in average GDP per capita, many people can be worse off even though average income is increasing.

- It is not always intuitively the case that a rise in GDP should be classed as a welfare improvement. If a state purchases weapons and ammunition, and then uses them on their own people it is hard to see this as a welfare improvement, even if the increased output of weapons manufacturers would increase GDP.

It has, therefore, long been clear that GDP is an inadequate metric to gauge welfare over time particularly in its environmental, and social dimensions. It has also been speculated that there appears to be an increasing gap between the information contained in aggregate GDP data and the factors which contribute towards people's well-being (Stiglitz et al, 2009). This is the impetus to this work exploring how to develop a statistical system that complements measures of market activity by measures centred on people's well-being and by measures that

[5] Recognising that there are other products, such as cordless vacuum cleaners which would have had an impossibly high reservation price.

capture sustainability, which is informing the current debate around improvements / revisions to the System of National Accounts (see, for example Van Rompaey (2020)). Such a system must be plural (composed of multiple measures), because no single measure can summarise something as complex as the wellbeing of the members of society.

Our Spectrum framework aims to contribute to this debate by demonstrating a practical empirical application of what can already be achieved to produce, as far as possible, objective, monetised measures of economic welfare in a country which has well-developed National Accounts, a Household satellite Account produced in line with SNA08, and a set of Environmental Accounts produced in line with the System of Environmental Economic Accounts. This series of measures better able to make a contribution to the wider plural measures of welfare and well-being.

This paper remains only a relatively small contribution to ONS's, and the international statistical community's, broader work on this topic – it does not deal with distributional issues, or comprehensively tackle the interlinkages between the Stiglitz's three pillars of the Economy, Environment, and Society. It brings together many pieces of work which have previously been treated in isolation and adds value by combining them within a framework consistent with those already in place for National Accounts.

The authors consider the estimates contained within may provide a more useful contribution to the baskets of indicators used to measure well-being than any of these pieces of work in isolation, and may perhaps be more useful for welfare analysis than GDP by itself.

***Spectrum of measures***

Different users will inevitably have different priorities and requirements for a measure of welfare - one statistic is unlikely to satisfy everyone's needs. Therefore, HMM19 proposed a practical spectrum of methodologically consistent measures, stretching from traditional measures of economic production, to multi-dimensional measures of wider human well-being.

Little of this Spectrum framework is necessarily new, but it is instead an attempt to deliver an operable set of measures using pre-existing data within a consistent logical framework. The overarching principles of which are:

- *The best should not be the enemy of the good.*

  The work of better measuring, and thereby improving, the welfare of society has always been urgent – the effect of the Covid-19 pandemic, as well as the societal and economic recovery from it has only made this clearer. GDP is a poor measure of welfare, but as a single-measure index it is often preferred for decision making over other more complex presentations. GDP has many strengths – frequency of publication, objectivity of weights – which make it dominant in many user's eyes, even if it is not completely conceptually aligned with the item of interest. The Spectrum framework recognises that production of more suitable metrics alone is insufficient – there are plenty of alternatives to GDP already. Any new metric has to be better conceptually aligned and equally timely, objective etc if it aspires to deliver user value. And while there can and should be continuous development of welfare measures into the future, there is also a need for us to construct the best *possible* measures now.

The Spectrum framework therefore attempts to produce aggregate, single-measure indices which are superior to GDP[6] *for assessing changes in welfare* through capturing more relevant factors on a consistent basis, whilst retaining the defining power of GDP – uniting and measuring value within an holistic framework. Whilst the measures described in this paper equally fail to tackle questions of distribution, the longer-term aim would be to incorporate this aspect to provide distributional assessments of welfare.

- *There are merits to both production-based approaches – such as GDP – and approaches which attempt to measure more directly the various dimensions of well-being.*

  Furthermore, both approaches may be complementary when assessing the performance of an economy. To the extent that some facets of well-being are (directly and indirectly) influenced by processes of production, understanding those processes is useful towards understanding well-being. Similarly, to the extent that productive activity is aimed towards improving well-being, comparing the two helps one evaluate the effectiveness of production.

- *Through the accounting identity of production with income (as well as expenditure), we can interpret changes in production as changes in income, or more generally as changes in resources, and thus as a change in welfare.*

  The Spectrum framework assumes the flows of benefits which are identified outside of GDP can be assumed to either be equivalent to income or close enough to be considered proxies for income. Adding all sources of income together presents a method to estimate what might be considered an ‘economic’ definition of welfare – welfare measured by the resources made available from productive activities, whether these are the result of human activity or not which is superior to GDP. This excludes, for example, cultural phenomena which may be related to well-being – such as the general level of trust in a society. The Spectrum framework also works in the same way as the national accounts in that gross measures of output are not the only estimate produced – any measure which is net of the impact of depreciation and depletion will again be superior if trying to measure welfare.

- *When referring to “welfare” in this article, we are using it in this narrow sense – as “economic” welfare. We reserve “well-being” for a more expansive and general definition.*

  To clarify the relationship between these concepts, it should be noted that, to the extent that “welfare” is based on resources, it is therefore based to a certain extent on the capabilities a society has to increase its well-being. Welfare in this sense is neutral toward the outcome of the use of resources – whether they do in fact raise life satisfaction, decrease anxiety, etc. or not. This is to be contrasted with more direct measures of well-being, for example those that directly ask about life satisfaction or anxiety. Economic welfare in this context therefore is the aggregate sum of goods and services which can be received, either from human or non-human activity, paid or unpaid. Taking each of these outputs as having an equivalent

[6] With GDP remaining the pre-eminent measure of economic production for international comparison.

income which can be calculated or imputed, one can take the measures developed as attempting to provide a universalist estimate of total income of households in the UK over the time period studied.

- *Market prices are the most objective way to compare, and so aggregate, production of goods and services – and remain so when creating a singular measure of (production-based) welfare.*

  Any 'single measure' approach to calculating an economic value of welfare needs to be weighted to bring contributing factors together into a meaningful common metric. In many ways, how to weight the importance for welfare of food against leisure services, vaccines against illicit drugs, or solar panels against oil is a highly subjective and an ever-changing question. However, to the extent that these *can* be directly compared in an objective fashion, in a way which involves the input of society as a whole, market prices – or their closest substitutes - offer one such method for comparison. This only works as a solution when focussing solely on economic welfare and does not offer a solution of how to compare economic welfare with environmental and societal measures of well-being. The production of an aggregate measure of overall well-being, including societal and environmental factors, would necessitate substantially more subjective intervention on behalf of statistical compilers, and so, alongside many other authors and statistics producers we consider such aggregates remain undesirable, both because their subjective nature could be used to distort debate, but also because even if subjective weights could be agreed on within one society, they may not apply to another making comparisons potentially invalid.

  However, there are ways to improve upon this market price approach for economic welfare purposes – for example by introducing a 'democratic' approach to weighting where possible – while still maintaining the key advantages of market prices. Alongside its relative objectivity, another obvious advantage of market prices are their common use in the data available, as well as their ease of understanding.

  This means that all production-based welfare measures from the Spectrum exclude consumer surplus[7], as well as most externalities (i.e. only economic flows which are conducted under mutual consent are included) – save those generated from natural capital assets as a key aspect of this work is to 'internalise' the impact of humanity on the environment within our understanding of economic welfare.

- *One cannot 'cherry-pick': Creating a broader measure of production must be done through a consistent expansion of the production and asset boundaries.*

  For example, there is a strong discussion in de Haan, Obst & van de Ven (2020) for accounting for depletion/degradation of environmental assets ('natural capital') in the National Accounts. Whilst the authors agree with the necessity to address our understanding on how the environment and the economy interact, as argued in this paper the national accounts are an integrated set of stocks and flows measures and if one adds one flow relating to a particular type of asset or type of transaction then one should look to add all other stocks and flows relating to that asset or transaction.

[7] In the case of the household satellite account, where the producer is the consumer, the distinction between consumer surplus (which is excluded from National Accounting frameworks) and producer surplus (which, as this money is included in the transaction, is included in National Accounting frameworks) is conceptually a little more difficult to determine.

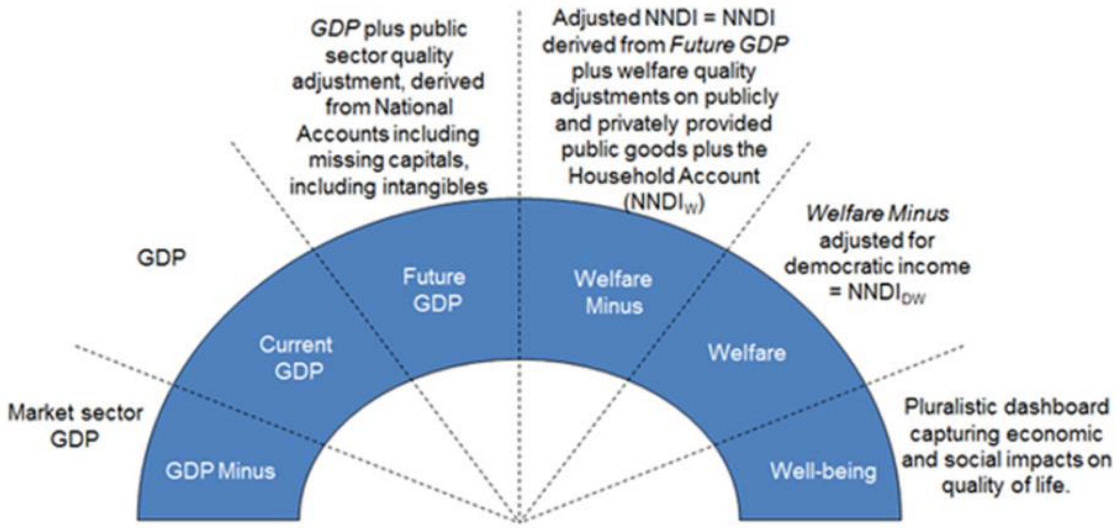
The way Spectrum looks to do this consistently is to implement measures which move both the production boundary and the asset boundary simultaneously so that as we bring more assets / services into scope, both the flow of benefits from these assets and the depletion / depreciation are added to the measure together.

- *'Standing on the shoulders of giants'*[8] *is key to moving this agenda forward.*

  The paper assumes that the work to create the national accounts and satellite accounts are significant monuments to human endeavour and worth relying on, particularly as the guiding tenets of the framework under which these are delivered is that they are designed to complement one another and to clearly link together. There is no conceptual reason why one cannot combine monetised values from the different accounts that we can see, and if such a reason can be identified one assumes it would be a priority for being addressed as part of the updates of these manuals.

The following figure is a diagrammatic representation of how a national statistical institute could, through bringing together existing statistical estimates, all of which are stated in money terms, provide better / more inclusive measures of economic welfare which could offer improvement upon GDP. In our estimates we undertake to address this on both nominal and volumes terms. How we tackle the key questions of deflation are considered in later sections and annexes.

**Figure 1: The Heys, Martin and Mkandawire spectrum from traditional measures of economic production to multi-dimensional measures of wider economic welfare**




The different elements of this spectrum are described below:

- **GDP Minus** is represented here by market sector GVA, i.e. Gross Value Added excluding General (i.e. Central and Local) Government, Non-Profit Institutions Serving Households, and imputed rent.

[8] A quote from Isaac Newton when asked how he had been able to move the horizon of scientific achievement so far.

- **Current GDP** relates to GDP as it is currently measured based on the European System of Accounts, 2010 (ESA10) which is itself based on the SNA08. However, as has been discussed in section 2, GDP is a measure still centred on market production and not well-being. To get to an improved measure of welfare, several adjustments will be necessary as described and discussed below.

- **Future GDP** is GDP plus:

  - Quality adjustment to non-market public services.

  - The flow of benefits / shadow income from services produced by the household for own-use as recorded in the household satellite account.

  - The flow of benefits / income received from natural capitals, as measured in the Natural Capital Accounts[9].

  - Investment in additional Intellectual Property Products (IPPs, i.e. additional 'intangible capitals').

  This therefore is a wider measure of the income derived from the aggregate of these services than just GDP, but is still a gross measure, failing to capture the impact of depreciation or depletion of various types of asset. For ease we refer to this measure as **augmented Gross Domestic Income (GDI+)** in our following presentation.

  For simplicity, this can be thought of as GDP including adjustments for improved/expanded measures of: intangible investment, production of services at home for own-use, public services, and environmental asset benefits.

- **Welfare Minus** denotes the most sophisticated *plutocratic* aggregate measure of welfare possible using currently available data, and its measure will be referred to as **augmented Net National Disposable Income** (**NNDI+**). This takes the concept of GDI+ and converts it to a net measure in line with the methodological steps used to convert GDP to NNDI by taking account of depreciation and depletion through the consumption of capitals, covering productive capital, including a wider set of IPPs ('intangible capitals'), household durables, and environmental assets. Importantly we have not included any adjustment for human 'capital', as discussed below. This measure is classified as 'Welfare Minus' because it fails to take account of issues relating to the distribution of income which would be required to deliver a fuller measure of welfare. Building on Aitken and Weale (2018a), Welfare Minus would be described as a '*plutocratic'* measure, as it reflects the average household, not the average of all households.

- **Welfare** is a '*democratic'* measure which would attempt to adjust NNDI+ to take income distribution into account (Aitken and Weale 2018a), delivering the growth rates of different percentiles of the economy. Life expectancy, schooling and access to digital technology all clearly correlate with the income distribution, and therefore one can assume that welfare adjusted measures of income will behave similarly. In

[9] These accounts are produced against the System of Environmental Economic Accounting (SEEA, UN(2012)), and use exchange values.

this work we have used pre-existing aggregate data so have been unable to attempt to produce this metric. However, further work utilising microdata should enable the production of this measure – at which point this would present the most sophisticated measure of economic *welfare* possible (given current data restrictions) within the Spectrum framework.

- **Well-being** would incorporate quality of life, which is a broader concept than economic production and living standards. It includes the full range of factors that influences what we value in living, reaching beyond its material side. Well-being includes intangible aspects that cannot be traded in a market. This paper again does not attempt to deliver this component of the spectrum, in the main because existing 'dashboards', such as the UN's Sustainable Development Goals (United Nations (2015)) are clearly superior in terms of their spread and depth. The authors propose that NNDI+, particularly if a democratic measure could be developed could naturally fit into such a 'dashboard' and provide a powerful context for the other measures.

This paper does not yet deliver the full 'Welfare' measure, nor Well-Being - although ONS already publishes a dashboard of Well-being measures (ONS 2018c) and as such we do not propose to explore this area further. Welfare as defined above in particular requires a microdata driven approach so separate elements of the index can be appropriately deflated, which is beyond the scope of this paper.

***Benefits and Uses of Spectrum***

The benefits of Spectrum fall into two broad categories: the use of its expanded measures of economic welfare, and the use of its framework for comparing production and asset boundaries.

When evaluating the health of the UK economy, many policy makers, citizens, researchers, and others turn to GDP due to its expansive definition of what constitutes 'the economy'. It includes both the market and non-market 'sectors'; it includes the private, public, and third sector; it includes wages, profits, and other sources of income; it includes manufacturing, services, construction, and agriculture; it includes consumer spending, government spending, investment, and trade. However, for many users it is not expansive enough, and may be falling further short as time and patterns of economic behaviour change over time, such as either the expansion of own-account production in the household or a greater weight being placed on the environment in lieu of unbridled market gains.

