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The Digital Economy, Welfare and Productivity Growth

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16 May 2019

References

1. Diewert, W.E., K.J. Fox and P. Schreyer (2019), "Experimental Economics and the New Goods Problem", Discussion Paper 19-03, Vancouver School of Economics, University of British Columbia.

1. Brynjolfsson, E., A. Collis, W.E. Diewert, F. Eggers and K.J. Fox (2019), "GDP-B: Accounting for the Value of New and Free Goods in the Digital Economy", NBER Working Paper 25695. https://www.nber.org/papers/w25695

2. Diewert, W.E., K.J. Fox and P. Schreyer (2018), "The Digital Economy, New Products and Consumer Welfare", Economic Statistics Centre of Excellence (ESCoE) Discussion Paper 2018-16, London, UK.
https://www.escoe.ac.uk/wp-content/uploads/2018/11/ESCoE-DP-2018-16.pdf

Challenges

1. **How does the digital economy affect welfare and GDP?**

2. **Are benefits from free and new goods appropriately measured?**

3. **Can mismeasurement help explain the productivity growth slowdown in industrialized countries?**

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Experimental Economics and the New Commodities Problem

W. Erwin Diewert, Kevin J. Fox and Paul Schreyer

Discussion Paper 19-03
Vancouver School of Economics
University of British Columbia

Summary

- **Brynjolfsson, Collis, Diewert, Eggers and Fox (2019) have used experimental economics to measure the welfare benefits of free (digital) commodities and to define an extended measure of output, GDP-B.**

- **Adapt their methodological approach to new commodities which may or may not be free.**

- **Provide a new method for estimating Hicksian reservation prices, the prices that reduced demand to zero in the period before they existed.**

- **Show that the Total Income Approach to GDP-B is (approximately) the difference between a true index and measured GDP.**

Background

- **Statistical agencies typically use a “matched model” approach to construct price indexes → maximum overlap index**
- **These are used to deflate value aggregates.**
- **From the economic approach to index numbers, reservation prices for the missing products should be matched with the zero quantities for the missing products in each period**
  - **The reservation price for a missing product is the price which would induce a utility maximizing potential purchaser of product to demand zero units of it (Hicks 1940; Hofsten 1952; Hausman 1996).**

The Paper in Two Figures: q_1=regular good, z=new good; w^R=reservation price

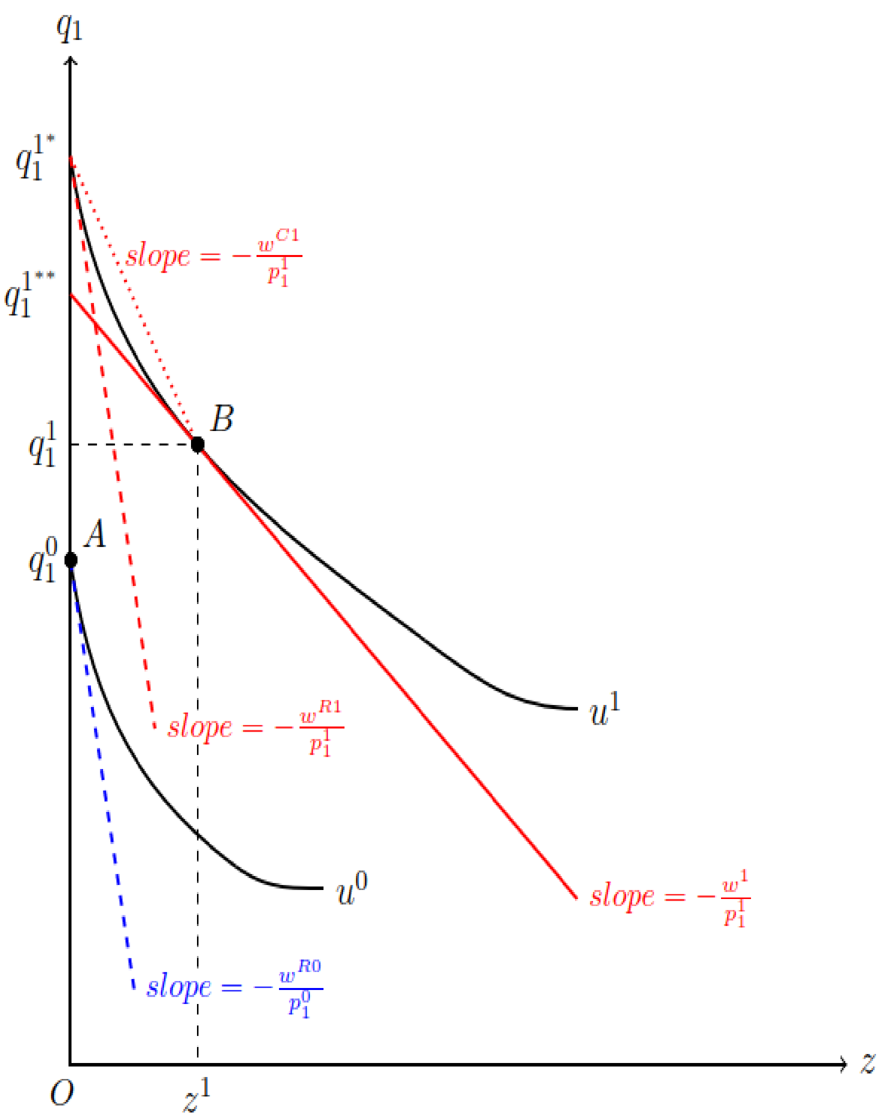

Figure 1: The Two Commodity Case, when $w^1 > 0$

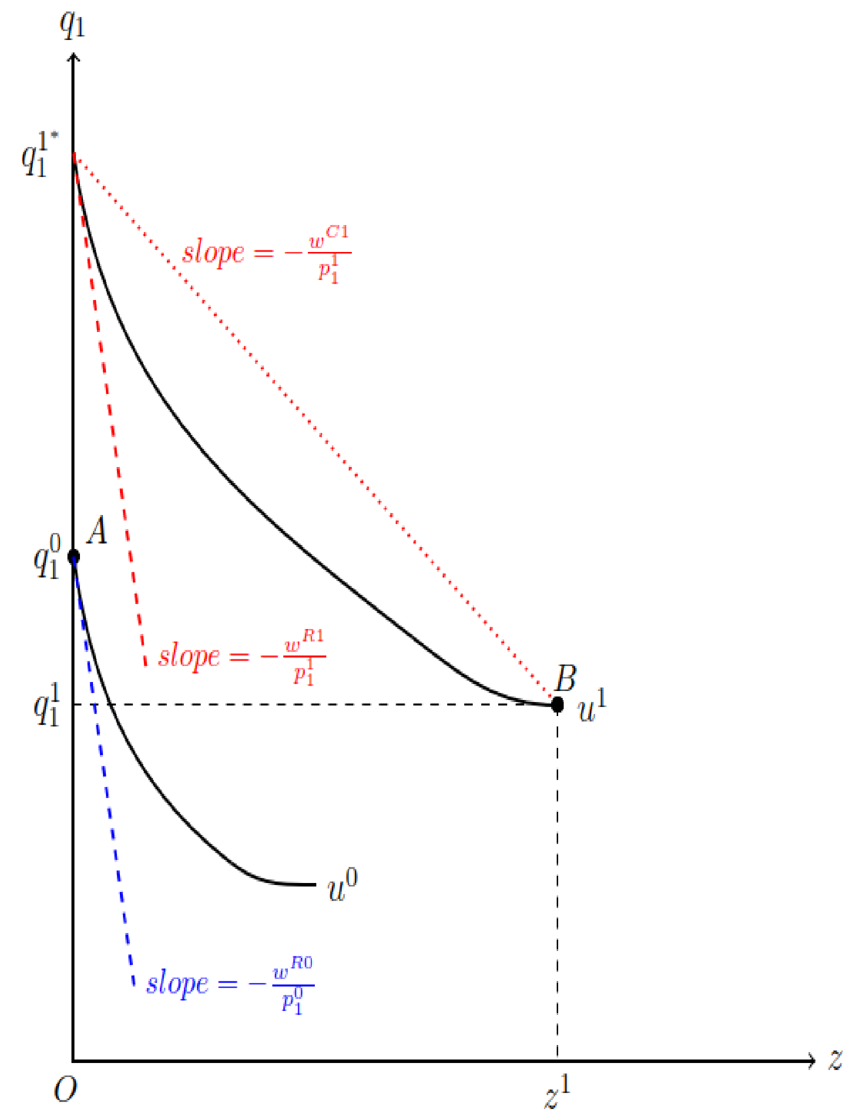

Figure 2: The Two Commodity Case, when $w^1 = 0$

The Paper in Two Figures: q^1=regular good, z=new good; w^R=reservation price

Utility function is homogeneous of degree 1. Hence:

$$-w^{R1}/p_1^{\,1} = -w^{R0}/p_1^{\,0}$$

and we can solve for the new commodity's reservation price in period 0:

$$w^{R0} = w^{R1}/[p_1^{\,1}/p_1^{\,0}]\ ;$$

The period 0 reservation price is the inflation adjusted *carry backward* period 1 reservation price. That is, deflated by the inflation of the continuing, regular commodity.

