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The Digital Economy, GDP and Consumer Welfare: Theory and Evidence

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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?**

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**

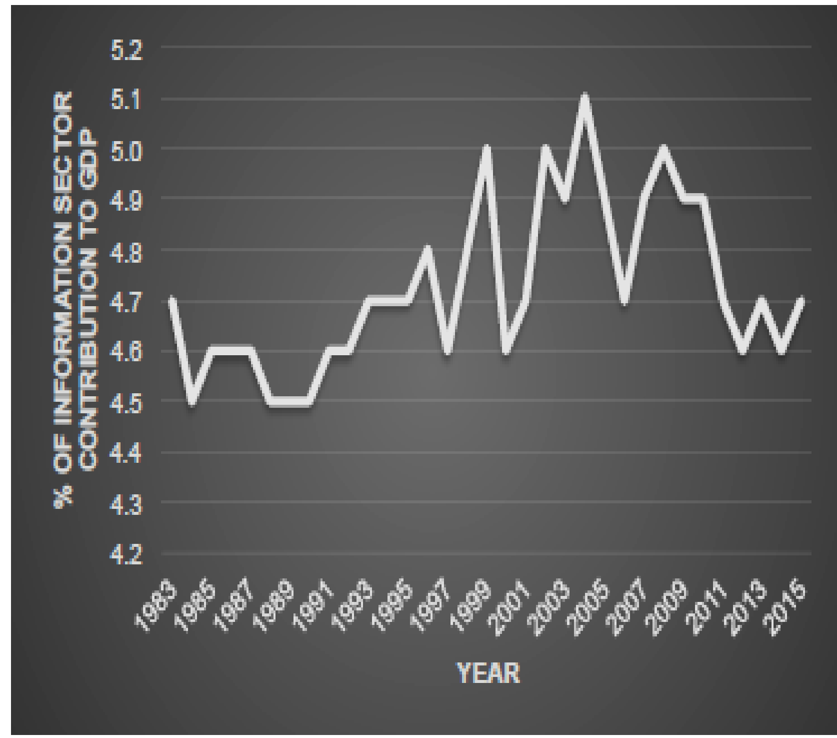
- ➢ **We introduce a new metric, we call “GDP-B”**
  - ❖ **We account for the benefits of free goods and new goods**
  - ❖ **In the future, we will add other adjustments**

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

So far, no economic justification for taking the average of V_L and V_P.

Diewert and Mizobuchi (2009) assumed that consumer preferences can be represented by a (flexible) normalized quadratic cost function:

$$C(u,p) \equiv b \cdot p + [c \cdot p + ½(\alpha \cdot p)^{-1} p^T B p]u$$

where

$b \cdot p^* = 0$;

$c \cdot p^* = 1$;

$Bp^* = 0_N$ and $B = B^T$.

Welfare Change and the New Goods Problem

Then, for normalized prices, we have the following exact equality:

$$V_B(p^0,p^1,q^0,q^1) = \tfrac{1}{2}\, Q_E(q^0,q^1,p^0) + \tfrac{1}{2}\, Q_C(q^0,q^1,p^1)$$

i.e., the observable Bennet variation is *exactly equal* to the arithmetic average of the unobservable equivalent and compensating variations.

Hence, a strong justification from an economic perspective for using the Bennet quantity variation. Also, it has strong justification from an axiomatic perspective (Diewert, 2005).

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

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

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

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:

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

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

Terms:

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

Welfare Change and the New Goods Problem

Bennet variation measure of welfare change:

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

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Terms:

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

2. $-\tfrac{1}{2}(p^1 - p^0)\cdot(q^1 - q^0)$**: sum of the consumer surplus terms associated with the continuing commodities**

Welfare Change and the New Goods Problem

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

Terms:

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

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

Terms:

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, $-\frac{1}{2}(p_0^{\,1} - p_0^{\,0*}) q_0^{\,1} = \frac{1}{2}(p_0^{\,0*} - p_0^{\,1}) q_0^{\,1}$, 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

Consumer holding $Z^{**} > 0$ free goods has utility $u^{**} \equiv f(x^{**}, z^{**})$.