Policy makers, citizens, and researchers may – for example – wish to turn to a measure of economic welfare to evaluate when 'the economy' has recovered from the Covid-19 downturn – a reduction in the use and rental of office accommodation may, for example, appear to decrease activity in the real estate sector within GDP, as might railway and road transport. However, this may have been substituted for by increased DIY undertaken in the home and the benefits of reduced carbon emissions. Restaurant meals may have been substituted for by home-cooked meals. Purchased formal childcare may have been substituted for by informal familial care. The societal impacts of Covid-19 may cause a permanent shift in productive activity – encouraging, for example, an upwards step change in the undertaking of household production of services. To evaluate the overall impact on economic welfare, one would wish to take into account these societal shifts and use a measure which is more expansive than GDP, such as NNDI+. Similarly, if the UK economy shifts over the next years and decades away from production reliant on the degradation of environmental assets, statistics users may wish to have a broader measure of economic welfare which would fully reflect the positive benefit of reducing this degradation.

More technical users will benefit from the framework which Spectrum provides in building up to NNDI+. So, for example, when analysing the impact of the Covid-19 downturn on economic welfare, analysts could examine if and to what extent economic production shifted between different production boundaries – from the market to non-market, or from market to household production, for example. By building on top of the already-existing National Accounts framework underlying GDP, Spectrum offers value added to people who want to understand trends in GDP by offering an aggregable framework of which GDP is a part. If NNDI+ is a user's focus, as it is the most expansive measure of economic welfare available, they can still disaggregate movements into GDP and non-GDP components. Similarly, if GDP is a user's focus, they can quickly obtain comparable valuations of economic activity which lie outside GDP's production boundary.

## 3. Existing UK Data sources

For each of the metrics outlined above (excluding "Welfare" and "Well-being") we have derived estimates in both current price (CP) and chain volume measure (CVM) terms.

Importantly, our use of these data is predicated on the joint assumptions that i) statistics have been accurately produced against a relevant international framework, ii) where measures have been monetised, these are in a form where they can be used, aggregated or compared in equivalent terms – that is £100 of market output is equivalent to £100 for services received from trees acting as stores of carbon is equivalent to £100 of home-produced transport services (*'dad's taxi'*), for example, and iii) the frameworks under which these statistics are derived are mutually consistent without double-counting or exclusions.

While the data available make a substantial contribution to fleshing out the Spectrum framework (up to the 'welfare minus' measure, Augmented Net National Disposable Income), there are still several areas where data are unavailable or experimental. As such, the estimates presented in this article should be treated as experimental and as proofs of concept. Contingent on user feedback, the aim is both to update Spectrum to further improve these measures, as well as use the Spectrum framework as a means to highlight gaps and identify areas for future work.

The assumptions made to compile these Spectrum estimates are important and worth further consideration at this point.

### Assumptions

Under point i) the authors are wholly reliant on the wider statistical system in terms of the quality of the statistics produced. We undertake no quality assurance of these beyond taking the relevant statistical 'badging'[10] as a suitable kite mark to guarantee the quality of the data used. This allows us to proceed, whereas a microdata approach using data across the breadth of the human / natural environments in the UK would be impracticable.

[10] As managed by the UK Office for Statistical Regulation, a part of the UK Statistics Authority, a non-ministerial government body which reports direct to Parliament

Under point ii), which effectively is a subset of i), the consistent application of the necessary guidance and methods, utilising internationally agreed frameworks, assumes that the different methods to monetise the flows of benefits and costs described in this work are internally coherent and consistent. The beauty of GDP is that because everything measured[11] has a value which can be described in an observable and consistent denominator – pounds sterling in this case – different products, industries, types of income or types of expenditure can be aggregated and compared objectively (or with minimised subjectivity) across the whole economy. To operate this framework, we assume that this logic applies equally to benefit and cost streams valued under SEEA (UN (2021)) or within the Household Satellite Account. In nominal terms this assumption is relatively easy for economists to make. In volume terms for this assumption to hold one needs to review the deflators used to derive these volume measures and ensure they adequately control for the relative change in real value over time of different flows of benefit or cost.

This is one of the most complex issues in this study: how best to ensure that prices have been adjusted into comparable terms which make conceptual sense. In a number of instances we have derived volume measures in terms of chain-linked volume measures (CVM) values from available current price estimates. As such, we made every attempt to utilise deflators from other ONS data sources (such as producer price indexes), from National Accounts, or have used the GDP deflator where appropriate local deflators are unavailable. Both GDI+ and NNDI– have been constructed by chaining together the relevant components.

In this paper we utilise the three-facing nature of GDP, as well as several of the items we add to it, as simultaneously a measure of income, production, and expenditure. While we believe the most intuitive way to interpret these new series and their components are as streams of benefits (i.e., income), we acknowledge that economic welfare is more associated with the expenditure interpretation (e.g., people receive utility through what they consume), and we utilise the production approach for much of our data processing (e.g., through our use of deflators and chain-linking methodologies). As a result, expenditure, production, and income can often be thought of interchangeably, and all as measures of economic welfare in this framework. Hence when we refer to 'income' in this paper, unless otherwise specified we mean income in this national accounting sense.

However, this is very much a first attempt method. The primary challenge with this is that by thinking about this work in 'income' terms, the key question arises of 'whose' income and what do they consume from this income? Once this question is addressed, there is the further issue of sourcing a relevant deflator for this group.

As with any measure of economic welfare – and building on top of GDP – a core component, and useful framing device for questions such as these, are households. Drawing on the work of Aitkin and Weale (2018a & 2018b), the question of 'whose income this is' can be expanded into several more particular questions:

- How do we allocate what is normally considered non-household income to households, particularly if in the long-term one wishes to derive a microdata-driven 'welfare' measure?

[11] Recognising the processes applied to capture goods and services without a market price, for example the public services.

- While a deflator relevant to the household could be considered optimal (such as the household final consumption expenditure deflator), if income/consumption from other sectors has been re-allocated to households, should adjustments be made for the business investment and other acquisitions which the GDP deflator accommodates?

- If by extension the consumption basket is extended further beyond market products and into those generated through household production or the environment, how should this be taken into account? Two possible approaches are:

    - Using one consistent deflator to try and place these data into common terms with those from the national accounts, or,

    - Source appropriate deflators from other sources of relevance to each item. For example, the output of household production might be deflated by average weekly earnings to represent the time commitment inherent in their production and the economic assumption that to produce these services and goods the household must gain at least equivalent value to if they had worked for an additional hour. We recognise the logic of the argument that to best achieve our goals if the measure reflects the benefits of environmental capital being consumed, so too should the deflator.

Under point iii), as listed in annex D of HMM19, it is clear that even where these frameworks exist, for example the SNA08 and System of Environmental Economic Accounting (SEEA), there are incidents of double-counting which need to be addressed[12]. This paper does not attempt to adjust for these, and this is clearly an important area for further development work, but as our previous paper described, these appear at this time to be generally small / second-order in terms of importance, although further work is needed to verify this. Where possible, in the sections and Annexes which follow, areas which may be subject to double counting are highlighted for transparency.

Expanding further upon this, it is important to point out that this paper does not attempt to completely integrate its adjustments throughout the National Accounting framework. Providing a complete enumeration of all the issues posed by fully implementing the Spectrum framework through the National Accounts is beyond the scope of this paper, but the following are worth highlighting to demonstrate the intricate work required to do so. While this paper proposes, advocates for, and (on a basic level) uses a National Accounting framework, it does not yet address these issues – and as such it should be emphasised that this paper serves as a proof of concept rather than a finished product:

- The implications of any adjustments to the production boundary for all three measures of economic output (income, production, and expenditure) should be considered, and final estimates of economic output will be based on a balanced estimate from these.

- The production and asset boundary must be defined precisely. This presents issues where it may make analytical sense to include something in the production or asset

[12] For example, grass and feed, timber and minerals and precious metals and stones

boundary – for example, ‘human capital’ as an asset – but creating a definition of production or assets which allow for this is difficult. In the case of human capital, for example, a definition would be required for what an ‘asset’ is which would allow for the unclear nature of who (if anyone) ‘owns’ human capital.

As a proof of concept, this paper simply states (in section 2) what items will be added to the production and asset boundary, basing these on common user request. Future work will be required to assess the consistency and any adjustments required to this boundary.

- Changes in economic output must be reflected in changes in the distribution of income accounts. Associated with this, economic ownership between institutional sectors must be identified (which can be difficult in the case of, for example, environmental assets).
- The adjusted data would need to go through a process of Supply-Use balancing, ensuring consistency across the accounts.

**Exclusions**

For concepts which do not have a full framework explaining how stocks and flows integrate or speak to other aggregates published under other frameworks this analysis has been more challenging, and we have generally set these issues aside, including – for the time being:

- the case of free digital services and platforms where we plan to propose a methodology for valuing these as part of the Household Satellite Account in a subsequent paper,
- Degradation of environmental assets other than the experimental, purpose-built estimates of carbon emission related atmosphere degradation presented in this paper,
- Human capital.

Human capital may represent the most significant remaining concept omitted from this analysis at this stage. It presents real challenges to an approach which is designed to aggregate existing UK aggregate data, primarily because to correctly estimate the stocks and flows these would need to be identified and correctly treated. The problem with doing this is that it may then be necessary to adjust existing aggregates. Whilst high quality guidance on the calculation of the capital stock exists in the form of a UN Manual, the key questions one would need to resolve relate to how to treat the flows, including:

- If human capital is a capital, it must be created through investment. One therefore needs to identify the process by which this investment occurs. Clearly education output would be one source, but also business and household spending on adult education, on-the-job training and apprentices, and sector specific training would need to be captured within our estimate of human capital investment. While business training would be captured in the existing estimates of uncapitalized intangibles incorporated into NNDI+ in this paper, one would need to resolve how the entirety of this educational investment is converted into capital as education is a long and complicated process. For example, would primary school spending in year 1 be treated as capital investment in year 1, or as ‘work in progress’ until the child has completed their school career and joined the labour force?

- If human capital is a capital, what is the rate of return and where would this be observed? When one considers primary and secondary allocations of income, we require an agreed treatment of compensation of employees (CoE), mixed income and gross operating surpluses based on agreed sectoral ownership of the human capital asset, and indeed whether there is a need to disaggregate CoE into a return to labour and a return to human capital.
- Importantly, how would one account for depreciation (e.g., skills eroded through unemployment hysteresis), depletion (e.g., untimely death whilst still in the labour force), and retirement (e.g., people leaving the labour market as they reach the end of their career)?
- If one captures retirement, how then does one account for human capital deployed in the household, either during retirement or before?
- Does one adjust the human capital stock for the health of the workforce?
- How does one account for imports (immigration) and exports (emigration)?

Due to these and further similar issues, this paper excludes human capital. But with the desire to move towards inclusion when a set of stock-flow consistent human capital estimates, which address the issues above, have been developed in the UK.

Similar to human capital, social capital would theoretically fit into and improve a measure of economic welfare, but progress towards establishing an appropriate and agreed-upon methodology for measurement and data collection is lacking. In this context, 'social capital' would refer to 'social networks and the associated norms of reciprocity and trustworthiness' (Stiglitz 2009). Much work toward measuring social capital – including that by ONS – is focussed toward non-monetary statistics on social capital related to well-being, such as measuring social isolation. As the framework for aggregation being proposed in Spectrum uses monetary values as weights, what data are available on social capital are (while useful in their own right) not appropriate for Spectrum.[13]

### Data sources

In the following tables, where available, we capture the Central Database Identifier (CDID) references of the data sources as provided by the ONS[14]. For more complicated constructions, reference is made to their respective annex where data sources and methodologies are detailed. Section 4 outlines their use.

#### *Market GVA*

**Table 1: Data used in the calculation of Market GVA**

[13] There is also a powerful argument by Dasgupta that social capital is a contextual factor which determines the value of other capitals: a machine might be valuable to its owner in a country with operating laws and justice functions, but the same machine has no value in a failed state where it could be immediately stolen

[14] CDIDs can be readily searched for at www.ons.gov.uk

| Variable | Source | Current Price CDID | Chain Volume Measure |
|---|---|---|---|
| GVA at basic prices | Blue Book | Household GVA: HAXE<br>Imputed Rent: ADFU<br>Public Non-Financial Corporations GVA: FACW<br>Private Non-Financial Corporations GVA: FARR<br>Financial Corporations GVA: NHDB | L48H |

***GDP***

**Table 2: Data used in the calculation of GDP**

| Variable | Source | Current Price CDID | Chain Volume Measure CDID |
|---|---|---|---|
| GDP at market prices | Blue Book | YBHA | ABMI |

***Augmented GDI (GDI+)***

**Table 3: Data used in the calculation of GDI+**

| Variable | Source | Current Price CDID | Chain Volume Measure CDID |
|---|---|---|---|
| GDP at market prices | Blue Book | YBHA | ABMI |
| Government, Health and Education adjusted for output growth | Public Service Productivity (ONS 2021a) | Not Applicable (no adjustment made to Current Prices) | Derived as described in Annex A |
| Additional Intangibles Assets (i.e. Intellectual Property Products) Investment | Experimental estimates of investment in intangible assets in the UK (ONS 2021b) | Derived as described in Annex C | Derived as described in Annex C |

| | | | |
|---|---|---|---|
| The flow of benefits from Carbon Sequestration[15] | Natural Capital Accounts, ONS (2020c) | - | Derived using GDP deflator |
| Household flow of benefits | Household Satellite Accounts, ONS (2018a) | - | SPPIs where available, otherwise Experimental Industry Deflators (Described in detail in in Annex D) |

***Augmented Net National Disposable Income (NNDI+)***

**Table 4: Data used in the calculation of NNDI+**

| **Variable** | **Source** | **Current Price CDID** | **Chain Volume Measure CDID** |
|---|---|---|---|
| Augmented GDI | As above | - | - |
| Employment, property, and entrepreneurial income from ROW | Blue Book | YBGG | YBGI |
| Subsidies (receipts) less taxes (payments) on products from/to ROW | Blue Book | QZOZ | QZPB |
| Other subsidies on production from/to rest of the world | Blue Book | YBGF | YBGP |
| Consumption of capital – tangible and intangible | Capital stocks and fixed capital consumption | NQAE | CIHA |

[15] The Natural Capital Accounts contain a number of flows of benefits from different types of natural capitals. These are not all available for all time periods, so for this proof of concept we use the largest single Natural Capital available, carbon sequestration.

| | | | |
|---|---|---|---|
| Consumption of capital - households | Blue Book | Taken from Household Consumption in Supply Use (Products 26, 27, and 29) | Capitalised using a PIM model and linear depreciation. Parameters described in Annex B, deflator sources and methods described in Annex D |
| Consumption of Capital - Uncapitalised intangibles | Experimental estimates of investment in intangible assets in the UK | - | Capitalised using a PIM model and linear depreciation. Parameters described in Annex B, methods described in Annex C |
| Degradation of Atmospheric Natural Capital[16] | Authors' Calculations | Derived as described in Annex E | Derived as described in Annex E |

## 4. Methodological Steps to fill data gaps and derive estimates

Further elaborations upon our methods are presented in Appendices.