⇒ if we have an estimate of w^{R1} from e.g. BCDEF-style Willingness-to-Accept experiments, then we have w^{R0}.

Some Theory

What is the income required for the household to achieve the utility level u^1, excluding the use of the new commodity?

$$c(u^1,p^1,0) \equiv \min_q \{p^1 \cdot q : f(q,0) = u^1\} > c(u^1,p^1,z^1) = p^1 \cdot q^1$$

Define the monetary compensation m^1 that is additional to $p^1 \cdot q^1$ that is required to keep the household at the utility level u^1 without using z^1 as follows:

$$m^1 \equiv c(u^1,p^1,0) - p^1 \cdot q^1$$

Some Theory

We convert m^1 into a period 1 *average compensation price per unit of z foregone* by setting m^1 equal to $w^{C1}z^1$:

$$w^{C1} \equiv m^1/z^1$$

Recall the two figures from earlier….

The Paper in Two Figures: q_1=regular good, z=new good; w^R=reservation price

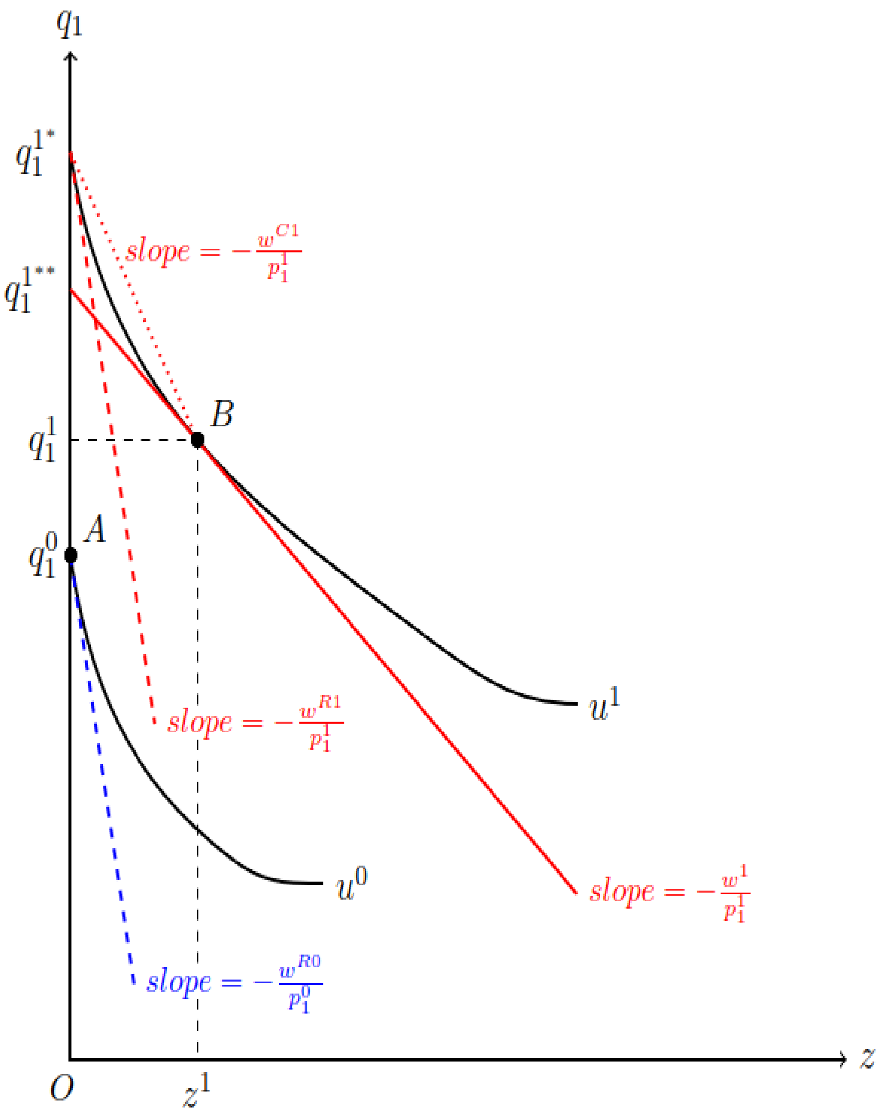

Figure 1: The Two Commodity Case, when $w^1 > 0$

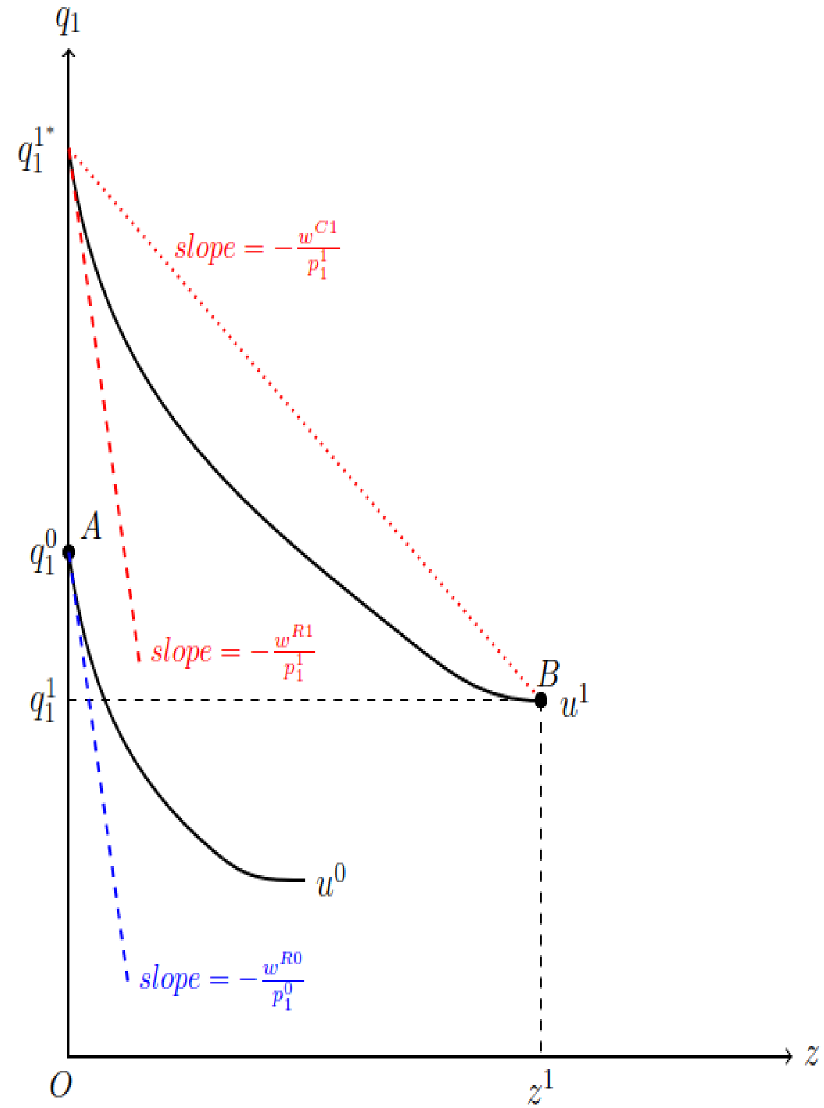

Figure 2: The Two Commodity Case, when $w^1 = 0$

Some Theory

First-order Taylor series approximations:

$$c(u^1,p^1,0) \approx c(u^1,p^1,z^1) + [\partial c(u^1,p^1,z^1)/\partial z][0 - z^1] = c(u^1,p^1,z^1) + w^1 z^1.$$

$$\Rightarrow \ c(u^1,p^1,0) - c(u^1,p^1,z^1) \approx w^1 z^1$$

$$c(u^1,p^1,z^1) \approx c(u^1,p^1,0) + [\partial c(u^1,p^1,0)/\partial z][z^1 - 0] = c(u^1,p^1,0) - w^{R1} z^1,$$

$$\Rightarrow \ c(u^1,p^1,0) - c(u^1,p^1,z^1) \approx w^{R1} z^1$$

Arithmetic average of the two first order approximations:

$$c(u^1,p^1,0) - c(u^1,p^1,z^1) \approx \tfrac{1}{2}(w^1 + w^{R1}) z^1$$

Some Theory

$c(u^1,p^1,0) - c(u^1,p^1,z^1) = m^1 = w^{C1}z^1 \approx \frac{1}{2}(w^1 + w^{R1})z^1$.