***"Global" willingness to accept (WTA) function* for the disposal of z^{**} as follows:**

$$W_A(u^{**}, p, z^{**}) \equiv c(u^{**}, p, 0_M) - c(u^{**}, p, z^{**})$$

That is, the amount of expenditure needed to achieve the same utility without access to the free good.

Marginal valuation price vector $w \equiv -\nabla_z c(u, p, z)$

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

So, can we just add something to GDP growth to fully capture the introduction of the new (free) good?

A decomposition of nominal GDP change can be written as follows (Diewert 2005):

$$p^1 \cdot q^1 - p^0 \cdot q^0 = p^0 \cdot q^0[½(1+Q)(P-1) + ½(1+P)(Q-1)]$$

where P and Q are price and quantity indexes, respectively, that satisfy
$$P \times Q = p^1 \cdot q^1 / p^0 \cdot q^0$$

Economic Price and Quantity Change Indicators:

$I_E = ½\, p^0 \cdot q^0(1+Q)(P-1)$ **and** $V_E = ½\, p^0 \cdot q^0(1+P)(Q-1)$

New and Free Goods, and GDP-B

Adapting Proposition 9 of Diewert (2005):

If a superlative index number is chosen for P and Q, V_B approximates V_E to the second order for $q^0=q^1$ and $p^0=p^1$.

The U.S. uses the superlative Fisher Quantity Index for GDP, so:

$$V_E^F \equiv ½\, p^0 \cdot q^0(1+P^F)(Q^F-1) \approx ½\,(p^0 + p^1)\cdot(q^1 - q^0) = V_B$$

Re-arranging:

$$Q^F \approx [(p^0 + p^1)\cdot(q^1 - q^0)]/[p^0 \cdot q^0(1+P^F)] + 1$$

Note that the numerator is 2 x $V_{B.}$

New and Free Goods, and GDP-B

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

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

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

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

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

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).

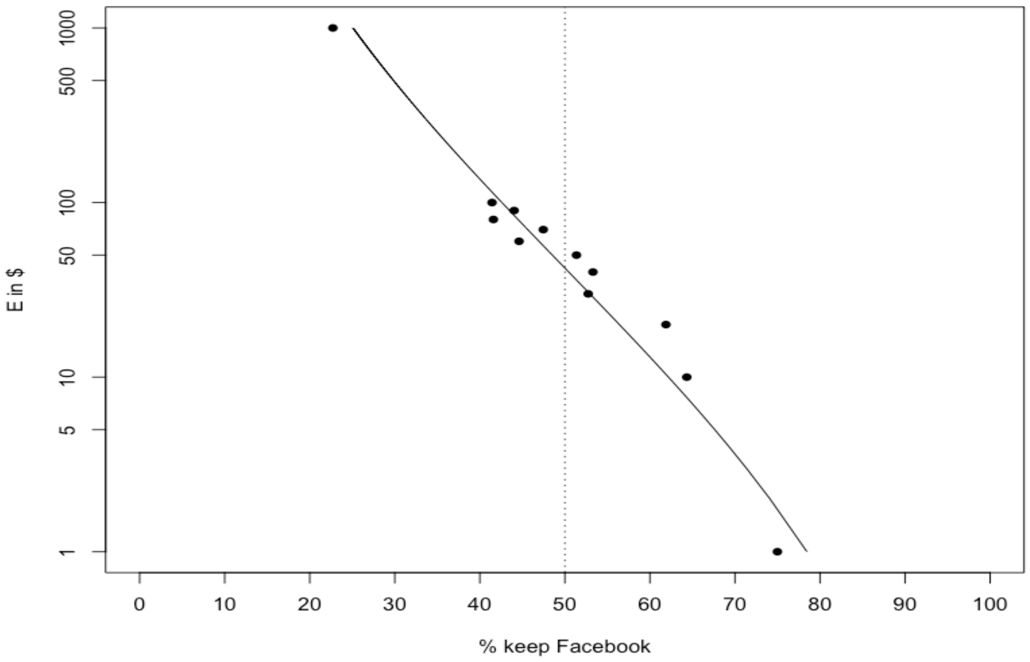
- **Informed that their decisions were consequential: that we would randomly pick one out of every 200 participants and fulfil that person's selection.**

- **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:

½ ($\gamma w_0^{0*} - w_0^1$) 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