***Market GVA***

Market GVA can be thought of as "GDP minus", i.e. GDP excluding central government, local government, and Non-Profit Institutions Serving Households (NPISH). In terms of their industry composition, in line with the methodology employed by ONS, these non-market sectors fall in industry

- E (Water Supply; Sewerage, Waste Management and Remediation Activities), specifically:
    - Division 38 (Waste collection, treatment and disposal activities; materials recovery)
- H (Transport and Storage), specifically:
    - Division 52 (Warehousing and support activities for transportation)
- J (Information and Communication), specifically:

[16] Whilst there is a range of natural capitals which are subject to depletion / degradation, data on this full set is not available at this time, so whilst this measure of atmosphere degradation depletion shouldn't be viewed as a proxy for depletion of all natural capitals, as the atmosphere is arguably the most important asset for the debate on climate change, the authors have created a simple model for capturing this element to provide an illustrative example which has some relationship with the flow of benefits from carbon sequestration services provided by natural capital captured above. Nevertheless, in the long term to inform policy development it is clearly essential to derive accurate estimates of the full impact of degradation / depletion for all assets, which currently are not available for any of our Natural Capitals.

    - Division 60 (Programming and broadcasting activities)
- M (Professional, Scientific and Technical Activities), specifically:
    - Division 72 (Scientific research and development)
- K (Finance and Insurance Services) where FISIM is excluded according to the methodology used for the Current Price market sector GVA, but included according to the methodology used for the CVM market sector GVA.
- L (Real Estate), where the value added from local government housing departments and imputed rents (68.2IMP) are excluded.
- O (Public administration and defence services; compulsory social security services).
- P (Education services), where state education provided by central government is excluded.
- Q (Human health services; Residential care services; Social work services without accommodation), where state health services, social work and probation services carried out by government employees is excluded.
- R (Arts, Entertainment and Recreation), specifically:
    - Division 91 (Libraries, archives, museums and other cultural activities)
    - Division 93 (Sports activities and amusement and recreation activities)
- S (Other Service Activities), specifically:
    - Division 94 (Activities of membership organisations)

In the construction of current price market sector GVA, data on the relevant market (Households and Corporations) non-market sectors (Government and Non-Profit Institutions Serving Households) are summed to give to derive the whole-economy market sector. Additionally, imputed rents have been allocated to the non-market sector. In the case of chained volume measures, these are derived using low level industry estimates such that industries with output clearly attributable to the non-market sectors are excluded. These are chained together to create a volume index, which is then given a monetary value using the Current Price market sector statistic in the base year (2016).

An example of how the current price GVA series can be constructed is shown in the table below.

**Table Five: Worked Example: Current Price GVA split into Market and Non-Market Institutional Sectors**

| | Sector | 2016 GVA (£ millions) | |
|---|---|---|---|
| Market | Households (excluding imputed rent on owner-occupied housing) | £ | 108,342 |
| | Public Non-Financial Corporations | £ | 28,494 |
| | Private Non-Financial Corporations | £ | 1,041,510 |

| | | | |
|---|---|---|---|
| | Financial Corporations | £ | 126,002 |
| Non-market | Non-Profit Institutions Serving Households | £ | 46,966 |
| | Central Government | £ | 142,654 |
| | Local Government | £ | 75,586 |
| | Imputed Rent on owner-occupied housing | £ | 207,812 |
| **Whole Economy** | | **£** | **1,777,366** |

***Gross Domestic Product (GDP)***

Current GDP relates to GDP as it is currently measured based on ESA10, which is itself based on the SNA08.

These series were used without adjustment.

***Augmented Gross Domestic Income (GDI+)***

Illustration: Gross Domestic Income (GDI+)

GDP (minus non-market gross value added in industries O, P, and Q)
Plus: Quality adjusted non-market GVA in industries O, P, and Q
Plus: Household flow of benefits (to be expanded to include household production using digital services in a future article)
Plus: The flow of benefits from carbon sequestration performed by a subset of environmental assets in the UK.
Plus: Investment in previously uncapitalized Intellectual Property Products (i.e. intangible capital)
= Augmented Gross Domestic Income (GDI+)

To derive this measure, we start with GDP (above), and remove the industries associated with the provision of public services (O, P, and Q). We then reintroduce these industries, after taking account of quality adjustments to the value of non-market public services.

As summarised in Foxton, Grice, Heys and Lewis (2019), to understand the value added from public services which are delivered at zero price, one needs to follow the methods laid out in SNA08 to quality adjust measures of public service output to take account of the quality of the outcomes achieved, in line with the methods proposed in Atkinson (2005)[17]. The UK does

[17] The rationale here is that the market price of services which deliver a higher quality outcome could be assumed to be higher. So, if we take an operation which delivers £1,000 of benefit to patients, one could quantify the value of 100 operations as £100,000. If we now assume the operations process is changed, such that 100% of patients die, but the number of operations is doubled, under SNA08 the value of the operations would fall to zero, assuming no-one would pay a positive price to lose their life. ESA10, which relies on the measurement of output without quality adjustment would see the 200 operations as doubling output.

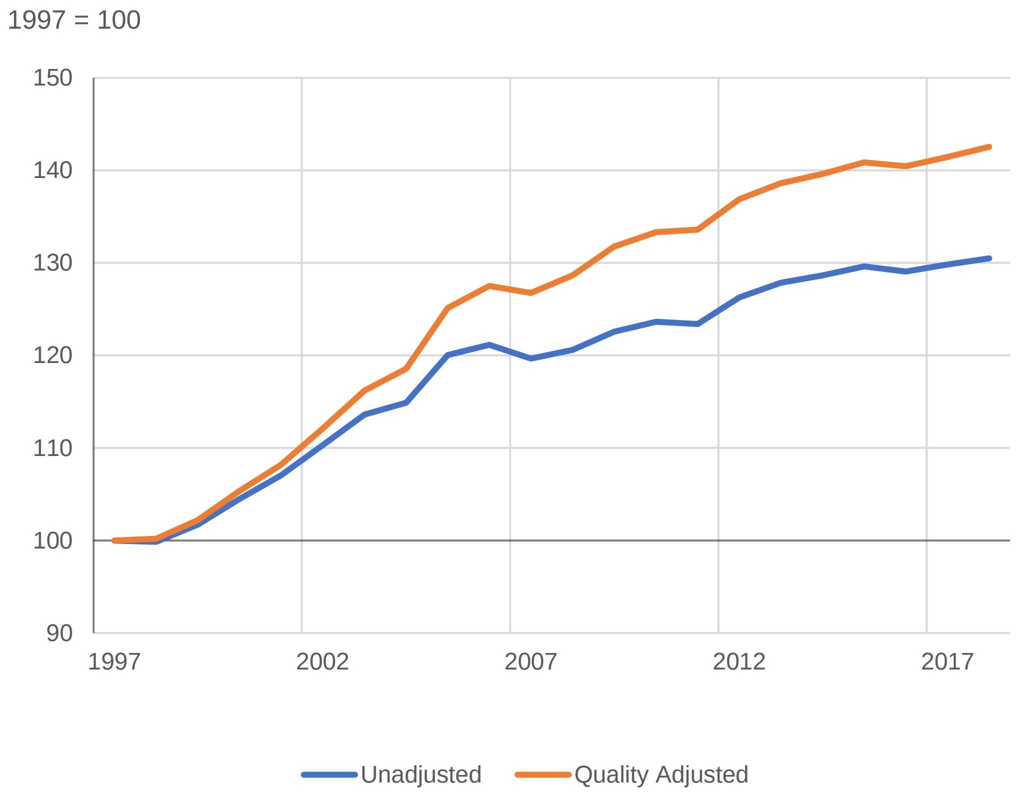
not currently conform to this standard because ESA10 deviates from SNA08 in this important dimension[18]. Therefore, this paper uses the UK's work to develop quality adjustments on the public services to produce public service productivity data to implement an adjustment to the non-market component of sectors O, P and Q, as described above[19]. To do this, we take the average quality adjustment on the 49.1% of the public services where quality adjustments exist and extrapolate this across the whole of the non-market portion (around 80%) of O, P, and Q. Whilst a simplifying assumption, given the whole of government is subject at any time to the same spending constraints and a consistent requirement for efficiencies and service improvements, extrapolating the calculated quality adjustment across services which we have not yet been able to derive such estimates for appears more likely to reflect reality than the alternative of assuming the other half of non-market public services exhibited no change in quality over the time period studied.

[18] The rationale for this is that ESA10 regulates the production of GNI estimates for each country in the EU, which then determines their contributions to the EU budget. The EU wished to observe further development to establish and confirm comparable methods across all countries to ensure consistent application and therefore a 'fair' allocation of the EU's costs.

[19] Whilst there are other non-market sectors of the economy, such as imputed rentals on owner-occupied housing, we do not propose any adjustment of these.

**Figure 2: The effect of quality adjustment on Government, Health, and Education (O, P, and Q) GVA**

*Chained Volume Measure, 1997 = 100*




GDI+ also includes the increase in value in equivalent income terms from:

- The flow of benefits from the household satellite account (within which, in future work, we hope to incorporate the impact of free digital services) and,
- The flow of benefits from carbon sequestration (from the Natural Capital Accounts)

A core assumption in this paper is that people derive economic utility or value both from what they produce and consume from within the productive economy as narrowly defined in SNA08 / ESA2010 (hence measured in the national accounts), but also from the more broadly defined productive economy – including the flow of services they produce and consume in the household satellite account, and similarly from environmental assets. By considering each of these in terms of providing either a proxy or equivalent to a flow of income one can view the summation of these incomes as a total measure of monetised and non-monetised income and hence a feasible measure of economic welfare. Clearly this is a limited perspective when put alongside dashboards or multi-indicator approaches of well-being measures, but its value lies in being a single, holistic, measure of the economic resources available to society to increase their well-being.

The flow of benefits from carbon sequestration in the Natural Capital Account are used as provided in current price terms but deflated using the GDP deflator. This deflator is used for the time being as the benefits received from environmental assets are difficult to compare with other broad categories of products from the market sector – in theory, the best deflator to use would be one which represents a market-equivalent of the service the environmental asset provides. Future work would be required to identify these market equivalents and their relevant deflators, which in some cases may require additional data collection.

We have only included carbon sequestration from ONS's work on the flow of services from environmental assets as the value from provisioning services (e.g., fossil fuel production) should already be included in GDP, and other environmental asset services have short time series which only begin after 2005. As such, these estimates should only be seen as a component of the contribution of environmental assets to value added – and not as a proxy for the entirety of environmental asset services. However, as ONS develops new measures and extended time series for environmental asset services, the authors would wish to add these into Augmented Gross Domestic Income.

Finally, we have added investment in additional Intellectual Property Products (IPPs), under the assumption that this would previously have been accounted for as intermediate consumption. It's important to note that this assumes the definitions for these additional IPPs are mutually exclusive from those already accounted for in the National Accounts – work is currently being undertaken in ONS to examine the extent to which this may (or may not) be the case.

***Augmented Net National Disposable Income (NNDI+)***

Augmented Gross Domestic Income (GDI+) addressed a wide range of capitals, each of which depreciate at different rates. Augmented Net National Disposable Income (NNDI+) addresses depreciation, and in doing so implicitly progresses towards a net measure of income. It is also capable of capturing degradation of natural resources.

Income and transfers from abroad are also taken into account to arrive at a NNDI+, derived from net national income by adding all current transfers in cash or in kind receivable by resident institutional units from non-resident units and subtracting all current transfers in cash or in kind payable by resident institutional units to non-resident units.

Illustration: Augmented Net National Disposable Income (NNDI+)

Augmented Gross Domestic Income (GDI+)
Plus: Income from abroad
= Gross National Income
Less: Transfers from Abroad
= Gross National Disposable Income
Less: Depreciation of
    Tangible and intangible productive assets
    Durables in the Household sector
    Uncapitalised intangibles
Less: Degradation of Atmosphere due to Carbon Emissions
= Augmented Net National Disposable Income +

A key feature of this measure is the subtraction of deprecation for all assets involved in the production of GDI+. This means that, as well as subtracting depreciation of those assets already capitalised in GDP, we also (for example) subtract depreciation of capitals involved in household production. In addition, we also capitalise assets which can be interpreted as being produced within the GDP production boundary, and used to produce goods and services within the GDP production boundary, but which are not currently capitalised in the National Accounts – uncapitalised IPPs and degradation of environmental assets[20]. In the case of the latter, it is worth pointing out that this relies on an interpretation of environmental assets as being 'produced' by economic activity, reflecting the extent to which the status of environmental assets is dependent on form and extent of economic production.

The calculation of natural capital degradation is key to the valuation of environmental assets within production accounts – as it provides a measure of how much of the capital is consumed in the production process, and so how much value it adds to production (or, equivalently, how much would need to be produced to replace it). However, as ONS have not yet produced estimates of environmental asset degradation, this paper presents experimental estimates for an area of environmental assets the authors view as of primary importance – the atmosphere.

A detailed description of the methodology to derive atmospheric degradation due to climate change is given in Annex E, but there are key assumptions and interpretations to note.

- This model only reflects degradation due to carbon emissions, but these are not the only greenhouse gas. To the extent that this excludes greenhouse gases such as methane, the model could be thought of as a lower bound estimate of atmospheric degradation – or, more accurately, atmospheric degradation purely accounted for by carbon emissions.
- The model makes no assumption of the proportion of the atmosphere – if any – would be included within the UK's national or domestic boundary, or which economic sector owns the atmosphere. Instead, degradation of the (global) atmosphere, as included in NNDI+ in this article, can be interpreted as a combination of two phenomenon, both of which have the same effect on the numbers. The first is the UK 'consuming' its own atmospheric environmental asset through the emission of carbon. The second is the UK importing degradation (akin to importing capital services) of the atmosphere through the emission of carbon. As both of these (consumption of 'capital' and importing of 'capital services') have the same effect on a 'net' measure of production, the question of which is taking place can be put to one side for the purpose of this article.

## 5. Empirical estimates of the different measures

A proof of concept, pilot model was compiled using the methods above to demonstrate that the following measures could be produced with minimal assumptions from data already publicly available to derive:

- GDP Minus (Market Gross Value Added)
- Current GDP (Gross Domestic Product, GDP)
- Future GDP (Augmented Gross Domestic Income, GDI+)
- Welfare Minus (Augmented Net National Disposable Income, NNDI+)

The objective of this initial development was to devise a workable system using robust methods. As part of the development certain assumptions were necessary which will need some refinement under a fully operating production system, alongside alternative methods in some instances, as described in Section 6.

Whilst data can be sourced for some variables for long time periods, the period for which all the key data are available is 2005-2016. We therefore use this time period to present results, but will continue to work to address data gaps to extend this period in the future. It should also be noted that National Accounts data in this paper are sourced from Blue Book 2020.

The Spectrum system has been developed to produce several informative tables and graphical summaries of economic welfare in the UK over time, but full tables are available in Annex F.

First, to give an idea of the scale of the adjustments associated with each stage of Spectrum, Figure 3 shows the current price amounts of different measures in grey, as well as the adjustments made to the 'previous' measure in order to get to the 'next' measure, where positive contributions are shown as green and negative contributions are shown as red. So, for example, Market GVA in 2016 amounted to £1,304bn. To get to GDP, we add non-market GVA (£473bn) and the net effect of taxes and subsidies (£217bn, required to move from a GVA measure to a GDP measure).