Can solve for the unknown reservation price w^{R1}.

$$w^{R1} \approx 2w^{C1} - w^1$$

Recall that w^1 is the observed market price for z^1 and w^{C1} is the period 1 compensation price per unit of z foregone, as elicited from experimental evidence.

If z is free, then $w^1 = 0$ and $w^{R1} \approx 2w^{C1}$.

Note

- It is unclear how good this approximation would be for truly novel products.
  - BCDEF (2018) argue that a reservation price of twice the per unit compensation price is too low, at least for innovative digital products with few substitutes.

- If q and z are perfect substitutes, then the indifference curves are linear:
  - Then the reservation price w^{R1}, the observed price w^{1} and the average compensation price w^{C1} are all equal.

What About GDP?

NSOs use *maximum overlap* price indexes (using only continuing goods) to deflate nominal value growth. Then the maximum overlap quantity index is:

$$Q_{MO} \equiv \{[p_1^1 q_1^1 + w^1 z^1]/[p_1^0 q_1^0]\}/[p_1^1/p_1^0]$$
$$= [q_1^1 + (w^1/p_1^1)z^1]/q_1^0 .$$

Laspeyres and Paasche "true" real indexes, Q_L and Q_p respectively:

$$Q_L \equiv [p_1^0 q_1^1 + w^{R0} z^1]/[p_1^0 q_1^0 + w^{R0} 0] = [q_1^1 + (w^{R0}/p_1^0)z^1]/q_1^0 \; ;$$
$$Q_P \equiv [p_1^1 q_1^1 + w^1 z^1]/[p_1^1 q_1^0 + w^1 0] \quad = [q_1^1 + (w^1/p_1^1)z^1]/q_1^0 \; .$$

What About GDP?

Approximate "true" Fisher quantity index:

$$Q_F \approx \tfrac{1}{2}Q_L + \tfrac{1}{2}Q_P$$
$$= [q_1^1 + \tfrac{1}{2}(w^{R1}/p_1^1)z^1 + \tfrac{1}{2}(w^1/p_1^1)z^1]/q_1^0$$

$$Q_F - Q_{MO} \approx [(w^{C1} - w^1)z^1/(p_1^1/p_1^0)]/p_1^0 q_1^0$$

If $w^1 = 0$:

$$Q_F - Q_{MO} \approx [m^1/(p_1^1/p_1^0)]/p_1^0 q_1^0$$

Note

- **Actually derived for the one continuing good case. Can easily generalise to multiple goods: only change in the above expressions is that $p_1^0 q_1^0$ becomes $p^0 \cdot q^0$.**
- **This is exactly the adjustment to GDP growth from the GDP-B Total Income Approach of BCEDF (2019).**
- **Thus if the approximation $w^{R1} \approx 2w^{C1} - w^1$, is a good one then the difference between the Total Income quantity index and the maximum overlap quantity index can be interpreted as the amount by which a maximum overlap index understates an approximate "true" Fisher index.**

Summary

- **Adapted the BCDEF (2019) approach to measure the benefits of new commodities which may or may not be free.**
- **Provided a new method for estimating Hicksian reservation prices, the prices that reduced demand to zero in the period before they existed.**
- **Showed that the BCDEF Total Income Approach to GDP-B is (approximately) the difference between a true index and measured GDP.**

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GDP-B: Accounting for the Value of New and Free Goods in the Digital Economy

Erik Brynjolfsson, Avinash Collis, W. Erwin Diewert, Felix Eggers, Kevin J. Fox

NBER Working Paper 25695

Background

There are two features of the Digital Economy that we focus on here:

1. **Free goods**
   - **E.g. Facebook, Wikipedia**
2. **New goods**
   - **E.g. Smartphones**

- **Free goods and new goods are poorly measured by GDP**

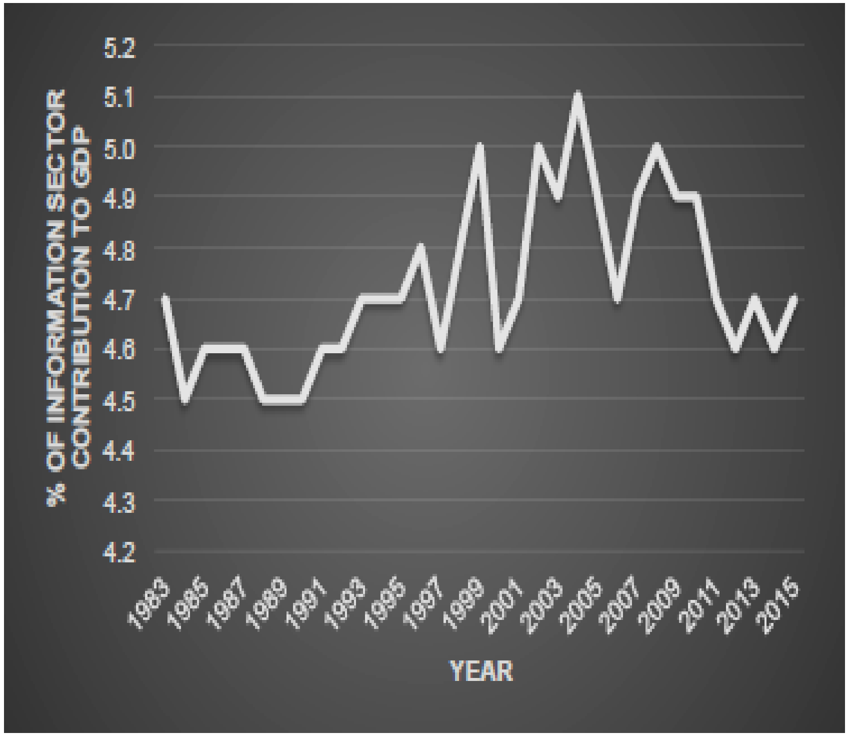
- **We introduce a new metric, we call “GDP-B”**
  - **We account for the benefits of free goods and new goods**
  - **In the future, we will add other adjustments**

Background

Brynjolfsson et al. (2017)

Explosion of free digital goods

Information goods as a share of GDP



Background

Brynjolfsson et al. (2017), Varian (2017)

Example: Smartphones and Cameras

- **Photos** taken worldwide
  - 2000: 80 billion photos
  - 2015: 1.6 trillion photos [20 times as many]
  - Price per photo has gone from **50 cents to 0 cents**.
- Increase doesn't show up in GDP measures since...
  - Price index for photography includes price of (**film, developing, cameras**) all of which are **vanishing**
  - Photos are mostly **shared, not sold** (non-monetary transaction)
  - GDP went *down* when cameras were absorbed into smartphones

Mismeasurement?

Simon Kuznets, 1934

"The welfare of a nation can scarcely be inferred from a measurement of national income as defined [by the GDP.]"

Charlie Bean (2016):

"statistics have failed to keep pace with the impact of digital technology"

Hal Varian (Google):

"There's a lack of appreciation for what's happening in Silicon Valley, because we don't have a good way to measure it."

The Wall Street Journal (2015): Silicon Valley Doesn't Believe U.S. Productivity is Down

Summary

- **Develop a new framework for measuring welfare change.**
  - **Based on the work of Hicks (1941), Bennet (1920) and Diewert and Mizobuchi (2009).**

- **Derive an explicit term that is the value of a new good's contribution to welfare change and GDP growth.**
  - **Welfare change mismeasurement if it is omitted from statistical agency collections.**
  - **Derive a lower bound on the addition to real GDP growth from the introduction of a new good.**

- **Then re-work the theory allowing for there to be "free" goods (with an implicit or imputable price).**

Summary

- **Brynjolfsson, Eggers and Gannamaneni (2018) suggested an approach to directly estimate consumer welfare by running massive online choice experiments.**

1. **We run incentive compatible discrete choice experiments**
   - **“Incentive compatible” => participants risk losing access to the good**
   - **Recruit a representative sample of the US internet population via online survey panel**
   - **Use data to estimate the consumer valuation of Facebook**

2. **Quantify the adjustment term to real GDP growth (GDP-B) for the contribution of Facebook from 2004 to 2017**

3. **Run additional incentive compatible discrete choice experiments to estimate the consumer valuation of several popular digital goods**
   - **Instagram, Snapchat, Skype, WhatsApp, digital Maps, Linkedin, Twitter, and Facebook**
   - **Conducted in a lab in the Netherlands**

Welfare Change and the New Goods Problem

Consumer's cost function:

$C(u,p) \equiv \min_q \{p \cdot q \, ; \, f(q) \geq u\}$

for each strictly positive price vector $p >> 0_N$ and each utility level u in the range of utility function, f(q), which is continuous, quasiconcave and increasing in the components of the nonnegative quantity vector $q \geq 0_N$.