- **For the reservation price of w_0^{0*} = $2,152 in 2003, accounting for Facebook would increase real GDP growth by 1.54 percentage points from 2003 to 2017**

- **Amounts to an increase in real GDP growth of 0.11 percentage points on average per year over this period.**

- **Real GDP grew by 28.82%, or 29.16% including the contribution from Facebook. Average real GDP growth over this period was 1.83% per year. Adding the contribution of Facebook makes it 1.91% per year.**

- **The corresponding growth estimate from using other reservation price estimate ($8,126) is 2.20% per year on average.**

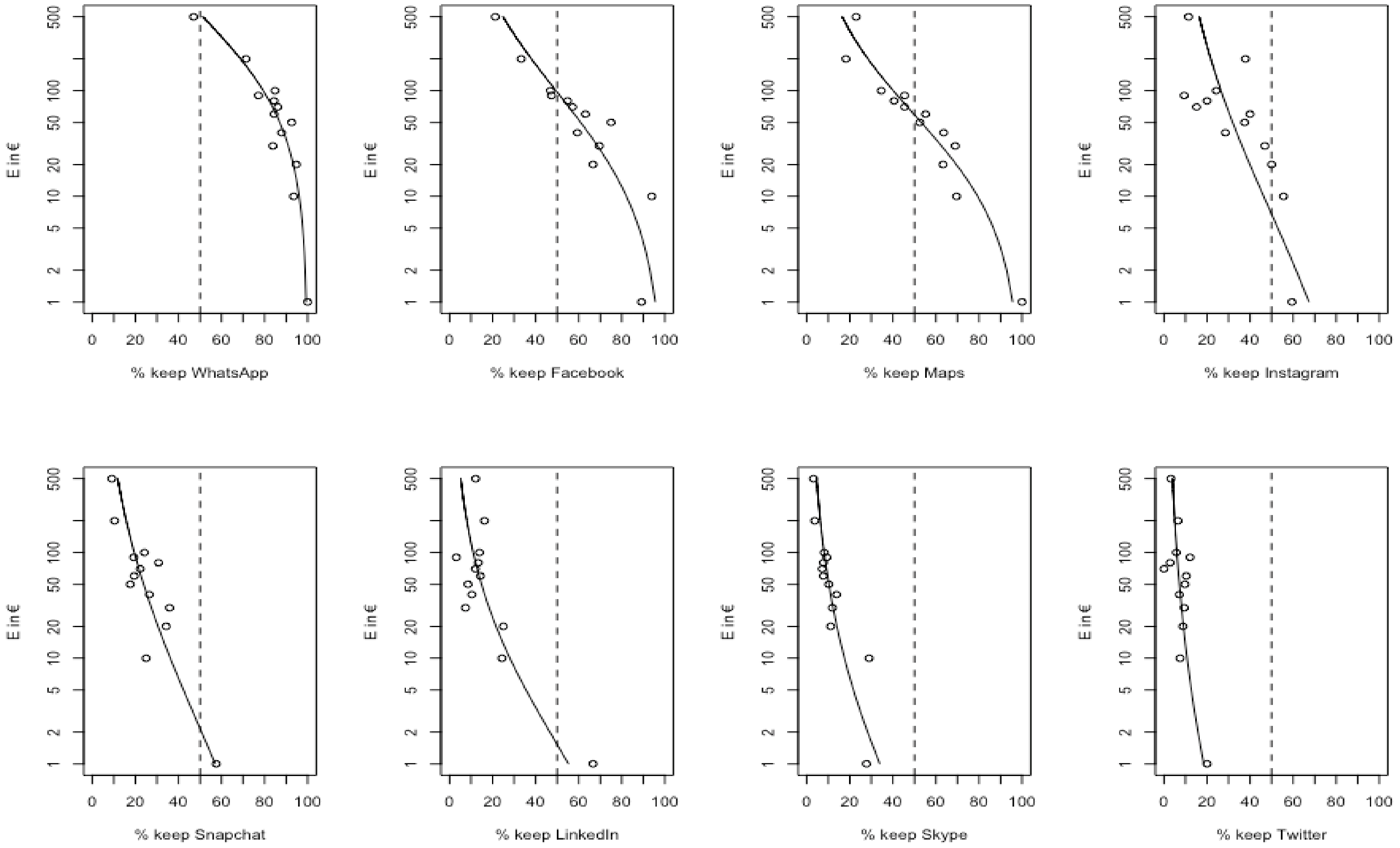
- **Considering that this is for just one product, each of these reservation prices results in a large impact on such an encompassing measure of economic activity as GDP.**

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

MIT INITIATIVE ON THE DIGITAL ECONOMY

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.