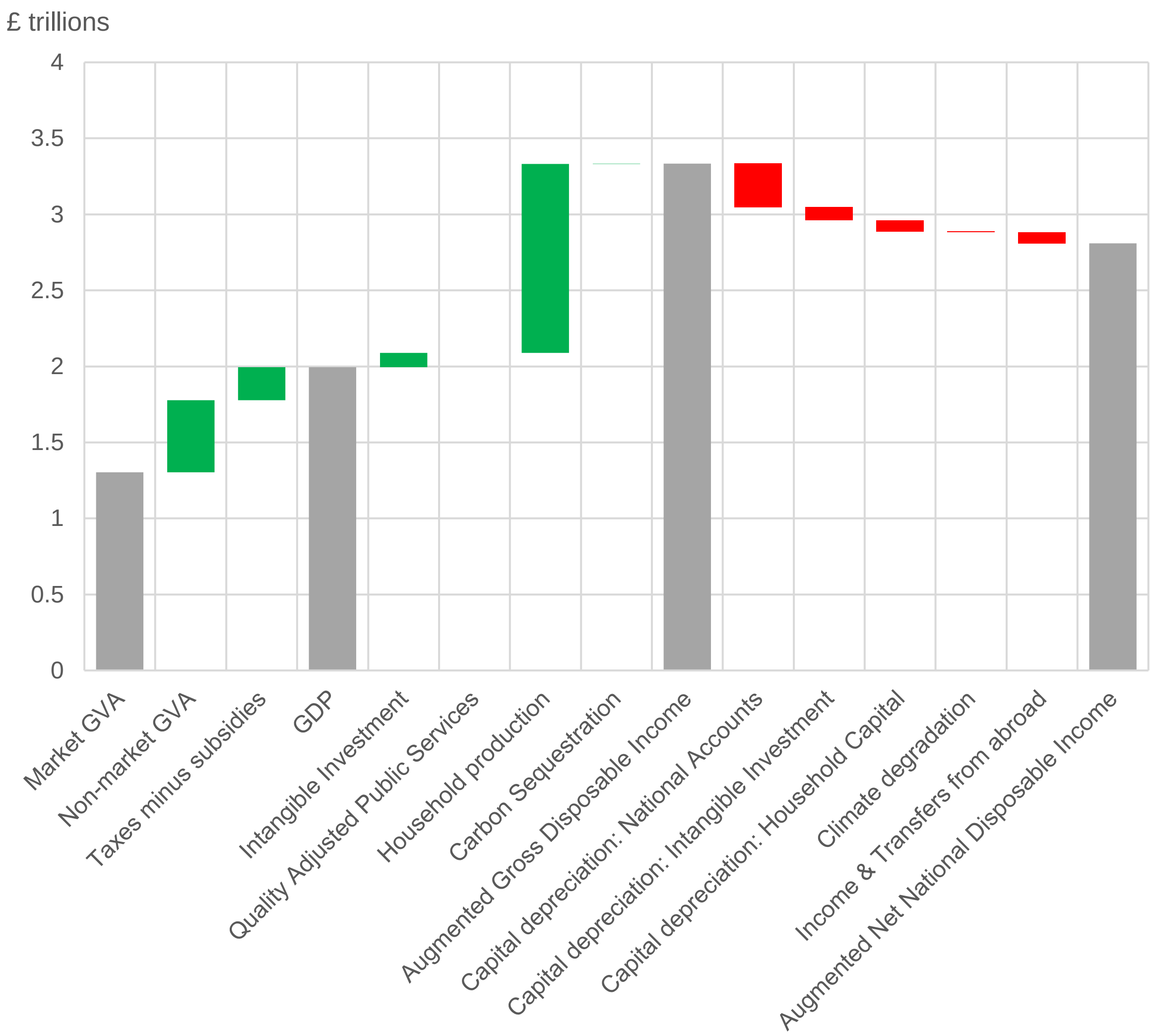
Figure 3 contains several points of interest. The inclusion of household production is by far the biggest adjustment – adding £1,243bn in 2016. For context, this is around three times bigger than the size of the non-market economy currently included in GDP. The size of other contributions added to GDP to get to GDI+ (investment in additional IPPs, £94.8bn, and carbon sequestration, £1.9bn) are substantially smaller. It is also worth noting the quality adjustment of public services has no effect on current price data, as the quality adjustment only applied to volume measures.

When turning to the contributions subtracted from GDI+ to move to NNDI+, we see less of a dominance of any one component. That said, depreciation of capitals already included in National Accounts still account for just over half the contributions at this stage (-£287.3bn). In contrast with its effect on GDI+, the effect of accounting for household production on moving to net figures is much more subdued, amounting to just -£72.1bn.

Finally, it's worth noting that the effect of carbon-emission related degradation of the atmosphere is relatively small, at -£5.9bn. Annex E considers this in more detail, but it is worth highlighting that this only covers the effect of carbon emissions (not methane, for example), a subset of the possible effects of climate change, and only measures the impact of climate change on market activity. As such, we re-emphasise that this measure, in particular, is intended as a partial proof-of-concept, and we would encourage users interested in its compilation to read the relevant annex.

**Figure 3: Progression through Spectrum from Market GVA to Augmented Net National Disposable Income (NNDI+)**

*UK, £billions, Current Prices, 2016*



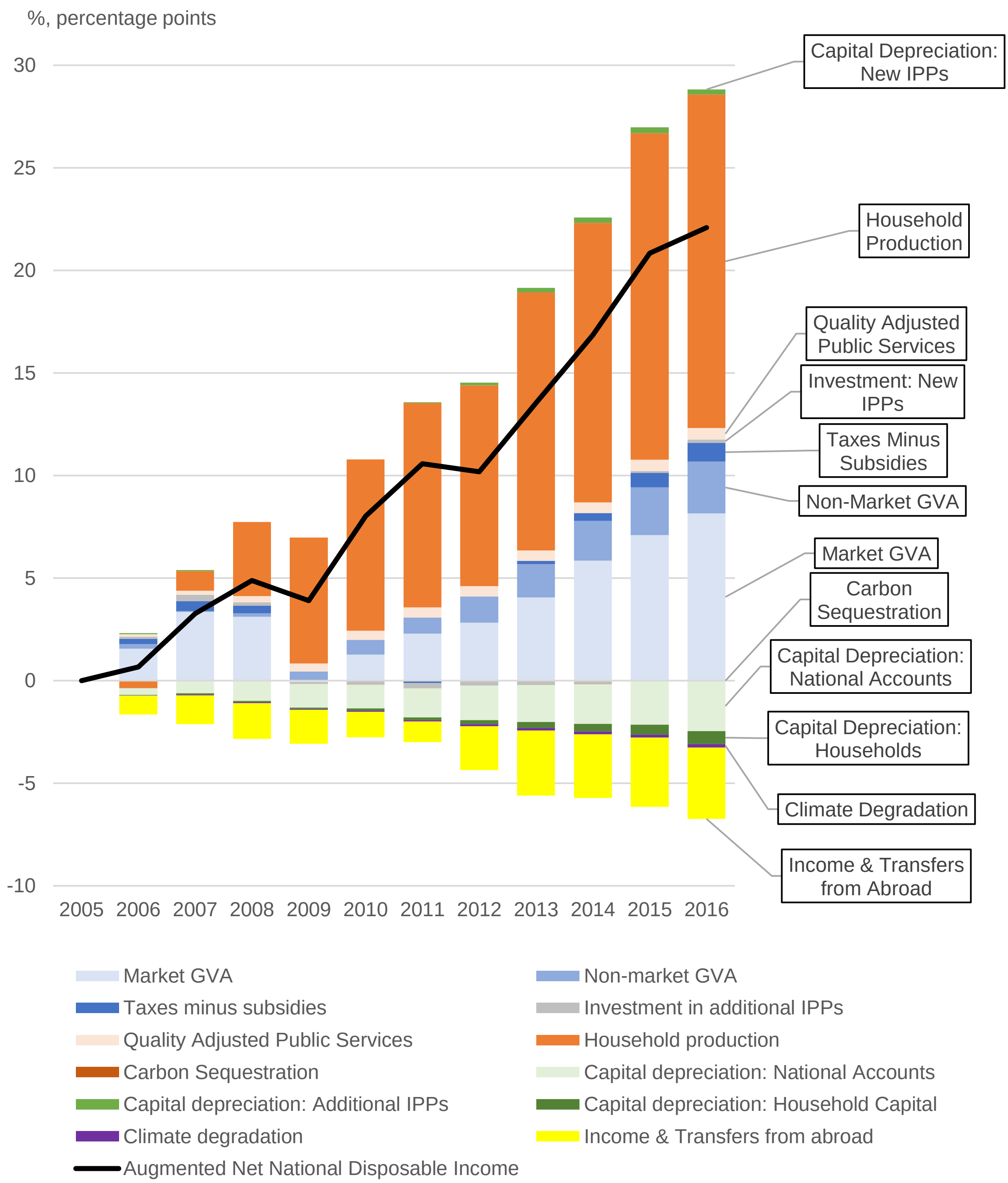

*Note: The different Spectrum measures are shown in grey, and the green and red bars represent components added to progress from measures on the left to measures on the right. Green bars represent additions, while red bars present subtractions. So, for example, to progress from Market GVA to GVA, Non-market GVA and taxes minus subsidies are added to Market GVA.*

*Quality Adjustment of Public Services has no impact on current price data, but are included for completeness.*

As with standard GDP data, comparisons of growth in resources over time are best undertaken using Chained Volume Measures (CVM) – which control for changes in prices – as shown in Figure 4. Figure 4 shows growth in CVM NNDI+ since 2005, but also decomposes it into the various components and adjustments made at each stage of Spectrum.

**Figure 4: Contributions to growth in CVM NNDI– since 2005**

*UK, % and percentage points*



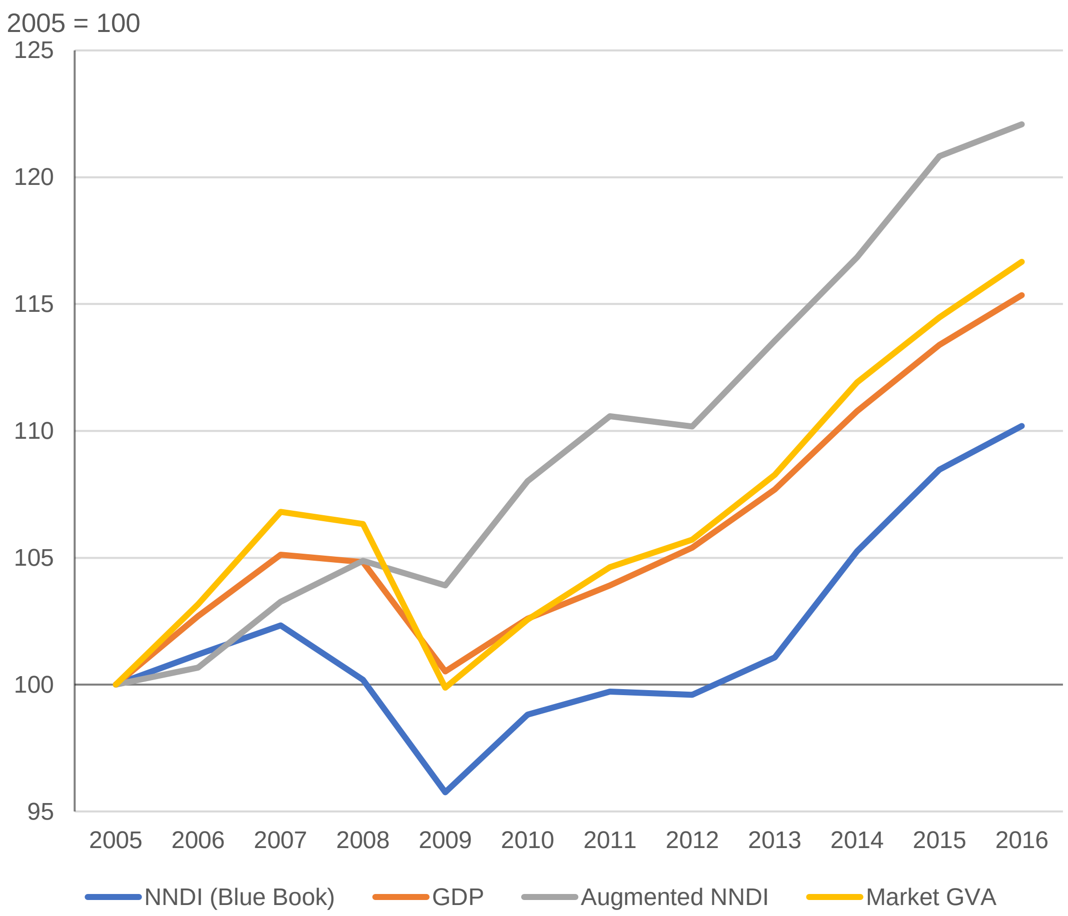

*Notes: "IPPs" refers to a subset of assets called Intellectual Property Products, otherwise known as "intangible capital". The derivation of the contribution from IPPs is described in more detail in Annex C.*

Again, certain stories dominate: by far the most significant driver of growth in NNDI+ is the production of services within the household – possibly driven by greater use of free digital products as intermediate consumption in the production of these services. While (CVM) GDP grew by 15.4% between 2005 and 2016, household production grew by 43.1%. Additionally, an interesting narrative which comes out of this data is that, despite carbon emissions falling over the period, carbon-related climate degradation increased (albeit mildly) so that climate degradation contributed negatively to NDDI+. This can be attributed to the global temperatures increasing over time, such that the higher marginal damage per unit of carbon emitted outweighed the effect of carbon emissions falling, or put another way, the price grew faster than the volume fell.

Having generated this data, we can also compare the growth in NNDI+ to the standard measure of GDP and NNDI, as shown in Figure 5. Once again, the general trajectory of NNDI+ over time is correlated with that of GDP but demonstrates stronger overall growth through the period (22.1% compared to 15.4%). Comparing to Blue Book NNDI also shows similar overall trends, excepting 2008-9:  Blue Book NNDI falls compared with 2007 6.4% by 2009 whilst NNDI+ grew by 0.6%.