Assume that the consumer minimizes the cost of achieving the utility level $u^t \equiv f(q^t)$:

$p^t \cdot q^t = C(f(q^t),p^t)$ for t = 0,1.

Welfare Change and the New Goods Problem

Valid measures of utility change over the two periods under consideration are the following Hicksian *equivalent and compensating variations*:

$$Q_E(q^0,q^1,p^0) \equiv C(f(q^1),p^0) - C(f(q^0),p^0)$$

$$Q_C(q^0,q^1,p^1) \equiv C(f(q^1),p^1) - C(f(q^0),p^1)$$

Hicks showed that the following provide a first-order approximation to equivalent and compensation variations, respectively:

$$V_L(p^0,p^1,q^0,q^1) \equiv p^0 \cdot (q^1 - q^0)$$

$$V_P(p^0,p^1,q^0,q^1) \equiv p^1 \cdot (q^1 - q^0)$$

Welfare Change and the New Goods Problem

The observable Bennet (1920) variation is the arithmetic average of the Laspeyres and Paasche variations:

$$V_B(p^0,p^1,q^0,q^1) \equiv ½(p^0 + p^1)\cdot(q^1 - q^0) = p^0\cdot(q^1 - q^0) + ½(p^1 - p^0)\cdot(q^1 - q^0)$$

$$= V_L + ½ \sum_{n=1}^{N} (p_n^1 - p_n^0)(q_n^1 - q_n^0)$$

Bennet variation is equal to the Laspeyres variation V_L plus a sum of N Harberger (1971) consumer surplus triangles of the form:

$$(1/2)(p_n^1 - p_n^0)(q_n^1 - q_n^0)$$

Also:

$$V_B(p^0,p^1,q^0,q^1) = V_P - ½ \sum_{n=1}^{N} (p_n^1 - p_n^0)(q_n^1 - q_n^0)$$

Welfare Change and the New Goods Problem

Recap:

Hicksian equivalent variation can be approximated by V_L

Hicksian compensating variation can be approximated by V_P

Hicks (1941) obtained the Bennet quantity variation V_B as an approximation to the arithmetic average of the equivalent and compensating variations.

Welfare Change and the New Goods Problem

A decomposition of nominal GDP change into Bennet quantity and price variations:

$$p^1 \cdot q^1 - p^0 \cdot q^0 = V_B + I_B$$

where

$$V_B(p^0,p^1,q^0,q^1) \equiv \tfrac{1}{2}(p^0 + p^1) \cdot (q^1 - q^0)$$

$$I_B(p^0,p^1,q^0,q^1) \equiv \tfrac{1}{2}(q^0 + q^1) \cdot (p^1 - p^0)$$

Welfare Change and the New Goods Problem

Introduction of a new good in period 1.

Assume (as per Hicks 1940) that there is a "shadow" or "reservation price" for the new good in period 0 that will cause the consumer to consume 0 units in period 0.

Let the new good be indexed by the subscript 0 and let the N dimensional vectors of period t prices and quantities for the continuing commodities be denoted by p^t and q^t for t = 0,1.

The period 0 quantity is observed and is equal to 0; i.e., $q_0^0 = 0$.

Period 0 reservation price for commodity 0 is not observed but we make some sort of *estimate* for it, denoted as $p_0^{0*} > 0$.

Welfare Change and the New Goods Problem

Bennet variation measure of welfare change:

$$V_B = \tfrac{1}{2}(p^0 + p^1)\cdot(q^1 - q^0) + \tfrac{1}{2}(p_0^{0*} + p_0^1)(q_0^1 - 0)$$

$$= p^1\cdot(q^1 - q^0) - \tfrac{1}{2}(p^1 - p^0)\cdot(q^1 - q^0) + p_0^1 q_0^1 - \tfrac{1}{2}(p_0^1 - p_0^{0*})q_0^1$$

Terms:

Welfare Change and the New Goods Problem

Bennet variation measure of welfare change:

$$V_B = ½(p^0 + p^1)\cdot(q^1 - q^0) + ½(p_0^{0*} + p_0^1)(q_0^1 - 0)$$

$$= p^1\cdot(q^1 - q^0) - ½(p^1 - p^0)\cdot(q^1 - q^0) + p_0^1 q_0^1 - ½(p_0^1 - p_0^{0*})q_0^1$$

<u>Terms:</u>

1. $p^1\cdot(q^1 - q^0)$: change in consumption valued at the prices of period 1

Welfare Change and the New Goods Problem

Bennet variation measure of welfare change:

$$V_B = ½(p^0 + p^1)\cdot(q^1 – q^0) + ½(p_0^{0*} + p_0^1)(q_0^1 – 0)$$

$$= p^1\cdot(q^1 – q^0) – ½(p^1 – p^0)\cdot(q^1 – q^0) + p_0^1 q_0^1 – ½(p_0^1 – p_0^{0*})q_0^1$$

Terms:

1. $p^1\cdot(q^1 – q^0)$: change in consumption valued at the prices of period 1

2. $– ½(p^1 – p^0)\cdot(q^1 – q^0)$: sum of the consumer surplus terms associated with the continuing commodities

Welfare Change and the New Goods Problem

$$V_B = p^1 \cdot (q^1 - q^0) - ½(p^1 - p^0) \cdot (q^1 - q^0) + p_0^1 q_0^1 - ½(p_0^1 - p_0^{0*}) q_0^1$$

<u>Terms:</u>

3. $p_0^1 q_0^1$: the usual price times quantity contribution term to the value of real consumption of the new commodity in period 1 which would be recorded as a contribution to period 1 GDP

Welfare Change and the New Goods Problem

$$V_B = p^1 \cdot (q^1 - q^0) - ½(p^1 - p^0) \cdot (q^1 - q^0) + p_0^1 q_0^1 - ½(p_0^1 - p_0^{0*})q_0^1$$

<u>Terms:</u>

3. $p_0^1 q_0^1$: the usual price times quantity contribution term to the value of real consumption of the new commodity in period 1 which would be recorded as a contribution to period 1 GDP

4. The last term, $- ½(p_0^1 - p_0^{0*})q_0^1 = ½(p_0^{0*} - p_0^1)q_0^1$, is the additional consumer surplus contribution of commodity 0 to overall welfare change (which would not be recorded as a contribution to GDP).

Welfare Change and the Free Goods Problem

Welfare change including the free goods, and adjusting for inflation by using γ = 1 + Growth Rate of CPI:

$$V_B = p^1\cdot(q^1 - q^0) - \tfrac{1}{2}(p^1 - \gamma p^0)\cdot(q^1 - q^0) + p_0^1 q_0^1 - \tfrac{1}{2}(p_0^1 - \gamma p_0^{0*})q_0^1$$

$$+ w^1\cdot(z^1 - z^0) - \tfrac{1}{2}(w^1 - \gamma w^0)\cdot(z^1 - z^0) + w_0^1 z_0^1 - \tfrac{1}{2}(w_0^1 - \gamma w_0^{0*})z_0^1$$

The last term is for the introduction of a new free good.

Period 0 reservation price for commodity 0 is not observed but we make some sort of *estimate* for it, denoted as $w_0^{0*} > 0$.

New and Free Goods, and GDP-B

Under some assumptions, can make an adjustment to real GDP growth for new and free goods.

$\mathscr{P}^F = P^F/\gamma$, P^F **the Fisher index GDP deflator and** Q^F **a Fisher index of GDP:**

$$\text{GDP-B} = Q^F + (\gamma p_0^{0*} - p_0^{1})q_0^{1}/[\gamma p^0 \cdot q^0 (1+ \mathscr{P}^F)]$$

$$+ [2\gamma w^0 \cdot (z^1 - z^0) + (w^1 - \gamma w^0) \cdot (z^1 - z^0) + 2\gamma w_0^{1} z_0^{1}] /[\gamma p^0 \cdot q^0 (1+ \mathscr{P}^F)]$$

$$+ (\gamma w_0^{0*} - w_0^{1})z_0^{1}/[\gamma p^0 \cdot q^0 (1+ \mathscr{P}^F)],$$

where the highlighted term is the contribution from new free goods. This will be our focus in what follows.

Consumer Valuation of Facebook in US

- **Discrete choice experiments on a representative sample of the US internet population.**

- **Set quotas for gender, age, and US regions to match US census data (File and Ryan 2014) and applied post-stratification for education and household income.**

- **Recruited respondents through an online professional panel provider, Research Now, during the year 2016-17. A total of 2885 participants completed the study including at least 200 participants per price point.**

- **Disqualified participants who did not use Facebook in the previous twelve months.**

Consumer Valuation of Facebook in US

- **Discrete Choice**
  1) Keep access to Facebook
  2) Or give up Facebook for one month and getting paid $E.

- **Allocated participants randomly to one of twelve price points:**
  E = (1, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 1000).