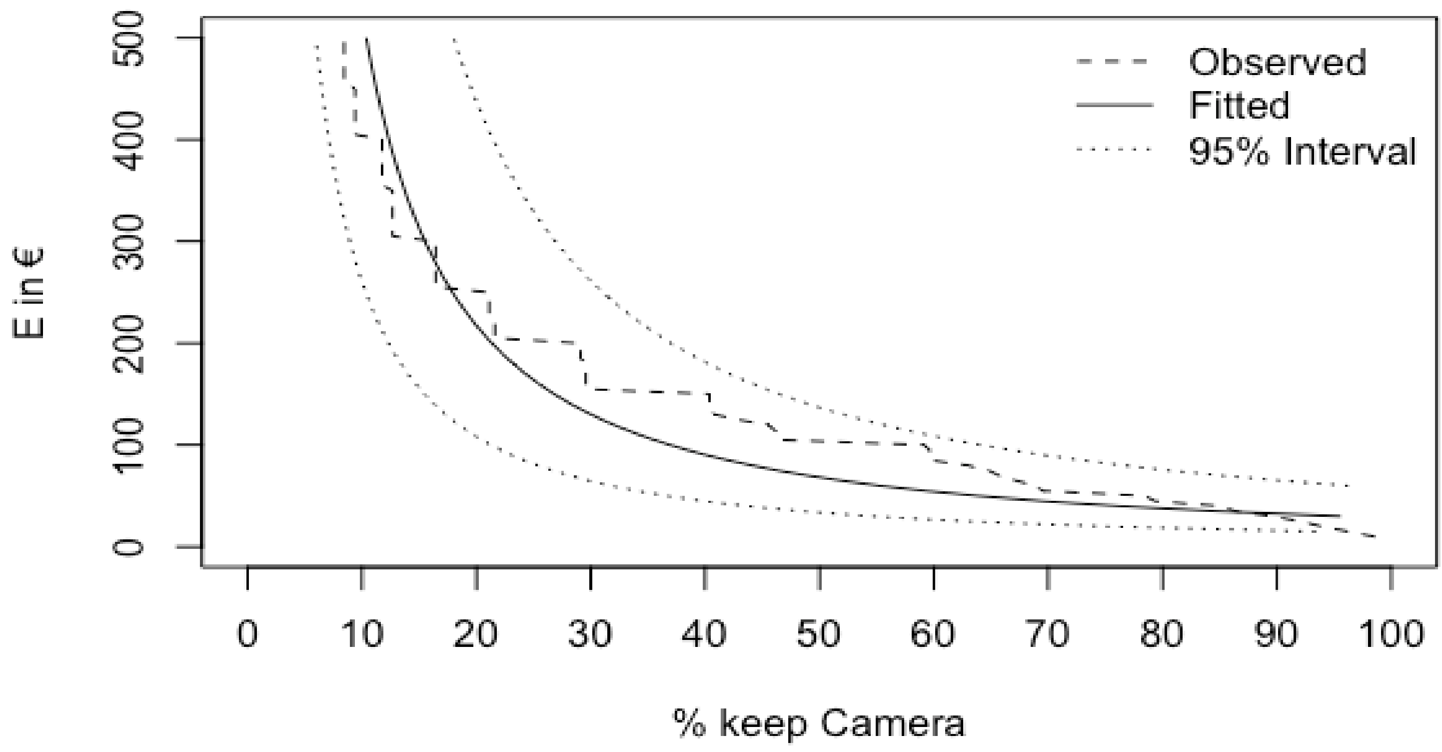
- **Asked participants to state the minimum amount of money they would request in order to give up their smartphone camera (both main camera and front camera) for 1 month.**
- **Participants informed that one out of 50 would be selected for the lottery and that we would block their smartphone cameras 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**