**Figure 5: A comparison of standard GDP and Net National Disposable Income, as published by the ONS in Blue Book 2000, with Augmented NNDI**

*UK, 2005 = 100, Chained Volume Measures*



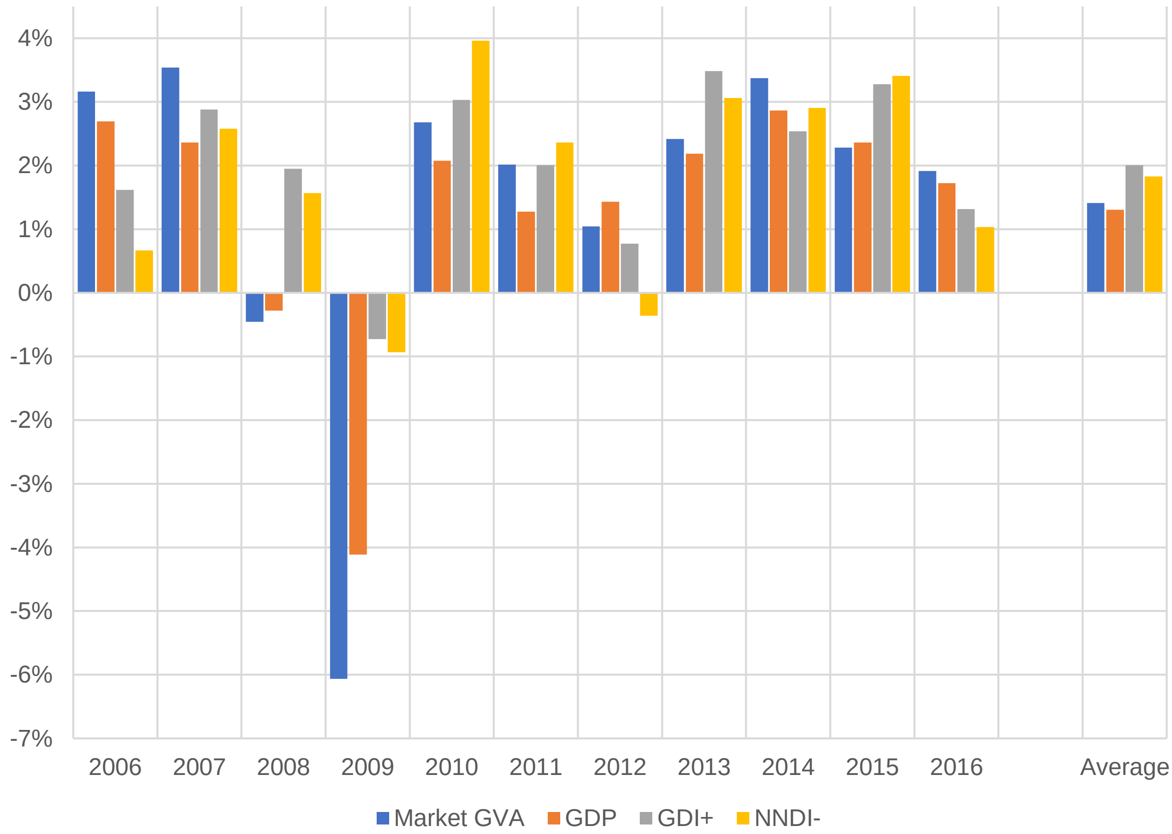
This demonstrates that whilst market GVA is a relatively large component with substantial points of inflection – such as the 2008-09 recession and subsequent recovery, it is clear the degree to which other components of NNDI+ mitigate these Market GVA effects. So, for example, when market sector GVA pushed NNDI+ growth downwards by 3.0 percentage points in 2009, household production partially offset this through a 2.4pp upwards contribution, as did non-market GVA through a 0.3pp contribution. Interestingly, household production generally demonstrates a stronger counter-cyclical dynamic (i.e. growth in household production is negatively correlated with growth in market GVA) than non-market GVA currently included in GDP (see Annex G).

However, NNDI+ does not always show stronger growth than GDP, with 2012 telling a very different story: whilst market GVA grew at 1.0% and GDP grew at 1.4%, NNDI fell 0.1% and NNDI+ fell by 0.4%. Compared to GDP, this is driven by negative contributions in that year from capital depreciation (from national accounts capitals), household production, and income and transfer from abroad.

Finally, annual growth figures are summarised in Figure 6 for all welfare measures in the Spectrum model. Differences between the growth rates mostly lie in a range of 0.8-1.9 percentage points, however 2008 and 2009 show far higher variation (2.4 percentage points and 5.3 percentage points respectively), which shows how the 2008-9 economic downturn was primarily a market phenomenon, whereas in 2014 and 2015 variation is lower, with the difference between the maximum and minima being only 0.8 and 1.1 percentage points respectively. NNDI+ growth was exceeded by market GVA growth in 2006, 2007, 2012, 2014 and 2016 over the eleven years under review.

These analyses demonstrate the power of the Spectrum in assessing expansions of the production and asset boundaries in order to better measure welfare – and evaluating how these expansions can change our understanding of events like the 2008-09 recession. However, this is before we apply estimates from free digital services, develop a treatment for human capital, expand the scope of environmental asset degradation, or consider income distribution, which are all likely to have significant effects of equal, if not greater importance for welfare, and will be the subject of future work.

**Figure 6: Comparison of annual growth for economic welfare measures**
*UK, % change on same time previous year, Chained Volume Measure (CVM)*




This spectrum of measures is useful when analysing economic welfare during an economic downturn, for example that caused by the Global Financial Crisis in 2008-09 and is likely to provide a unique perspective on the Covid-19 pandemic of 2020-21. During the latter, we had a situation where roughly a quarter of the UK workforce were furloughed and had more time for training, self-development, or to undertake jobs at home that they wouldn't have previously done, thereby shifting a volume of consumer services from the market economy back to the household economy. For example, time use data taken between 28 March and 26 April indicates that time spent on paid work was below 2014-15 level, but time spent on gardening and DIY increased during lockdown (ONS 2020b). GDP fell over this period, but Spectrum would allow us to analyse the effect of the wider basket of contributors to economic welfare, which we have discussed above, such as reduced pollution from fewer car journeys. While this would not fully capture the effect of the lockdown on wider well-being – for example, the effects of a possible increase in domestic violence (ONS 2020a) or reduced socialising due to social distancing – being able to judge the extent to which economic activity 'shifted' outside the traditional production boundary and the extent to which economic activity as a whole declined would be a useful advancement of our understanding of the lockdown.

## 6. Areas of further development identified in developing these estimates, both empirically and conceptually.

There are still areas that require further development. Top on the agenda is the impact of free digital services – and free digital *platforms* in particular – on the measurement of production of household services in the household satellite account. Agreed international guidance on how to measure this sector is currently lacking, but some progress is being made by a number of countries, including the United Kingdom, on research in this area. This work is regarded as a priority within the SNA2008 revision by the Inter-Secretariat Working Group on National Accounts (ISWGNA).

The economic welfare of societies can be argued to have been increased partly through access to free digital platforms such as those provided by Facebook, YouTube, Instagram, Twitter just to mention a few. Households use these platforms to engage in activities – such as sending tweets, developing TikTok dances, or composing pictures on Instagram – which may be thought of as own-account production within a household, or free-at-the-point-of-use trade in services between households. It is a familiar curiosity springing from the production boundary that if a news story breaks and is shared widely via Twitter, that production is not included in GDP – but if it broke in a newspaper which sold widely as a result, it would be included. While the business model underlying these platforms is similar in some respects to long established industries, such as advertisement funded TV programming, the pace at which digital services have expanded mean the way in which we account for these services may impact not just our understanding of the long-run level of economic welfare, but its growth (or decline) in the short term.

Accounting for this impact is, however, primarily thought of as a problem at a household level. These are still not included in both household consumption and, also, household disposable income. Theoretically however, the value of these services should be included in NNDI+. A future article by the authors is planned to explore possible ways forward in both conceptualising as well as practically measuring this component. In addition, these are currently being addressed on an international level by the SNA2008 update.

Another developmental area currently being addressed on an international level through the SNA and SEEA updates is the framework for environmental degradation measurement, and its relation to National Accounts. This article presents a highly experimental model for estimating atmosphere degradation related to carbon-emission induced climate change, but this represents a highly simplified approach which – while attempting the follow SEEA guidance where possible – falls far short of the integrated set of environmental asset accounts which would be required to fully understand the economic effects of climate change (see Annex E). ONS plan to continue work to implement the SEEA framework to realise a fully integrated set of accounts.

Quality adjustment of output, particularly that of public sector output, remains problematic and challenging in the National Accounts. While quality adjustment of market output can be achieved indirectly through adjusting prices and deflators, this approach cannot be used for public sector output due to their being non-market. Hence, finding conceptually ideal indicators with which to quality adjust the output of this sector remains very challenging and an area always needing further improvement and development. While this paper uses those adjustments available and expands them to cover all non-market production of public services, this is no substitute for the rigorous development of new and improved quality metrics.

Finally, significant further work is required to derive microdata measures of welfare, as defined in the Spectrum.

## 7. Conclusion

This paper presents an indicator of welfare based on an augmented concept of Net National Disposable Income. This marks an improvement on GDP as a measure of welfare. It broadens and extends this measure to include output emanating from the production of household services, quality adjustment of some public services such as health and education, and the impact of carbon emissions. All these substantially improve the measurement of economic welfare beyond that of GDP.

However, the estimates presented here represent current data availability, and to that extent remain incomplete. Work is still required to estimate components of economic welfare such as valuing household production utilising digital platforms, human and perhaps even social capital. But there is user need from policy makers, analysts, and citizens today to be able to utilise what data is available in the best framework possible to assess economic welfare now. While it remains a small part of the overall picture for understanding multidimensional welfare and well-being, it nevertheless takes another step forward and offers users and stakeholders of economic statistics a chance to assess our position and destination.

There is now a great opportunity for the UK to take the lead in producing additional measures to better meet user requirements. The work outlined in this paper proves that, for a modest cost, this proof of concept could be transformed into a routine production system. To get to that stage the following issues would need to be resolved:

- Further development is required on the inclusion and measurement of the production of household services. This work is regarded as a priority within the SNA2008 revision. The United Kingdom, along with a number of other countries, are researching this area, which should be addressed as part of the SNA2008 update.

- The calculation of volume measures has used the most appropriate already-developed deflators for the particular purpose at hand. A further developed model will require more targeted sourcing, development, and application of deflators for each component.

- Human Capital has <u>not</u> been included in the calculation of capital depreciation or in the quality adjustment of education services and requires the creation of a framework, where investment, depreciation and stocks are considered in the round.

- Estimates of the impact of free digital services and household production involving these need to grapple with fast developing economic and legal framework involving these services, as well as the lack of data available to NSIs on these activities. A forthcoming paper developing the methodology proposed in Heys, Martin, and Mkandawire (2019) will seek to address these issues, as well as showcase some worked results.

- More work is needed to assess to relationship between economic welfare, like the measures focussed upon in this paper, and the environment and society. Only by doing so can we arrive at a comprehensive understanding of well-being, and national statistics institutes can present users with a nuanced and inter-related picture of well-being.

**Annex A: Deriving CVM GVA for Government, Health, and Education (OPQ)**

To apply the quality adjustment for public services to non-market GVA in Government, Health, and Education, we take the following steps:

1. Use the difference between quality-adjusted and non-adjusted growth in public services gross output to calculate the quality-adjustment to output growth.
2. Use the implied deflator from GDP low-level aggregates and supply-use table values for gross output in Government, Health, and Education (OPQ) to calculate an estimate for unadjusted CVM gross output in OPQ, and the annual growth in this measure.
3. Calculate the portion of OPQ gross output which is accounted for non-market output. This is done by using the market-proportions for each industry division from National Accounts, and weighting the proportions in divisions 84 to 88 by their gross output from the supply-use tables. This gives proportions for non-market output in OPQ as a whole in each year between 1997 and 2018 – these tend to be just over 80% non-market output.
4. Multiply the quality adjustment calculated in step (1) by the non-market portions calculated in step (3) and add these to the CVM gross output growth calculated in step (2) to calculate growth in quality-adjusted CVM gross output.
5. Chain together the growth rates calculated in step (4) and use the current price value of OPQ gross output in the base year (2016) to give these monetary values.
6. Subtract the quality-adjusted CVM gross output measure in step (5) from the non-adjusted CVM gross output measure in step (2) to calculate the effect of quality adjustment on CVM gross output.
7. The change in gross CVM output in OPQ calculated in step (6) can be added to CVM GVA in OPQ to derive quality-adjusted CVM GVA. As GVA is equal to gross output minus intermediate consumption, this step reflects the logic that the increase in gross output due to quality adjustment should result in the same absolute change in GVA. So, if quality adjustment causes CVM gross output to increase by £10bn in 2015, it should also increase CVM GVA by £10bn in 2015. Note that, so long as intermediate consumption is above £0, this means the *proportional* change in GVA due to quality adjustment will be larger than to gross output.

This methodology is intended to incorporate a gross output quality adjustment into an accounting framework largely based on GVA, and as such it is imperfect.

For example, CVM GVA estimates are typically derived using current price (CP) gross output and CP intermediate consumption to calculate CP GVA, which is then deflated to calculate CVM GVA. By incorporating the use of CVM gross output, this methodology deviates from standard practice – and to that extent is inconsistent with the calculation of GVA in other industries. In the future, this process may be made more coherent by incorporating it with a system of double-deflated estimates of GVA – whereby all CVM

GVA measures would be derived by calculating CVM gross output and CVM intermediate consumption. ONS are currently working on creating such a double-deflated framework.

**Annex B: Additional Capitals Specifications**

All capitals (beyond those standardly used in the National Accounts – see HMM19) incorporated in Net National Disposable Income + (NNDI+) use a Perpetual Inventory Model (PIM) with linear depreciation. Below is a list of these additional capitals as well as the asset lives used in their PIM.

| Set of Capitals | Capital | Asset Life |
|---|---|---|
| Household Assets | Cars | 10 years |
| | White Goods | 10 years |
| | ICT | 4 years |
| (Previously uncapitalised) Intellectual Property Products (i.e. Intangible Assets) | Organisational Capital | 10 years |
| | Design | 13 years |
| | Financial Product Innovation | 10 years |
| | Branding | 5 years |
| | Training | 5 years |

## Annex C: Previously Uncapitalised Intellectual Property Product (i.e. 'Intangible') Investment

The contribution to CVM Augmented Gross Domestic Income (GDI+) from investment in additional Intellectual Property Products (IPP) (outside of those already included in SNA 2008) is calculated by residual in Figure 4. First, adjusted current price GVA estimates by industry are calculated by adding the additional IPP investment to GVA for each industry (with GVA data coming from the ONS "GDP Output Approach – Low Level Aggregates" dataset). Second, GVA for each industry is deflated using the implied deflator for that industry. A whole economy estimate of additional-IPP-adjusted chained volume GVA is then calculated – and the difference between this estimate and the original (non-adjusted) whole economy GVA figure yields an estimate for the contribution from the additional IPPs to CVM GDI+.

To calculate capital consumption (i.e., depreciation) for the additional IPPs, a linear PIM is constructed. To calculate current price capital consumption, these series are then reflated using the implied deflators for investment of the respective assets from the Investment in Intangible Assets in the UK statistical bulletin (ONS 2021b).

It is worth noting that these expanded IPPs are a potential area of overlap with other assets already included in National Accounts. For example, "Design" as an asset may have overlaps with Research and Development, which is already capitalised in the National Accounts. This article has made no attempt to quantify the potential extent of this overlap, and so the data should be treated with caution.

## Annex D: Household Production

Household production data have been deflated using three sources: Services producer price indices (SPPIs), experimental industry deflators, and the whole economy implied GVA deflator. Where available, SPPIs are used, then experimental industry deflators, followed by the implied GVA deflator. Where higher priority sources are available but only for select time periods, they have been spliced together along with lower priority sources.

The deflator sources for the different activities of household production are as follows:

- Household housing services: Experimental Industry Deflator for division 81 (Services to buildings and landscape activities)
- Transport: SPPI for Other Passenger Land Transport Services N.E.C. (CDID: HQDB)
- Nutrition: Experimental Industry Deflator for division 56 (Food and beverage service activities)
- Clothing: Whole economy implied GVA deflator
- Laundry: SPPI for Washing and (Dry-)Cleaning Services of Textile and Fur Products (CDID: I437)
- Childcare: Experimental Industry Deflator for division 88 (Social work activities without accommodation)
- Adult Care: Experimental Industry Deflator for division 88 (Social work activities without accommodation)
- Voluntary activity: Whole economy implied GVA deflator

Once volume estimates for all activities are calculated, a chained volume estimate for household production is calculated.