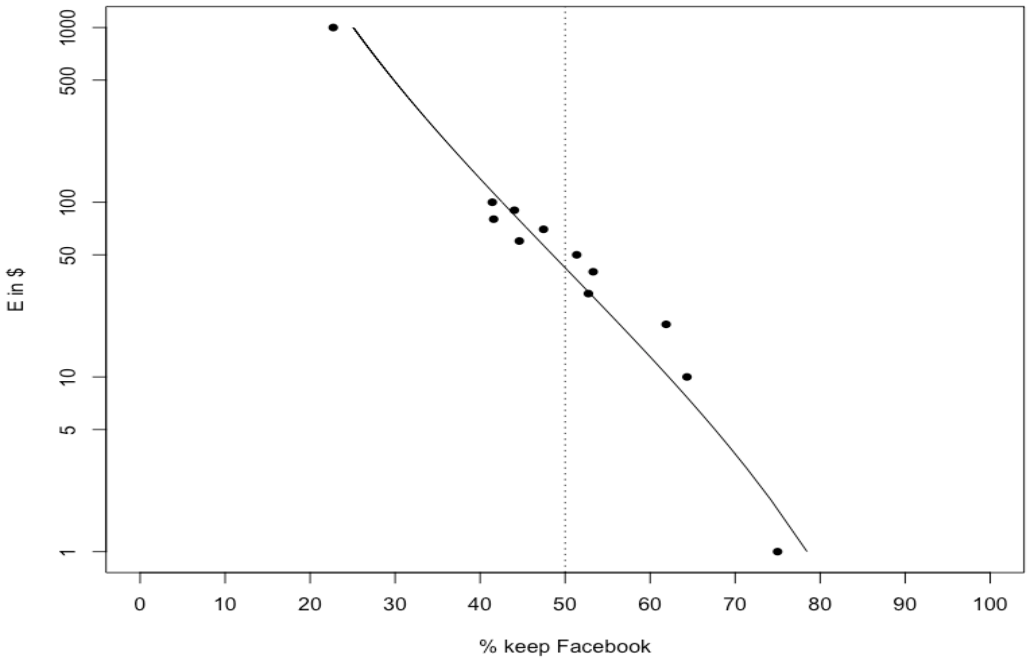
- **Informed that their decisions were consequential: that we would randomly pick one out of every 200 participants and fulfil that person's selection.**

- **Monitored their Facebook online status remotely. To check if the selected participants gave up Facebook and qualified for the payment, we monitored their online status on Facebook for 30 days.**

Consumer Valuation of Facebook in US

Fitted a binary logit model to the participant's decisions using the monetary values (in log scale) as predictors.

Figure 1: WTA demand curve for Facebook



The median WTA of Facebook in period 1 is $42.17/month (95% C.I.: [$32.53; 54.47])

Consumer Valuation of Facebook in US

w_0^1 = \$506.04 (95% C.I.: [390.36; 653.64]), price per year assuming linear relationship

γ = 1 + Growth rate of CPI = 1.3

Number of Facebook users in US in 2017 = 202 million

Nominal GDP in 2003 = \$11.5 trillion

Welfare Change Estimates, Different Reservation Prices, Facebook:

$\frac{1}{2}(\gamma w_0^{0*} - w_0^1)$ x (No. of Facebook users in US in 2017)

	Estimated 1	Estimated 2
Reservation Price w_0^{0*}, 2003\$	\$2,152	\$8,126
Contribution to Welfare Change, 2017\$	\$231 billion	\$1,013 billion
Per year, 2017\$	\$16 billion	\$72 billion
Per user in 2017	\$81.65	\$358.48
Per user over the period	\$1,143	\$5,018

Consumer Valuation of Facebook in US

Adjustment to real GDP growth from accounting for Facebook, 2003-2017

$$=(\gamma w_0^{0*} - w_0^1) z_0^1 / [\gamma p^0 \cdot q^0 (1 + \mathscr{P}^F)]$$

$$= (\gamma w_0^{0*} - w_0^1) \text{ x (No. of Users in 2017) / } [\gamma\text{(Nominal GDP in 2003) x } (1+\mathscr{P}^F)]$$

w_0^1 = \$506.04 (95% C.I.: [390.36; 653.64])

γ = 1 + Growth rate of CPI = 1.3

P^F = 1+ Growth rate of GDP Deflator = 1.31

$\mathscr{P}^F = P^F/\gamma = 1.0078$

Number of Facebook users in US in 2017 = 202 million

Nominal GDP in 2003 = \$11.5 trillion

GDP-B Contributions for Different Reservation Prices, Facebook

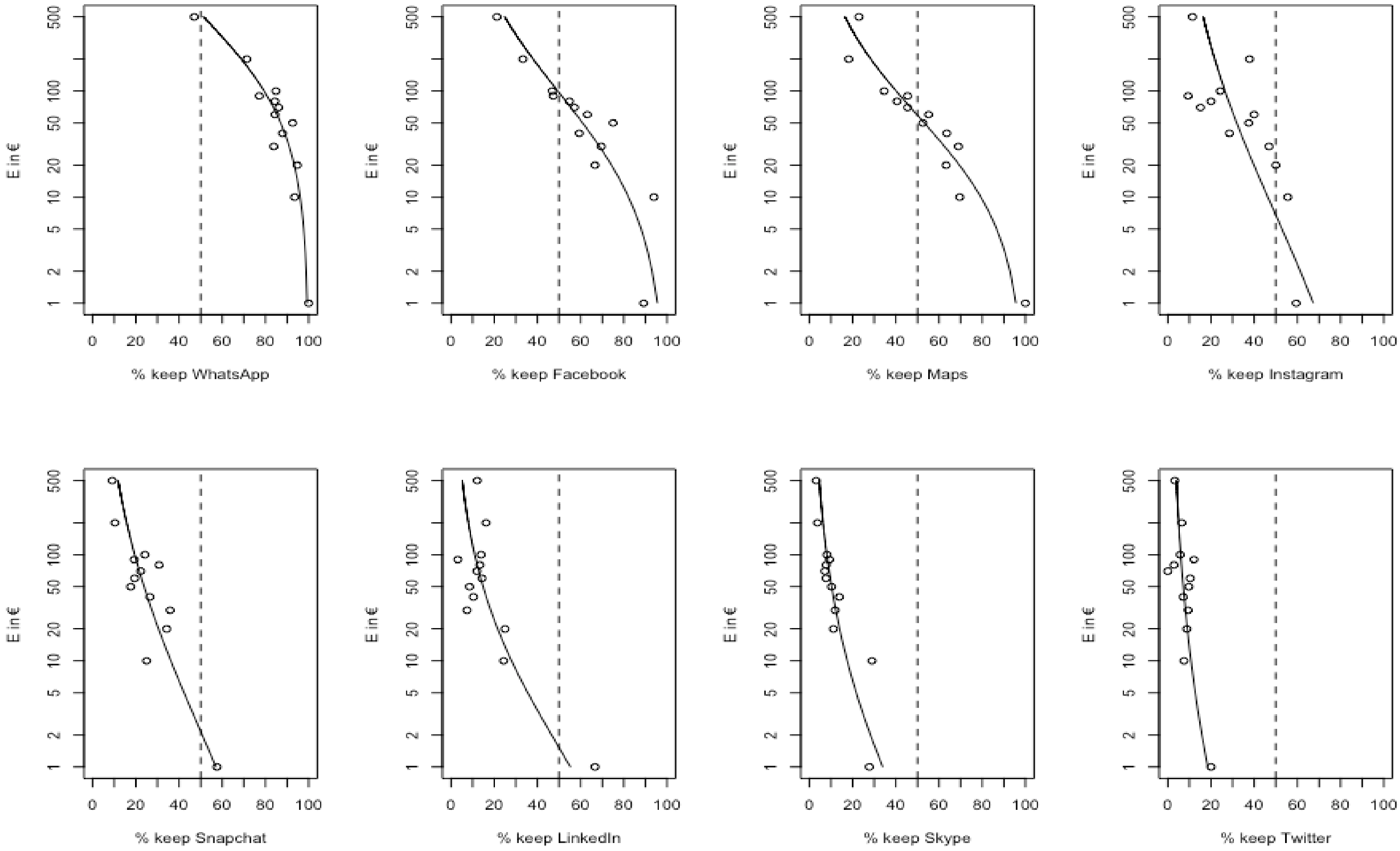
	Total Income	Estimated 1	Estimated 2
Reservation Price w_0^{0*}, 2003$	—	$2,152	$8,126
Percentage Points, 2004-2017	0.53	1.54	6.76
Percentage Points Per year	0.04	0.11	0.47
GDP Growth per year without Facebook, %	1.83	1.83	1.83
GDP Growth per year with Facebook, %	1.87	1.91	2.20