Depreciation of household capital has been calculated by interpreting household demand for the following products from Supply Use tables as investment in household capital:

- CPA26 Computer, Electronic and Optical Products
- CPA27 Electrical Equipment
- CPA29 Motor Vehicles, Trailers and Semi-Trailers

This investment is capitalised using a PIM with linear depreciation, as described in Annex B. Deflators are calculated using Producer Price Indices (PPIs) and Import Price Indices (IPIs), chained together using the domestic, EU, and non-EU supply for each respective product from the previous year (from Supply Use tables) as weights.

**Annex E: Climate Change Related Degradation of Atmospheric 'Natural Capital'**

*Introduction*

While ONS have undertaken extensive work to deliver ecosystem accounts and environmental asset valuations to meet policy maker and user needs, estimates of environmental asset depletion or degradation have not been produced to date. Depletion measures the amount of a natural resource extracted or used as part of economic production, while degradation adds to this the valuation of any loss of future ecosystem services due to the extraction / use of the natural resource in the current period. As set out in the System of Environmental-Economic Accounting (SEEA 2021), by subtracting degradation from measures of value added, national accounting frameworks can be adjusted to incorporate the (over-)use of environmental assets.

This paper aims to create an expanded measure of economic welfare, covering key areas of user demand such as household production and expanded Intellectual Property Products. One key criticism of GDP is that it does not fully reflect the negative impacts of economic production of carbon emissions and other contributors to climate change. The inclusion of these effects is a central tenet of several proposals for expanded economic welfare measures, such as the 'inclusive wealth' measure proposed by Dasgupta (2021). Despite the absence of data and established methodologies for how to measure the impact of climate within a national accounting framework in the UK, the authors of this paper see it as an important aspect of showcasing the framework being developed in this paper to also demonstrate what inclusion of climate-change related degradation due to carbon emissions might look like.

A thorough approach to measuring the impact of climate change on economic welfare would look to elaborate upon the carbon cycle, such as that outlined in Figure 13.1 of the new SEEA (UN 2021). Carbon can move between oceans, the Biosphere, the Geosphere, the Atmosphere, or be accumulated within the economy. By systematically valuing these sources of natural and non-natural assets – and particularly through measuring their supply of environmental services and degradation – as well as the flows of carbon between each, when undertaken on a global scale this could serve as a comprehensive framework for measuring the impact of climate change related degradation due to carbon.

While the work undertaken by ONS to value environmental assets and their corresponding environmental services will be integral to populating this comprehensive framework, there remains significant work to do. In the absence of substantial parts of this thorough framework, this paper presents a simplified model of degradation due to carbon emissions. For ease, this can be thought of as degradation of the atmosphere – but will include both direct and indirect degradation. For example, some degradation of the atmosphere may impact and degrade the biosphere.

The model primarily draws on analysis and studies by international bodies such as the International Panel on Climate Change (IPCC) and the Organisation for Economic Co-operation and Development (OECD), tying together these studies through simplifying assumptions and relations. The sources and assumptions are detailed in the 'Model' section of this annex, and the implications of the assumptions are explored in the 'Robustness Checks' section.

It is important to note that this model is not intended as a long-term proposal for how to measure climate change related degradation. Its use lies in giving a simple and indicative sense of both what the scale and the mechanics of climate change related degradation might be. Many important questions – such as the ownership of the atmosphere – are left unanswered or given simple answers. A selection of these issues will be explored toward the end of this annex in the 'Issues and Further Work' section.

*Model*

One simple method for valuing degradation – employed in this paper - is the damage-based approach. Under this approach, the damage caused by, or embodied in, the degradation of an environmental asset is used to value the degradation. In our case, that means valuing the loss of economic output (as measured by GDP) estimated to be associated with global warming resulting from carbon emissions.

This valuation method is combined with a presentation approach, as outlined in section 12.3.3 of SEEA 2021, of "Polluter pays". Under this method, the cost of the degradation is borne by the economic unit which caused the degradation. This method is useful where there are multiple contributors to degradation, and the effects of the degradation happen over a long timeframe – both of which are key features of atmosphere degradation due to climate change. Simply put, this presents the damage to the atmosphere caused by UK carbon emissions as being degradation in the UK's accounts, regardless of who owns the atmosphere.

The virtues of this method are worth highlighting, as its simplicity helps put to one side (for the time being) several difficult questions. The method allows us to examine the UK's impact on the entire global atmosphere, as opposed to one part of it. Accordingly, this method could be interpreted as measuring the UK's degradation of an atmosphere asset which is owned by the world as a whole, or otherwise by some entity independent of any particular country (e.g. "Mother Nature") from which the UK imports "Atmosphere services". But the method could also be interpreted as measuring the combination of the UK's degradation of its own portion of the atmosphere, as well as importing "Atmosphere services" from other countries for the portion of their Atmosphere which the UK degrades. Both of these approaches to conceptualising the atmosphere (as being owned by an entity separate to nations, or being split between nations) have their own merits and issues. However, the model and results presented in this paper are consistent with both approaches, and so can be interpreted using either.

With these approaches established, the proposed model for (atmospheric) degradation at time t can be described by the following equations:

$$Degradation_t = \frac{\partial Atmospheric\ capital\ value_t}{\partial global\ temperature\ anomoly} \qquad [Equation\ AE1]$$

$$Atmospheric\ capital_t = \sum_{y=t}^{t+200} Discount\ factor_y \cdot Atmospheric\ services_y \qquad [Equation\ AE2]$$

$$Atmospheric\ services_t = f(global\ temperature\ anomoly_t, global\ GDP_t) \qquad [Equation\ AE3]$$

$$Global\ temperature\ anomoly_t = f(Atmospheric\ CO_2\ Concentration_t) \qquad [Equation\ AE4]$$

$$Atmospheric\ CO_2\ Concentration_t = f(CO_2\ Emissions_{t-1}, CO_2\ Emissions_{t-2}, \dots) \qquad [Equation\ AE5]$$

$$CO_2\ Emissions_t = UK\ Produced\ CO_2\ Emissions_t + Other\ Country\ Produced\ CO_2\ Emissions_t \qquad [Equation\ AE6]$$

Atmospheric degradation due to climate change at time t can be measured by the change in the value of atmospheric natural capital due to change in the global temperature anomaly (i.e. the deviation of global temperatures from their long-run trend). Atmospheric natural capital in turn can be valued using the discounted value of future flows of atmospheric services, where 'atmospheric services' measures the extent to which economic production relies directly or indirectly on the status of the atmosphere. These atmospheric services are modelled as being a function of the global temperature anomaly and global GDP – the latter to account for the idea that the value of services provided by the atmosphere would be proportional to the size of the economy. The global temperature anomaly is simplified as being a function solely of the concretion of carbon in the atmosphere, while that concentration is a function of historic carbon emissions. Finally, $CO_2$ emissions can be decomposed into those produced by the UK, and those produced by other countries.

Simply put, this model results in carbon emissions in one current period resulting in higher global temperatures in the current *and future* periods. As will be discussed shortly, higher global temperatures are associated with lower global GDP – which this model attributes to reduced Atmospheric Services. Resultantly, increased carbon emission in one current period result in reduced atmospheric services in the current and future periods, and the discounted value of this reduction is our measure of atmospheric degradation due to carbon emissions.

This model contains 4 exogenous variables:

- Discount factors, sourced from HMT's guidance on valuing environmental assets
- Global GDP, including forecasts for 2021-25, sourced from IMF (2020)
- UK Produced $CO_2$ emissions, sourced from the Global Carbon Project (2020)
- Other Country Produced $CO_2$ emissions, sourced from the Global Carbon Project (2020)

Although, as will be elaborated upon later, the model is calculated for each year independently, and the global temperature anomaly (taken from NASA) is treated as semi-exogenous to account for other factors which may have impacted global temperatures.

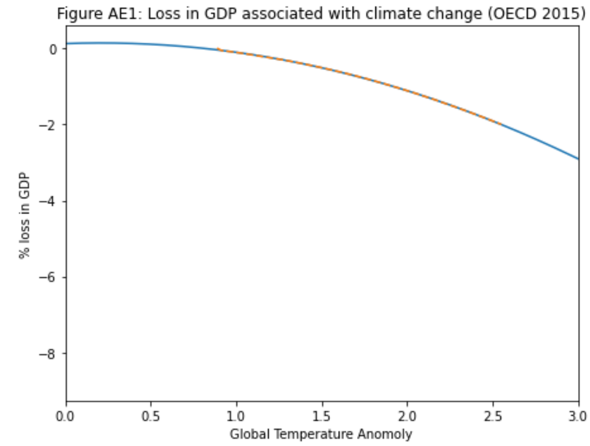
The key functions sourced from other models and research, are:

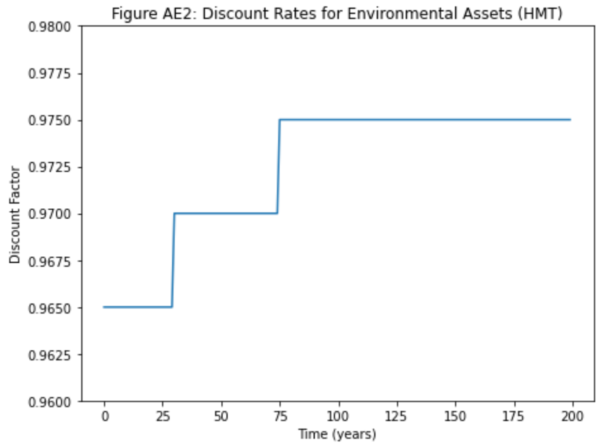
- AE3, describing the relationship between atmospheric services, global temperature anomaly, and GDP, is sourced from OECD (2015) and extended beyond the global temperature anomaly range examined in that source using a quadratic polynomial (see Figure AE1)

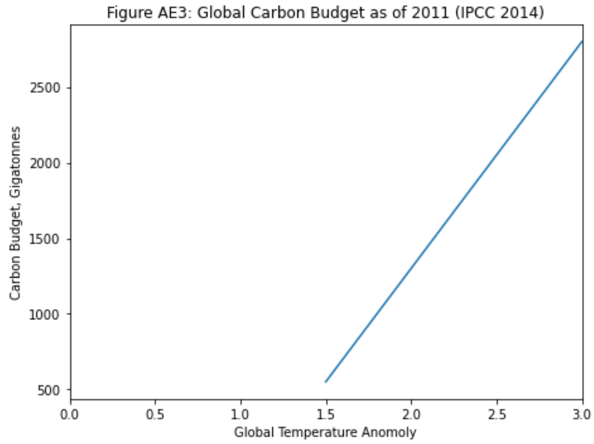
- AE4, describing the relationship between the (smoothed) global temperature anomaly and atmospheric carbon concentration, is sourced from IPCC (2014) and extended using a linear extrapolation (see Figure AE3), and

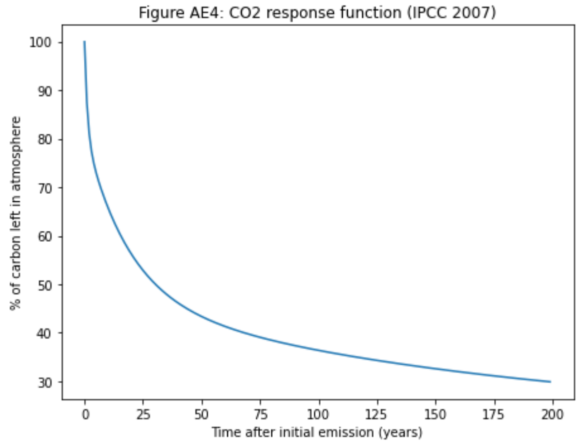
- AE5, describing the relationship between atmospheric $CO_2$ concentration and historic carbon emissions is sourced from IPCC (2007).

Figures AE1 to AE4 visualise these functions as they are used in our model (as well as the discount rates advised by HMT when measuring the net present value of environmental assets).




*Robustness Analysis*

Along with the general structure of the model, and implicit assumptions about the functioning of the economy and climate within it, there are two key parameters which need to be chosen for the model to function which have implications for the output: The asset life and the forecast for global GDP growth in the long term from 2026 onwards (for 2021 to 2025, IMF forecasts are used). While it is a technical term for the purpose of Net Present Value (NPV) models of asset value, 'asset life' may be a slightly misleading term in the context of environmental assets – it simply represents the period over which we consider the flow of benefits from an asset for the purpose of measuring its NPV.

Figures AE5 to AE8 below explore the implications for our atmosphere degradation estimates as both the asset life window is changed from 50 to 100, 200, and 500 years, as well as when the long term global GDP growth forecast is changed from 0%, to 1.5%, 2.4%, and 3.5% - and the interaction between this two parameters. The calibration chosen for this article is an asset life of 200 years, accompanied by a growth forecast of 2.4%. Care should be taken when comparing across the figures to note the different scales of the y-axes.