Consumer Valuation of Facebook in US

- **A simple method that doesn't require estimation of reservation prices.**
- **Consumer has a total income (T) that is used to achieve the level of utility at an observed equilibrium, t=0,1:**
- **$T^t = p^t.q^t + w^t.z^t$ (market income plus imputed income), where $z^0 = 0$**
- **Nominal Total Income Growth = T^1/T^0**
- **Deflating this by the GDP deflator gives a quantity index. Of course, the GDP deflator is the wrong deflator as it doesn't take into account new free goods, which would typically mean that the deflator's growth is too high. The resulting quantity index then provides a lower bound estimate on the actual real growth rate.**

WTA Demand Curves for Popular Digital Goods

Netherlands lab experiment; x-axis: % keep, y-axis: € required



Consumer welfare generated by popular free digital goods among participants in a lab

Table 1: Median WTA

Service	Median WTA	Lower CI	Upper CI
WhatsApp	€535.73	€269.91	€1141.42
Facebook	€96.80	€69.54	€136.68
Maps	€59.16	€45.17	€78.31
Instagram	€6.79	€2.53	€16.22
Snapchat	€2.17	€0.41	€8.81
LinkedIn	€1.52	€0.30	€5.84
Skype	€0.18	€0.01	€2.58
Twitter	€0.00	€0.00	€0.49

Contributions to GDP-B growth in the Netherlands, percentage points per year, Total Income Method

Users Service	Average per year 10 million	Average per year 2 million
WhatsApp	3.28	0.73
Facebook	0.42	0.09
Maps	0.28	0.06
Instagram	0.06	0.01
Snapchat	0.02	0.00
LinkedIn	0.00	0.00
Skype	0.00	0.00
Twitter	0.00	0.00

Importance of adjusting for quality changes: The case of smartphone cameras

Brynjolfsson et al. (2017)

Example: Smartphones

Smartphones substituted

- Camera
- Alarm Clock
- Music Player
- Calculator
- Computer
- Land Line
- Game Machine
- Movie Player
- Recording Device
- Video Camera

Plus:

- GPS Map and directions
- Web Browser
- E-book reader
- Fitness monitor
- Instant messaging
- etc

Importance of adjusting for quality changes: The case of smartphone cameras

BDM lottery (Becker, DeGroot, and Marschak 1964) in order to estimate the consumers' valuation of their smartphone camera.

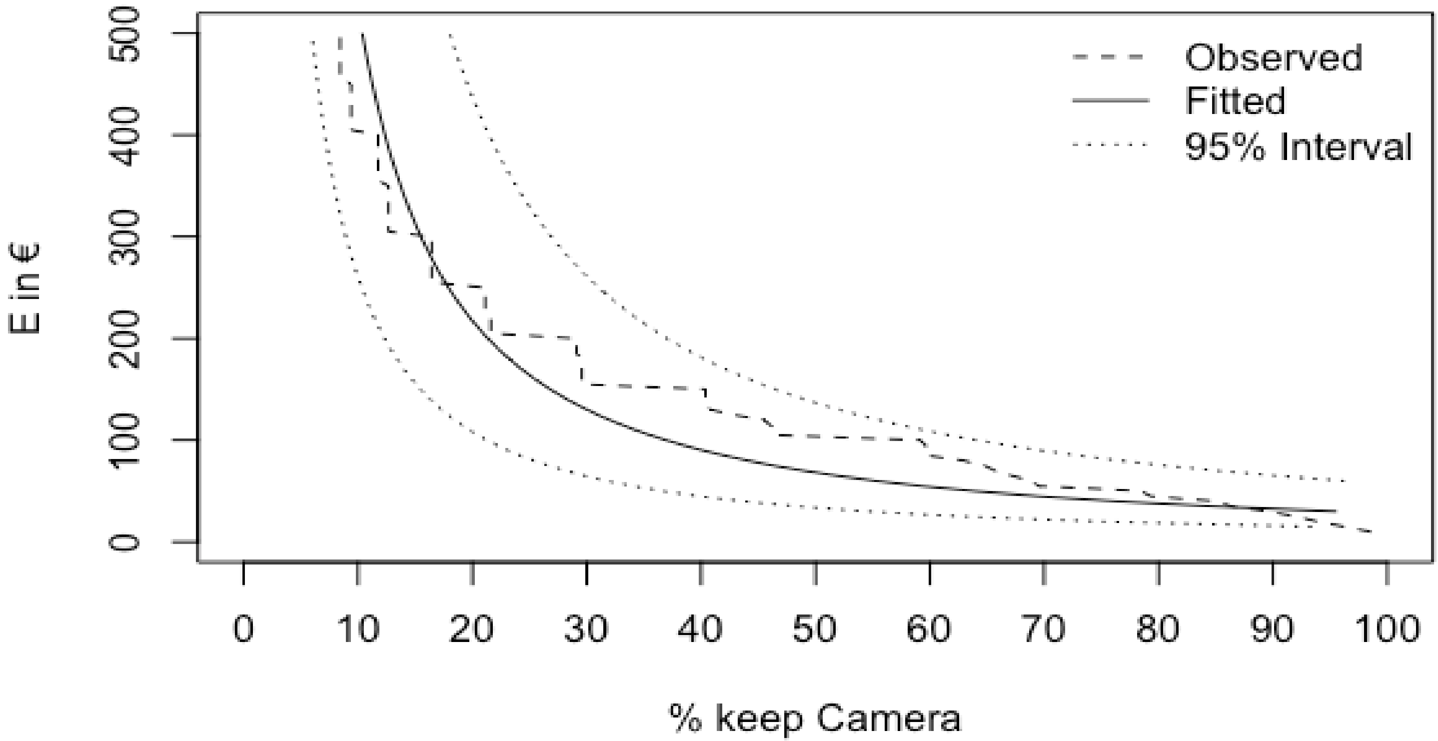
- **Asked participants to state the minimum amount of money they would request in order to give up their smartphone camera (both main camera and front camera) for 1 month.**
- **Participants informed that one out of 50 would be selected for the lottery and that we would block their smartphone cameras with a special sealing tape, if their bid was successful.**
- **If, after the one month period, the seal was still intact participants were rewarded with the money and the seal could be removed.**

Importance of adjusting for quality changes

Lab in Netherlands, 213 students were available for the analysis.

Importance of adjusting for quality changes: The case of smartphone cameras

Demand function for the smartphone camera



Importance of adjusting for quality changes: The case of smartphone cameras

- **The median WTA for giving up the smartphone camera for 1 month is €68.13, albeit having a wide confidence interval (95% CI = [€33.53; €136.78]).**

- **Analysts have estimated that it costs between €20- €35 to manufacture smartphone cameras present in the latest flagship models.**

- **A modular smartphone sold in the Netherlands charges €70 for adding front and back cameras.**

- **Consumers seem to obtain a significant amount of surplus from using smartphone cameras and this surplus seems to be an order of magnitude larger than what they actually pay.**

- **Therefore, even for paid goods such as smartphones, it is crucial to adjust for quality improvements before estimating GDP statistics.**

Conclusions

- **Derived new theory for the measuring welfare from new and free goods**
  - Defined a new metric: GDP-B.
  - GDP-B provides an approximate additive adjustment to traditional GDP growth for new and free goods.
  - GDP-B is a lower bound on the adjustment
  - Additional terms can be added to GDP-B as other types of welfare implications are considered

- **Empirically implemented theory using both massive online experiments and lab experiments.**
  - Find that consumers can have very high valuations of “free” digital goods, with significant variation over different products
  - Estimated effects of quality change in a physical good: digital cameras in smart phones
    - Valuations dramatically exceed the market price
    - This emphasizes the importance of quality adjustment for goods with rapid quality change

Conclusions

- **This line of research is still in its infancy**
- **This paper demonstrates the feasibility of implementing simple adjustments to official data to better understand the impact of digital goods and services on the economy**
- **We call this GDP-B**

UNSW Business School

Centre for Applied Economic Research

The Digital Economy, New Products and Consumer Welfare

W. Erwin Diewert, Kevin J. Fox and Paul Schreyer

https://www.escoe.ac.uk/wp-content/uploads/2018/11/ESCoE-DP-2018-16.pdf

Background

- Benefits of the Digital Economy are evident in everyday life, but are they reflected appropriately in official statistics?
- Many new products, and many disappearing products.
- The measurement of the net benefits of new and disappearing products depends on what type of index the NSO is using to deflate final demand aggregates.
- Derive expressions for quantifying biases in e.g. GDP from standard NSO practices.