Figure AE5: Atmosphere degradation, 0% global GDP growth forecast

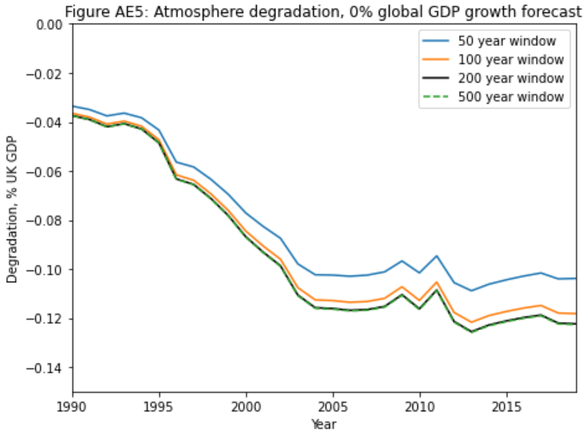



Figure AE6: Atmosphere degradation, 1.5% global GDP growth forecast

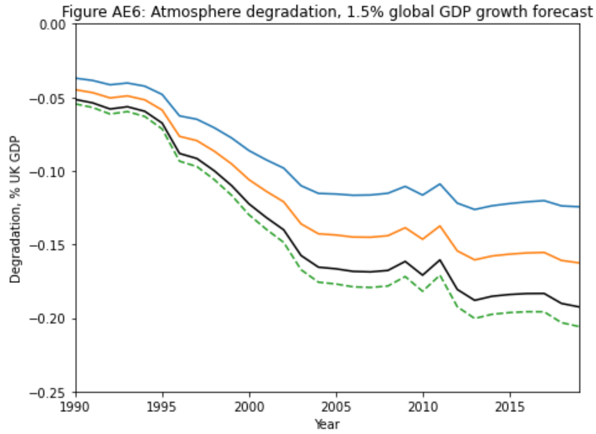



Figure AE7: Atmosphere degradation, 2.4% global GDP growth forecast

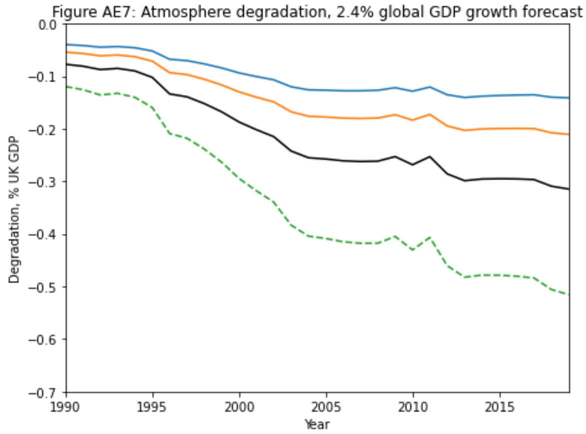
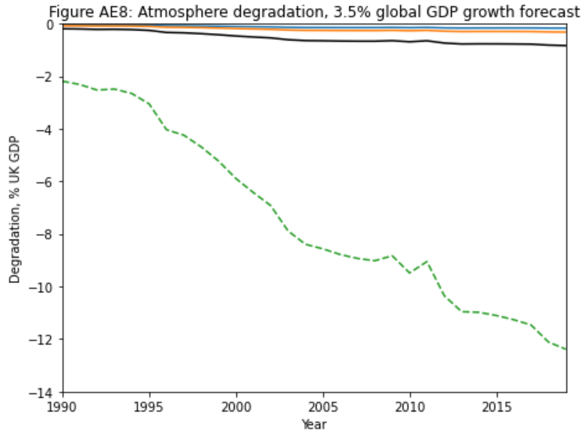
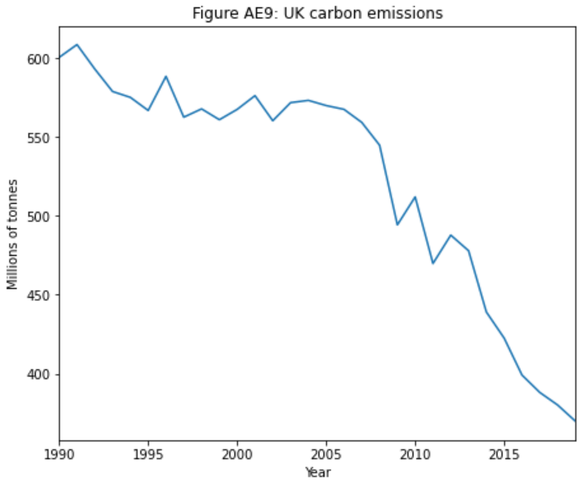
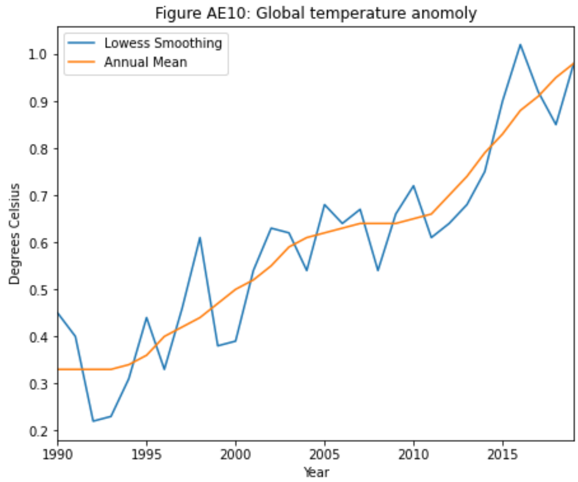



Figure AE8: Atmosphere degradation, 3.5% global GDP growth forecast




Despite changes in the scale of degradation, the broad trajectory for degradation over time remains similar across the varying assumptions. That trajectory involves degradation increasing in scale from the mid-1990s, but then the pace of increase slowing during the mid-2000s – or, under some assumptions, the scale of degradation relative to GDP remaining broadly constant from the point onward. This is an interesting result given the reduction in UK carbon emissions from around 2007 onwards shown in Figure AE9. This outcome reflects the fact that, while fewer emissions have been produced in recent years, they are being emitted into a warmer world (Figure AE10). Figure AE1 shows the relationship between GDP loss and temperature anomaly used in this model – as the temperature increases, the marginal effect on GDP of an increase in temperature increases, i.e. there are increasing marginal costs to global warming. The result of this implies the marginal damage per unit of carbon emitted increases over time, as the global temperature has increased. This higher marginal damage either counterbalances or outweighs the reduction of carbon emissions, leaving degradation as a portion of GDP unchanged or still increasing.

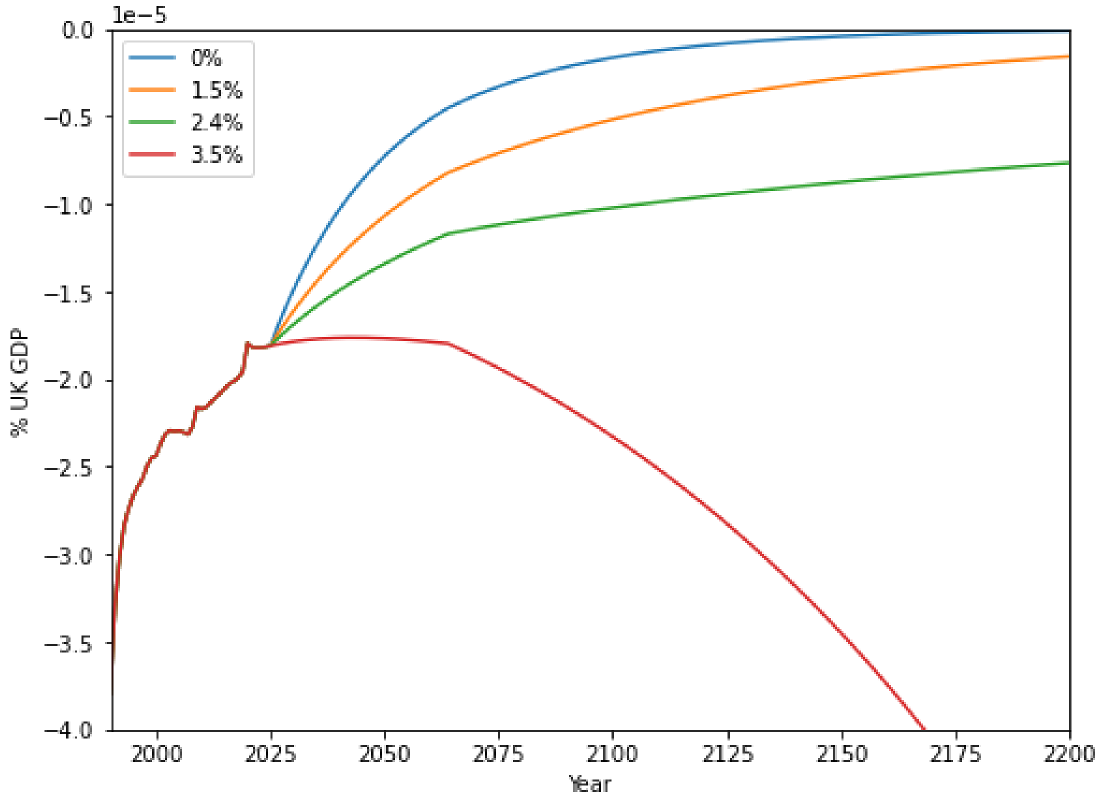



However, this robustness analysis demonstrates that the scale of degradation is highly dependent on the choice of these parameters, varying from around 0.1% of GDP in 2019 when using a 50 year window and 0% global GDP forecast, to 0.5% of GDP in 2019 when using a 500 year asset life. The fundamental contradiction here is difficult to escape for any analysis of the long-term impacts of climate change – the effects of carbon emissions have the potential to extend far beyond the standard time frames examined by economists, extending further in the future than the time span between the industrial revolution and today. Unfortunately, forecasting what the size of the global economy may look like over that time span is as difficult as it is necessary for this analysis – 2.4% over the next 200 years has been chosen as being broadly in line with estimates of global GDP growth over the previous 200 years.

Another reason to restrict both the assumption for global GDP growth as well as the timeframe is particular to the model – so that emissions produced in one year produce damages which tends to zero over time. There are two factors in the model which cause damages of emissions produced in one year to decay over time – the discount factor and the decay function of carbon. These are offset by the assumption that damages will be proportionate to GDP. If GDP growth is assumed to be high, then the damage of emissions one year will initially decrease, but then start to increase again over time (as demonstrated in Figure AE11). This would mean that, if the asset life were infinite, then the degradation caused by emissions would be infinite as well. Even if a finite asset life is chosen, the scale of degradation becomes highly dependent on the asset life chosen (as can be seen in Figure AE8).

**Figure AE11: Net present value of damage due to climate change impacts associated with UK carbon emissions in 1990, by year of damage and assumption for GDP growth from 2026 onward**




There exists a plausible argument that the net present value of climate change inducing emissions could be infinite – for example, when considering the possibility of climate change prompting an extinction event. However, for the purposes of this analysis, which seeks to examine the scale and trajectory of degradation over time, having finite valuations is a requirement.

*Issues and Further Work*

As referenced earlier, this model of atmospheric degradation due to carbon-related climate change is only intended as a simple example of how measurement in this area might be undertaken, and is not intended as a definitive or complete measure of the UK's contribution to the damage of climate change. To draw out the ways in which this model is heavily simplified, but also to suggest where future work may be valuable in the future, this section explores some of the issues and deficiencies in the model and its sources.

The first point to note is that the climate-change associated damages which are accounted for in this model (from OECD (2015)) only reflect a select group of damages due to climate change, and exclude others. Those included are the effect of climate change on:

- Agriculture (Changes in crop yields, changes in fisheries catches)
- Coastal zones (loss of land and capital from sea level rise)
- Extreme events (capital damages from hurricanes)

- Health (Mortality and morbidity from infectious diseases, cardiovascular and respiratory diseases, Morbidity from heat and cold exposure)
- Energy demand (Changes in energy demand from cooling and heating)
- Tourism demand (Changes in tourism flows and services)

This excludes the effect on ecosystems and water stress. In addition, the OECD (2015) analysis excludes any modelling for tipping points. Finally, the relationship between temperature anomaly and climate-change related damage taken from OECD (2005) is the output of a dynamic model that does account for economic shifts over time – but in our analysis this has been treated to some extent as a static relationship.

A second point is that the intuition for our degradation model assumes that the value of damage associated with emissions in one period should take into account the damage of all previous emissions (by being dependent on the temperature anomaly in the respective year), but does not take into account future emissions. So, for example, if 2 countries were to pollute the same amount, but in different years, the country which pollutes in the later year would be deemed to have caused more degradation than the country polluting in the earlier year (due to our model having increasing marginal costs to global warming). In the real world, this might be argued to underestimate the degradation caused by countries (such as the UK) which industrialised earlier and are now reducing emissions, and overestimate the degradation of countries which currently have lower but quickly growing GDP (with emissions correspondingly growing relatively fast).

Thirdly, the model proposed here only account from climate-change related degradation of the atmosphere due to carbon emissions. Other greenhouse gases – including, for example, methane – are not accounted for, and to that extent the outputs of the model should be treated as lower end estimates of degradation due to climate change.

Next, the $CO_2$ response function used in this paper uses the calibration of a Bern model presented for analysis in IPCC (2007). This calibration uses a set level of atmospheric carbon concentration, which simplifies the model but does mean the model is not dynamic in respect to changes in the concentration of carbon in the atmosphere. We have used this simplified model in the opinion that the added dynamism would provide minimal benefit given our intention of putting together only a basic, exploratory model.

Finally, we draw attention to the model not accounting for the interaction between the carbon budget, the $CO_2$ response function, and other stores of carbon such as the ocean and the biosphere. So, for example, we do not account for the interaction that over long periods of time, as carbon leaves the atmosphere this may affect the carbon budget. Nor do we account for the changing capacity of the ocean or biosphere to absorb carbon, or the effects this absorption would have on them.

These issues and others highlight that this model is very much intended as a contribution to the early stages of a conversation in the UK about how climate change and other ecological phenomenon could be reflected in a welfare measure. While the results paint an interesting narrative which the authors believe to be illuminating – that degradation as a share of GDP hasn’t fallen despite a fall in emissions – this should be treated with caution in light of these issues.

## Annex F: Spectrum Datasets

Table F1: Current Price Spectrum Estimates and Contributions

| | Market GVA | Non-market GVA | Taxes minus subsidies | GDP | Intangible Investment | Quality Adjusted Public Services | Household production | Carbon Seques-tration | Augmented Gross Domestic Income | Capital depreciation: National Accounts | Capital depreciation: Intangible Investment | Capital depreciation: Household Capital | Climate degradation | Income & Transfers from abroad | Augmented Net National Disposable Income |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | **630,082** | 230,158 | 91,510 | **951,750** | 47,063 | - | | | | - 123,341 | | | -1,247 | -5,197 | |
| 1998 | **660,861** | 237,676 | 98,710 | **997,247** | 52,582 | - | | 1,358 | | - 127,508 | | | -1,433 | 1,176 | |
| 1999 | **682,864** | 249,825 | 107,063 | **1,039,752** | 56,512 | - | | 1,354 | | - 135,199 | | | -1,652 | -11,240 | |
| 2000 | **721,880** | 260,783 | 113,237 | **1,095,900** | 61,286 | - | | 1,393 | | - 143,527 | | | -1,948 | -5,800 | |
| 2001 | **745,805** | 277,552 | 115,018 | **1,138,375** | 64,113 | - | | 1,440 | | - 153,142 | | | -2,188 | 1,533 | |
| 2002 | **777,503** | 290,886 | 119,282 | **1,187,671** | 66,588 | - | | 1,483 | | - 161,875 | | | -2,440 | 6,215 | |
| 2003 | **821,326** | 309,420 | 125,442 | **1,256,188** | 69,687 | - | | 1,519 | | - 170,439 | | | -2,917 | 5,502 | |
| 2004 | **855,997** | 328,238 | 133,224 | **1,317,459** | 73,379 | - | | 1,544 | | - 176,871 | | | -3,230 | 2,965 | |
| 2005 | **905,886** | 348,309 | 138,843 | **1,393,038** | 77,135 | - | 684,877 | 1,585 | **2,156,635** | - 186,481 | -75,758 | - 63,419 | -3,457 | 6,336 | **1,833,856** |
| 2006 | **960,069** | 364,539 | 146,111 | **1,470,719** | 80,261 | - | 710,686 | 1,629 | **2,263,295** | - 197,757 | -76,484 | - 65,517 | -3,709 | -10,825 | **1,909,003** |
| 2007 | **1,013,880** | 377,726 | 154,479 | **1,546,085** | 85,895 | - | 761,523 | 1,657 | **2,395,160** | - 208,892 | -79,149 | - 66,499 | -3,929 | -20,756 | **2,015,935** |
| 2008 | **1,045,902** | 391,780 | 151,577 | **1,589,259** | 84,326 | - | 822,438 | 1,718 | **2,497,741** | - 223,889 | -83,944 | - 66,809 | -4,040 | -28,294 | **2,090,765** |
| 2009 | **1,007,301** | 402,588 | 138,624 | **1,548,513** | 82,926 | - | 890,020 | 1,748 | **2,523,207** | - 233,399 | -85,654 | - 63,422 | -3,817 | -26,733 | **2,110,182** |
| 2010 | **1,034,193** | 412,284 | 159,550 | **1,606,027** | 82,472 | - | 917,950 | 1,780 | **2,608,229** | - 234,825 | -88,753 | - 62,015 | -4,213 | -18,815 | **2,199,608** |
| 2011 | **1,066,837** | 415,037 | 178,267 | **1,660,141** | 80,732 | - | 982,992 | 1,794 | **2,725,659** | - 241,971 | -87,591 | - 62,340 | -4,117 | -14,227 | **2,315,414** |
| 2012 | **1,106,340** | 423,325 | 182,105 | **1,711,770** | 81,826 | - | 1,021,507 | 1,748 | **2,816,851** | - 250,247 | -85,798 | - 63,037 | -4,808 | -38,678 | **2,374,284** |
| 2013 | **1,159,540** | 429,255 | 191,541 | **1,780,336** | 84,236 | - | 1,092,304 | 1,798 | **2,958,674** | - 257,408 | -84,180 | - 65,252 | -5,241 | -62,083 | **2,484,510** |
| 2014 | **1,217,478** | 443,755 | 201,775 | **1,863,008** | 86,586 | - | 1,144,063 | 1,816 | **3,095,473** | - 265,638 | -84,066 | - 66,556 | -5,441 | -61,955 | **2,611,816** |
| 2015 | **1,256,278** | 455,794 | 207,569 | **1,919,641** | 92,066 | - | 1,213,031 | 1,850 | **3,226,588** | - 274,744 | -84,017 | - 68,871 | -5,612 | -68,163 | **2,725,182** |
| 2016 | **1,304,348** | 473,018 | 217,346 | **1,994,712** | 94,832 | - | 1,242,874 | 1,894 | **3,334,312** | - 287,314 | -86,590 | - 72,132 | -5,854 | -72,277 | **2,810,144** |
| 2017 | **1,359,834** | 484,176 | 224,747 | **2,068,757** | 101,160 | - | | | | - 302,915 | -89,674 | - 74,070 | -6,116 | -48,074 | |
| 2018 | **1,413,482** | 496,765 | 231,545 | **2,141,792** | 105,413 | | | | | - 315,534 | -92,646 | - 76,666 | -6,619 | -53,366 | |
| 2019 | **1,458,981** | 518,115 | 237,266 | **2,214,362** | | | | | | - 327,897 | | | -6,965 | -64,808 | |

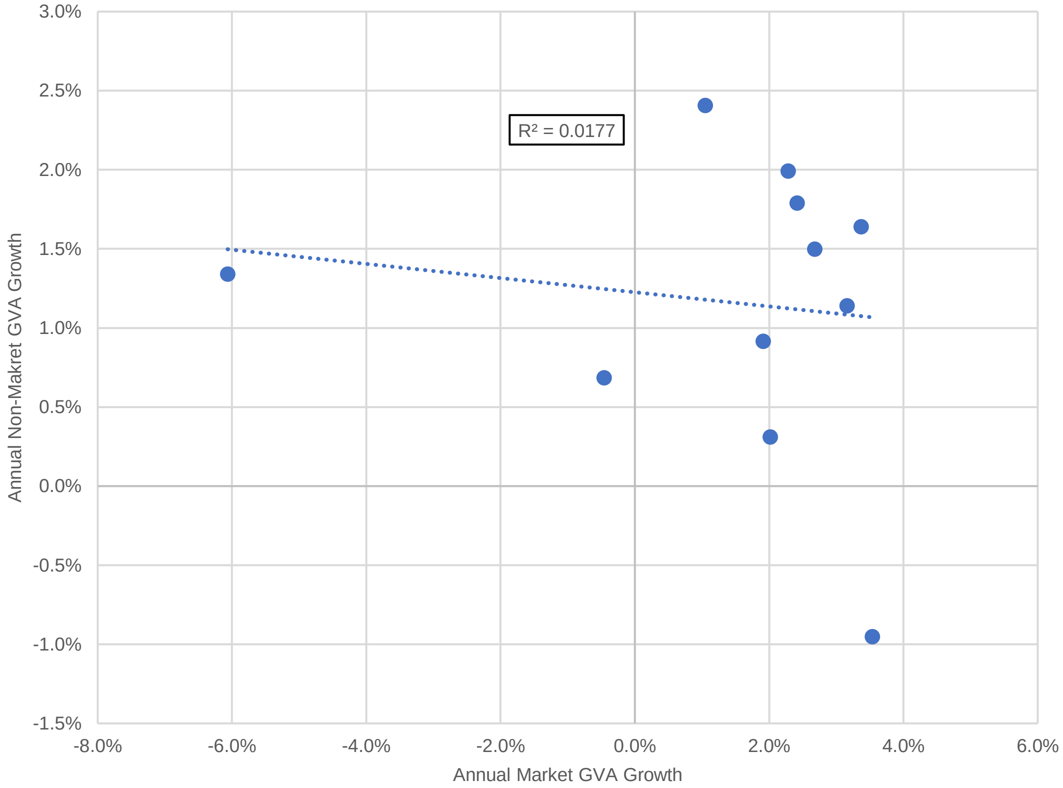
## Table F2: Chained Volume Spectrum Measures and Contributions (£2016)

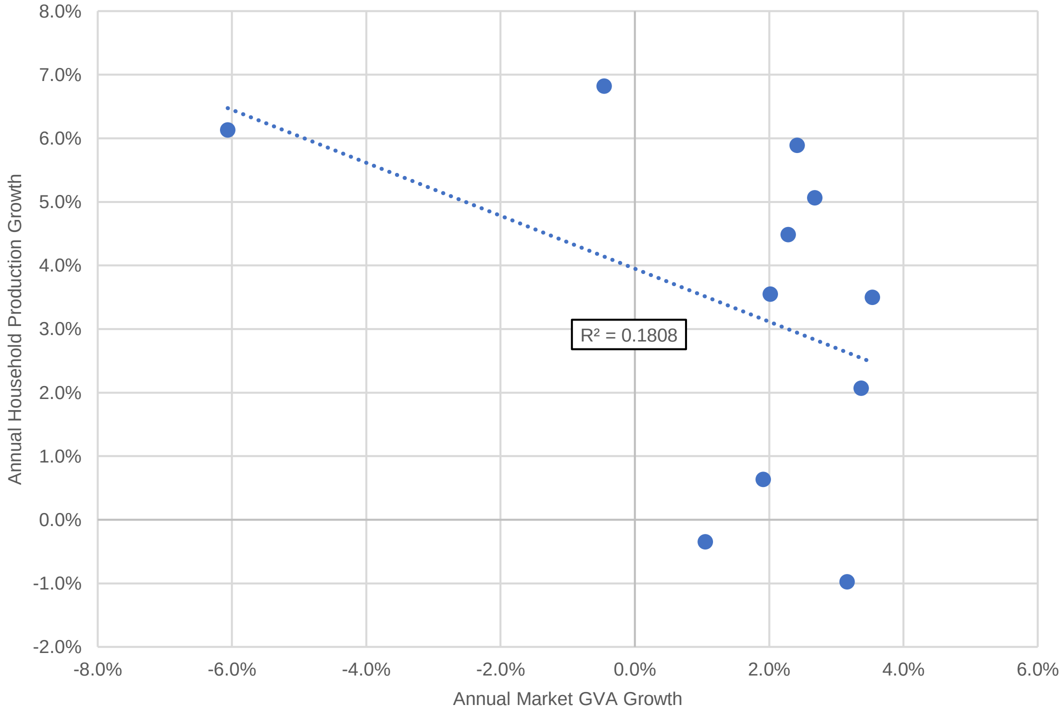
| | **Market GVA** | Non-market GVA | Taxes minus subsidies | **GDP** | Intangible Investment | Quality Adjusted Public Services | Household production | Carbon Seques-tration | **Augmented Gross Domestic Income** | Capital depreciation: National Accounts | Capital depreciation: Intangible Investment | Capital depreciation: Household Capital | Climate degradation | Income & Transfers from abroad | **Augmented Net National Disposable Income** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | **860,951** | 346,199 | 162,508 | **1,365,477** | 60,889 | -20,387 | | | | -172,210 | | | -870 | -7,456 | |
| 1998 | **900,395** | 347,198 | 172,726 | **1,416,106** | 69,120 | -19,615 | | 1,927 | | -177,694 | | | -1,010 | 1,670 | |
| 1999 | **927,597** | 357,972 | 182,394 | **1,462,769** | 74,613 | -19,621 | | 1,904 | | -186,376 | | | -1,175 | -15,813 | |
| 2000 | **968,400** | 366,927 | 182,686 | **1,514,058** | 80,610 | -19,349 | | 1,925 | | -194,663 | | | -1,410 | -8,013 | |
| 2001 | **994,242** | 377,938 | 187,230 | **1,555,396** | 84,327 | -19,137 | | 1,967 | | -202,969 | | | -1,602 | 2,095 | |
| 2002 | **1,014,644** | 386,982 | 191,898 | **1,589,285** | 84,958 | -18,346 | | 1,983 | | -210,388 | | | -1,824 | 8,317 | |
| 2003 | **1,050,007** | 399,107 | 197,115 | **1,642,079** | 86,784 | -17,164 | | 1,984 | | -218,015 | | | -2,233 | 7,192 | |
| 2004 | **1,078,569** | 404,676 | 200,346 | **1,679,621** | 89,107 | -14,982 | | 1,967 | | -223,489 | | | -2,536 | 3,780 | |
| 2005 | **1,118,013** | 416,790 | 197,058 | **1,729,266** | 91,417 | -12,707 | 868,285 | 1,967 | **2,679,943** | -231,112 | -92,213 | -58,876 | -2,786 | 7,865 | **2,301,765** |
| 2006 | **1,153,375** | 421,543 | 204,015 | **1,775,849** | 93,489 | -9,953 | 859,805 | 1,964 | **2,723,264** | -238,645 | -91,054 | -59,274 | -3,075 | -13,071 | **2,317,168** |
| 2007 | **1,194,179** | 417,531 | 209,905 | **1,817,768** | 98,290 | -8,022 | 889,876 | 1,947 | **2,801,655** | -245,190 | -91,093 | -59,970 | -3,343 | -24,403 | **2,376,963** |
| 2008 | **1,188,738** | 420,391 | 206,815 | **1,812,701** | 95,094 | -5,935 | 950,571 | 1,959 | **2,856,321** | -253,669 | -92,287 | -59,917 | -3,543 | -32,272 | **2,414,247** |
| 2009 | **1,116,652** | 426,031 | 196,971 | **1,738,128** | 89,191 | -3,655 | 1,008,826 | 1,960 | **2,835,613** | -257,493 | -92,539 | -59,885 | -3,403 | -30,006 | **2,391,671** |
| 2010 | **1,146,575** | 432,421 | 195,679 | **1,774,177** | 87,574 | -2,836 | 1,059,898 | 1,966 | **2,921,538** | -257,386 | -92,372 | -60,623 | -3,813 | -20,785 | **2,486,418** |
| 2011 | **1,169,697** | 433,762 | 193,653 | **1,796,811** | 85,591 | -1,605 | 1,097,526 | 1,942 | **2,980,153** | -263,254 | -91,311 | -61,418 | -3,803 | -15,398 | **2,545,139** |
| 2012 | **1,181,938** | 444,200 | 196,471 | **1,822,511** | 86,067 | -1,232 | 1,093,717 | 1,861 | **3,003,209** | -269,319 | -89,472 | -62,727 | -4,517 | -41,180 | **2,536,037** |
| 2013 | **1,210,500** | 452,156 | 199,816 | **1,862,354** | 86,596 | -1,268 | 1,158,145 | 1,880 | **3,107,794** | -271,991 | -87,519 | -64,746 | -5,012 | -64,943 | **2,613,667** |
| 2014 | **1,251,304** | 459,570 | 204,868 | **1,915,669** | 87,763 | -856 | 1,182,074 | 1,866 | **3,186,622** | -275,266 | -86,358 | -66,457 | -5,294 | -63,706 | **2,689,631** |
| 2015 | **1,279,866** | 468,726 | 212,367 | **1,960,937** | 93,518 | -427 | 1,235,075 | 1,890 | **3,291,023** | -280,013 | -85,707 | -68,893 | -5,495 | -69,629 | **2,781,349** |
| 2016 | **1,304,348** | 473,018 | 217,346 | **1,994,712** | 94,831 | - | 1,242,874 | 1,894 | **3,334,311** | -287,314 | -86,590 | -72,132 | -5,854 | -72,277 | **2,810,143** |
| 2017 | **1,336,991** | 471,396 | 221,046 | **2,029,426** | 99,407 | 420 | | | | -295,987 | -88,084 | -76,024 | -6,237 | -47,160 | |
| 2018 | **1,360,113** | 472,628 | 222,143 | **2,054,847** | 102,227 | 1,273 | | | | -302,966 | -89,959 | -81,732 | -6,902 | -51,200 | |
| 2019 | **1,377,794** | 480,970 | 222,558 | **2,080,756** | | | | | | -308,998 | | | -7,416 | -60,898 | |

Table F3: Contributions to Cumulative Growth in CVM Augmented Net National Disposable Income Since 2005 (percentage points)

| | Market GVA | Non-market GVA | Taxes minus subsidies | Investment in additional IPPs | Quality Adjusted Public Services | Household production | Carbon Sequestration | Capital depreciation: National Accounts | Capital depreciation: Additional IPPs | Capital depreciation: Household Capital | Climate degradation | Income & Transfers from abroad | **Augmented Net National Disposable Income** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** |
| 2006 | 1.56 | 0.22 | 0.27 | 0.10 | 0.12 | -0.36 | 0.00 | -0.33 | 0.05 | -0.02 | -0.02 | -0.91 | **0.67** |
| 2007 | 3.35 | 0.03 | 0.49 | 0.31 | 0.20 | 0.95 | 0.00 | -0.62 | 0.05 | -0.06 | -0.04 | -1.40 | **3.27** |
| 2008 | 3.12 | 0.17 | 0.37 | 0.17 | 0.30 | 3.61 | 0.00 | -0.99 | 0.00 | -0.06 | -0.05 | -1.74 | **4.89** |
| 2009 | -0.06 | 0.43 | 0.01 | -0.09 | 0.40 | 6.14 | 0.00 | -1.16 | -0.01 | -0.06 | -0.04 | -1.65 | **3.91** |
| 2010 | 1.26 | 0.73 | -0.03 | -0.16 | 0.44 | 8.35 | 0.00 | -1.15 | -0.01 | -0.10 | -0.06 | -1.25 | **8.02** |
| 2011 | 2.29 | 0.79 | -0.11 | -0.26 | 0.50 | 9.95 | 0.00 | -1.41 | 0.04 | -0.14 | -0.06 | -1.01 | **10.57** |
| 2012 | 2.82 | 1.27 | 0.01 | -0.23 | 0.51 | 9.79 | 0.00 | -1.68 | 0.13 | -0.20 | -0.10 | -2.13 | **10.18** |
| 2013 | 4.06 | 1.62 | 0.15 | -0.21 | 0.51 | 12.58 | 0.00 | -1.80 | 0.21 | -0.30 | -0.12 | -3.16 | **13.55** |
| 2014 | 5.85 | 1.94 | 0.37 | -0.16 | 0.53 | 13.62 | 0.00 | -1.94 | 0.27 | -0.37 | -0.14 | -3.11 | **16.85** |
| 2015 | 7.09 | 2.34 | 0.70 | 0.09 | 0.55 | 15.91 | 0.00 | -2.14 | 0.29 | -0.48 | -0.15 | -3.37 | **20.84** |
| 2016 | 8.16 | 2.52 | 0.92 | 0.15 | 0.57 | 16.25 | 0.00 | -2.46 | 0.26 | -0.63 | -0.16 | -3.48 | **22.09** |

## Annex G: Correlations of Household and non-Market GVA to Market GVA



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