Background

- **If reservation prices are estimated, elicited from surveys, online experiments, or guessed, then the "true" price index can be calculated and compared to its maximum overlap counterpart.**
- **An estimate of the bias in the deflator can be formed. This bias in the deflator translates into a corresponding bias in the real output aggregate.**
- **The context we consider is one in which transaction level data are available so that indexes can be calculated from the elementary level.**

Continuing, New and Disappearing Goods

	Period 0	Period 1
Group 1 Continuing	✓	✓
Group 2 New	X	✓
Group 3 Disappearing	✓	X

True Share and Maximum Overlap Shares

Group 1 Products: Present in both periods

$$p_1^t \equiv [p_{11}^t,...,p_{1N}^t] >> 0_N \text{ and } q_1^t \equiv [q_{11}^t,...,q_{1N}^t] > 0_N \text{ for } t = 0,1.$$

Group 2 Products: New goods only available from period 1

Period 0: $p_2^{0*} \equiv [p_{21}^{0*},...,p_{2K}^{0*}] >> 0_K$ and $q_2^0 \equiv [q_{11}^0,...,q_{1K}^0] = 0_K$.

NB: p_2^{0*} **are the positive reservation prices**

Period 1: $p_2^1 \equiv [p_{21}^1,...,p_{2K}^1] >> 0_K$ and $q_2^1 \equiv [q_{21}^1,...,q_{2K}^1] > 0_K$

True Share and Maximum Overlap Shares

Group 3 Products: **Disappearing goods, only available in period 0**

Period 0: $p_3^0 \equiv [p_{31}^0,\ldots,p_{3M}^0] >> 0_M$ and $q_3^0 \equiv [q_{31}^0,\ldots,q_{3M}^0] > 0_M$.

Period 1: $p_3^{1*} \equiv [p_{31}^{1*},\ldots,p_{3M}^{1*}] >> 0_M$ and $q_3^1 \equiv [q_{31}^1,\ldots,q_{3M}^1] = 0_M$.

NB: p_3^{1*} **are the positive reservation prices**

True and Maximum Overlap Shares

Group 1 True expenditure shares (continuing goods):

$$s_{1n}^0 \equiv p_{1n}^0 q_{1n}^0/[p_1^0 \cdot q_1^0 + p_2^{0*} \cdot q_2^0 + p_3^0 \cdot q_3^0] \; ; \qquad n = 1,\ldots,N;$$
$$= p_{1n}^0 q_{1n}^0/[p_1^0 \cdot q_1^0 + p_3^0 \cdot q_3^0] \qquad \text{since } q_2^0 = 0_K;$$

$$s_{1n}^1 \equiv p_{1n}^1 q_{1n}^1/[p_1^1 \cdot q_1^0 + p_2^1 \cdot q_2^1 + p_3^{1*} \cdot q_3^1] \; ; \qquad n = 1,\ldots,N;$$
$$= p_{1n}^1 q_{1n}^1/[p_1^1 \cdot q_1^1 + p_2^1 \cdot q_2^1] \qquad \text{since } q_3^1 = 0_M.$$

Can be calculated using observable data.

True Share and Maximum Overlap Shares

Group 2 True expenditure shares (new goods):

$s_{2k}^0 \equiv 0$ since $q_2^0 = 0_K$;

$s_{2k}^1 \equiv p_{2k}^1 q_{2k}^1/[p_1^1 \cdot q_1^1 + p_2^1 \cdot q_2^1]$ since $q_3^1 = 0_M$.

Group 3 True expenditure shares (disappearing goods):

$s_{3m}^0 \equiv p_{3m}^0 q_{3m}^0/[p_1^0 \cdot q_1^0 + p_3^0 \cdot q_3^0]$ since $q_2^0 = 0_K$;

$s_{3m}^1 \equiv 0$ since $q_3^1 = 0_M$

True Share and Maximum Overlap Shares

Maximum overlap share for product n in period t:

$s_{1nO}{}^{t} \equiv p_{1n}{}^{t}q_{1n}{}^{t}/p_{1}{}^{t}\cdot q_{1}{}^{t}$; t = 0,1; n = 1,...,N.

Relationships between the true Group 1 shares and the maximum overlap Group 1 shares:

$s_{1n}{}^{0} = s_{1nO}{}^{0}[1 - \Sigma_{m=1}\, s_{3m}{}^{0}]$; n = 1,...,N;

$s_{1n}{}^{1} = s_{1nO}{}^{1}[1 - \Sigma_{k=1}\, s_{2k}{}^{1}]$. n = 1,...,N;

(de Haan and Krisnich 2012)

Törnqvist Price Index

Törnqvist index is the target index for the US CPI.

Log of the Törnqvist maximum overlap index:

$$\ln P_{TO} \equiv \Sigma_{n=1} (1/2)(s_{1nO}^{0} + s_{1nO}^{1})\ln(p_{1n}^{1}/p_{1n}^{0})$$

Log of the true Törnqvist index:

$$\ln P_{T} \equiv \Sigma_{n=1}(1/2)(s_{1n}^{0} + s_{1n}^{1})\ln(p_{1n}^{1}/p_{1n}^{0}) + \Sigma_{k=1} (1/2)(s_{2k}^{0} + s_{2k}^{1})\ln(p_{2k}^{1}/p_{2k}^{0*})$$
$$+ \Sigma_{m=1}(1/2)(s_{3m}^{0} + s_{3m}^{1})\ln(p_{3m}^{1*}/p_{3m}^{0})$$

$$= \ln P_{TO} + \ln\kappa + \ln\mu$$

(de Haan and Krisnich 2012)

Törnqvist Price Index

$$P_T = P_{TO} \times \kappa \times \mu$$

κ can be regarded as a measure of the *reduction* in the true cost of living due to the introduction of new products. Thus κ is likely to be less than 1.

μ can be regarded as a measure of the *increase* in the true cost of living due to the disappearance of existing products. Thus μ is likely to be greater than 1.

Törnqvist Price Index

In case you're wondering…..

$$\ln\kappa \equiv (1/2)\Sigma_{k=1}\, s_{2k}^{1}[\ln(p_{2k}^{1}/p_{2k}^{0*}) - \ln P_{JO}^{1}];$$

$$\ln\mu \equiv (1/2)\Sigma_{m=1}\, s_{3m}^{0}[\ln(p_{3m}^{1*}/p_{3m}^{0}) - \ln P_{JO}^{0}],$$

where:

$$\ln P_{JO}^{1} \equiv \Sigma_{n=1}\, s_{1nO}^{1} \ln(p_{1n}^{1}/p_{1n}^{0});$$

$$\ln P_{JO}^{0} \equiv \Sigma_{n=1}\, s_{1nO}^{0} \ln(p_{1n}^{1}/p_{1n}^{0}).$$

Törnqvist Price Index

Imputed carry backward prices:

$p_{2kb}{}^{0} \equiv p_{2k}{}^{1}/P_{JO}{}^{1}$

Imputed carry forward prices:

$p_{3mf}{}^{1} \equiv p_{3m}{}^{0}P_{JO}{}^{0}$

Economic theory suggests that the reservation prices will be greater than their inflation adjusted carry forward or backward prices.

$1 + \kappa_k \equiv p_{2k}{}^{0*}/p_{2kb}{}^{0}$

$1 + \mu_m \equiv p_{3m}{}^{1*}/p_{3mf}{}^{1}$

Törnqvist Price Index

Exact relationship **between the true Törnqvist index P_T and its maximum overlap counterpart P_{TO}:**

$$\ln(P_T/P_{TO}) = \Sigma_{m=1}(1/2)s_{3m}^0 \ln(1 + \mu_m) - \Sigma_{k=1}(1/2)s_{2k}^1 \ln(1 + \kappa_k)$$

Using a first order Taylor's series approximation:

$$(P_T/P_{TO}) - 1 \approx \Sigma_{m=1}(1/2)s_{3m}^0 \mu_m - \Sigma_{k=1}(1/2)s_{2k}^1 \kappa_k$$

Törnqvist Price Index

Value aggregates for the goods and services in the group of N + K + M commodities under consideration, v^0 and v^1:

$$v^0 \equiv p_1^0 \cdot q_1^0 + p_3^0 \cdot q_3^0; \qquad v^1 \equiv p_1^1 \cdot q_1^1 + p_2^1 \cdot q_2^1$$

True implicit Törnqvist quantity index:

$$Q_T \equiv [v^1/v^0]/P_T$$

Maximum overlap Törnqvist quantity index:

$$Q_{TO} \equiv [v^1/v^0]/P_{TO}$$

Bias in Q_{TO} relative to Q_T:

$$Q_T/Q_{TO} = P_{TO}/P_T$$

Törnqvist Price Index

First order approximation:

$$(Q_T/Q_{TO}) - 1 \approx \Sigma_{k=1}(1/2)s_{2k}{}^1\kappa_k - \Sigma_{m=1}(1/2)s_{3m}{}^0\,\mu_m.$$

If there are no disappearing goods, the right hand side becomes:

$\Sigma_{k=1}(1/2)s_{2k}{}^1\kappa_k$

→ **the downward bias in the maximum overlap Törnqvist quantity index for the value aggregate in percentage points.**

That is, the downward bias in welfare from ignoring new goods and services.

Paasche Price Index

We derive similar results for Laspeyres, Paasche and Fisher indexes. Fisher result is very similar to that of the Törnqvist index.

Here we consider the Paasche price index, as it corresponds to a Laspeyres quantity index, which is used by many countries to construct GDP.

Maximum overlap Paasche price index:

$$P_{PO} \equiv p_1^1 \cdot q_1^1 / p_1^0 \cdot q_1^1 = [\Sigma_{n=1}\, s_{1nO}^1\, (p_{1n}^1/p_{1n}^0)^{-1}]^{-1}$$

True Paasche price index:

$$P_P \equiv [\Sigma_{n=1} s_{1n}^1\, (p_{1n}^1/p_{1n}^0)^{-1} + \Sigma_{k=1}\, s_{2k}^1\, (p_{2k}^1/p_{2k}^{0*})^{-1}]^{-1}$$

Paasche Price Index

Going through similar steps as before, we have:

$$(P_{PO}/P_P) - 1 = \Sigma_{k=1}\, s_{2k}{}^{1}\, \beta_k.$$

where P_P is the true Paasche index and P_{PO} is the maximum overlap Paasche index.

β_k expresses how much higher each reservation price is from its Paasche inflation adjusted carry backward price counterpart:

$$1 + \beta_k \equiv p_{2k}{}^{0*}/p_{2kb}{}^{0}$$

Thus, expect the Paasche maximum overlap index to have upward bias if there are new products in period 1.

Paasche Price Index

True and maximum overlap Laspeyres indexes:

$$Q_L \equiv [v^1/v^0]/P_P \qquad\qquad Q_{LO} \equiv [v^1/v^0]/P_{PO}.$$

The bias in Q_{LO}, the maximum overlap Laspeyres index, relative to its true counterpart Q_L can be measured by the ratio Q_L/Q_{LO}:

$$(Q_L/Q_{LO}) - 1 = (P_{PO}/P_P) - 1 = \Sigma_{k=1}\, s_{2k}{}^1\, \beta_k$$

Thus the upward bias in the maximum overlap Paasche price index P_{PO} translates into a downward bias in the companion maximum overlap Laspeyres quantity index, Q_{LO}.

Conclusions

- **NSOs often use a maximum overlap index to deflate a value aggregate to construct estimate of e.g. real consumption.**
- **Only products that exist in both periods being compared are then considered.**
- **Derive expressions which arise from the use of maximum overlap indexes for the Törnqvist, Laspeyres, Paasche and Fisher price and quantity index formulae.**
- **Simple expressions, but require transaction level data and Hicksian reservation prices for the missing products in both periods.**
- **Also consider bias formulae for replacement samples (*à la* Triplett 2004)**

Forward Agenda

THE DIGITAL ECONOMY
Welfare and Productivity

Proposed budget for five years (2020-2024)[1]

Online Experiments:

Google Surveys (Non-incentive Compatible)

Product type	Survey cost per product	Number of products	Total cost per product type
Digital	1000 responses x $0.13 cost per response = $130	19	$2,470
CPI	1000 responses x $0.13 cost per response = $130	20	$2,600
Environmental/ Infrastructure	1000 responses x $0.13 cost per response = $130	5	$650
		Total cost per one round of surveys:	**$5,720**

For a given country, it is planned to run Non-incentive Compatible surveys via Google four times a year over five years:
- Cost per year per country: **$22,880** (4 rounds x $5,720 cost per round)
- Total cost for five years per country: **$114,400** (5 years x $22,880 cost per year)

ProdegeMR Surveys (Incentive Compatible)

Product	Survey cost	Incentive compatibility payment[2]	Total cost per product
Facebook	1000 responses x $2 cost per response = $2,000	5 selected participants (1 out of 200 = 5 out of 1000) x $50 estimated mean WTA=$250	$2,250
Instagram	1000 responses x $2 cost per response = $2,000	5 selected participants (1 out of 200 = 5 out of 1000) x $9 estimated mean WTA=$45	$2,045
Twitter	1000 responses x $2 cost per response = $2,000	5 selected participants (1 out of 200 = 5 out of 1000) x $1 estimated mean WTA=$5	$2,005
		Total cost per one round of surveys:	**$6,300**

For a given country, it is planned to run Incentive Compatible surveys via ProdegeMR four times a year over five years:
- Cost per year per country: **$25,200** (4 rounds x $6,300 cost per round)
- Total cost for five years per country: **$126,000** (5 years x $25,200 cost per year)

[1] All costs are presented in Australian dollars unless otherwise indicated. Costs associated with the communication of results by involved researchers, such as, airfare, accommodation and other related expenses, will be covered by agreement and are therefore excluded from the budget. UNSW indirect costs (overheads) are excluded from the budget and will need to be included if funds are provided to UNSW.
[2] The incentive compatibility payment will depend on the participants' decisions about their willingness to accept (WTA) in the survey. Based on previous studies (see Brynjolfsson, E., A. Collis, W.E. Diewert, F. Eggers and K.J. Fox (2019), "GDP-B: Accounting for the Value of New and Free Goods in the Digital Economy," NBER Working Paper 25695, Cambridge, MA. https://www.nber.org/papers/w25695). the estimated mean of WTA is: $50 for Facebook, $9 for Instagram and $1 for Twitter.

Laboratory Experiments at UNSW[3]

Participation payment[4]	Incentive compatibility payment[5]	Total participants payments
400 participants[6] x $25 cost per participant = $10,000	8 selected participants (1 out of 50 = 8 out of 400) x $100 estimated mean WTA=$800	$10,800
	Total cost per one round of laboratory experiments:	**$10,800**

Laboratory experiments are planned to run once a year over five years:
- Cost per year: **$10,800** (one round of laboratory experiments)
- Total cost for five years: **$54,000** (5 years x $10,800 cost per year)

UNSW Personnel

Personnel	Cost
Post-Doctoral Fellow (0.5 full-time equivalent, Level A/6)[7]	$69,455[8]
Laboratory Experiments Research Assistant (casual, 32h, Level 5.2)[9]	$2,250[10]
Personnel cost per year:	**$71,705**
Total personnel cost for five years:	**$358,525**

Budget Summary Table

Description		Cost per year	Cost for five years
Online Experiments	Non-incentive Compatible	$22,880	$114,400
	Incentive Compatible	$25,200	$126,000
Laboratory Experiments at UNSW		$10,800	$54,000
UNSW Personnel		$71,705	$358,525
	Total[11]:	**$130,585**	**$652,925**

[3] To facilitate the carrying out of the laboratory experiments UNSW will provide in-kind research infrastructure support. The UNSW Business School's experimental laboratory (BizLab) will be used for this purpose, which contains 30 terminals hence is suitable to accommodate for the participation of 25 participants per session.
[4] Participants typically receive a fixed show-up fee and a performance payment fee. Thus, the participation payment consists of a show-up fee of $5 per participant, plus a performance fee of $20 per participant upon full completion of their tasks.
[5] The incentive compatibility payment will depend on the participants' decisions about their willingness to accept (WTA) in the experiment. The laboratory experiments will involve eight digital products and based on previous studies the estimated mean of WTA across the eight digital products is $100 (see Brynjolfsson, E., F. Eggers and A. Gannamaneni (2018), "Using Massive Online Choice Experiments to Measure Changes in Well-being", *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1815663116).
[6] To be able to draw statistically reliable conclusions from the experiments a sufficient number of independent observations is required (see Brynjolfsson, E., F. Eggers and A. Gannamaneni (2018)). Thus, it is planned to run 16 sessions with 25 participants per session, resulting in total of 400 participants.
[7] A part-time post-doctoral fellow is needed over the five years to assist with the design, implementation and results analysis of the online surveys and laboratory experiments.
[8] Cost per year includes 29.42% salary on-costs.
[9] A casual research assistant is needed to provide support for the post-doctoral fellow to ensure that experiments sessions run smoothly and that participants are received and paid quickly. For each session, a total of 2 hours research assistance is required, consisting of preparations before the session (estimated at 0.5h), assistance during the experimental session (estimated at 1h) and post-processing after the session (estimated at 0.5h). Laboratory experiments consist of 16 sessions per year, thus 32 hours per year are required.
[10] Cost per year is based on $70.3 per hour rate (UNSW casual level 5.2, including 15.67% salary on-costs) x 32h = $2,250.
[11] Based on 19th of April 2019 exchange rates (1AUD=0.72USD and 1AUD=0.55GBP), total cost per year is 94,021 USD/71,822 GBP and total cost for five years is 470,106 USD/359,109 GBP.