Consumption Inequality in the Digital Age

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[1] Views do not necessarily reflect the views of the Banque de France

Motivation

Digitalization creates **income polarization** (a U-shaped pattern):
Autor and Dorn (2013), Goos, Mannings & Salomons (2009), and many more

What about **welfare**? Consider **consumption**.

- (known) *income effect*: digitalization substitutes/complements workers and change factor prices, which reflects on expenditures

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- (new) *price effect*: digitalization affects production costs of some goods more than others, translating into price differences

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- (new) *price effect*: digitalization affects production costs of some goods more than others, translating into price differences

Consumption baskets differ along the income distribution.

→ Which households benefit from price effect? Does it reinforce or weaken income polarization?

→ Is the price effect quantitatively important?

This paper tries to answer these questions.

Contribution

1. **Input-based approach to measure digitalization in consumption, prices and leisure**. Three stylized facts:
    - The digital content in consumption increases with income
    - Inflation rates decrease with higher income, while single good/service inflation is lower the larger the digital content
    - leisure time-share with digital intensive activities increases with income

Contribution

1. **Input-based approach to measure digitalization in consumption, prices and leisure**. Three stylized facts:
    - The digital content in consumption increases with income
    - Inflation rates decrease with higher income, while single good/service inflation is lower the larger the digital content
    - leisure time-share with digital intensive activities increases with income
2. **Structural model** to quantify the size of the two channels:
    - production function with three types of labor that are to different degrees substitutable to digital capital → *income effect*
    - non-homothetic preferences over two consumption goods, one more digitalized →*price effect*
    - calibrate to the US economy, 1960-2017
3. **Results** Income gains get most amplified at the top, muted at the bottom. Welfare resembles a **J-shape**

Related literature

Automation literature:

- *income inequality*: **Autor & Dorn (2013)**, Gaggl & Wright (2017), Acemoglu & Restrepo (2018), Hémous & Olsen (2022)
- *structural models*: Karabarbounis & Neiman (2014), **Eden & Gaggl (2018)**, **Jaimovich, Saporta-Eksten, Siu & Yedid-Levi (2021)**
- *prices*: Graetz & Michaels (2018), Aghion, Antonin, Bunel & Jaravel (2022)

Literature on prices and consumption inequality:

- *inflation inequality:* Kaplan & Schulhofer-Wohl (2017), Jaravel (2019), Hochmuth et al. (2022), **Jaravel & Lashkari (2024)**
- *trade literature:* Fajgelbaum & Khandelwal (2016), Nigai (2016), **Borusyak & Jaravel (2018)**

Plan of the talk

1. Data analysis
2. Model
3. Calibration
4. Simulation

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Measuring digitalization

We measure the digitalization content of goods by studying how they are produced (input-based measure):

- measure **ICT intensity of 61 industries** as share of capital stock that consists of digital assets (`BEA Detailed Data for Fixed Assets`)
- trace input-output linkages to compute the ICT intensity of **394 final commodities** (`BEA Input-Output Accounts`)
- link with consumption data to determine the ICT intensity in the **consumption basket** of different households (`CEX`)
- link asset data with price data to compute **inflation** at the level of final commodities (`BLS CPI`)
- link ICT intensity of final commodities to activities in a **time use** survey (`ATUS`)

Data Image

Measuring digitalization

- measure **ICT intensity of 61 industries** as share of capital stock that consists of digital assets (`BEA Detailed Data for Fixed Assets`)
  - we classify 16 out of 96 assets as ICT assets more
  - investment in these assets has increased massively over the last 60 years Details
- trace input-output linkages to compute the ICT intensity of **394 final commodities** (`BEA Input-Output Accounts`)
- link with consumption data to determine the ICT intensity in the **consumption basket** of different households (`CEX`)
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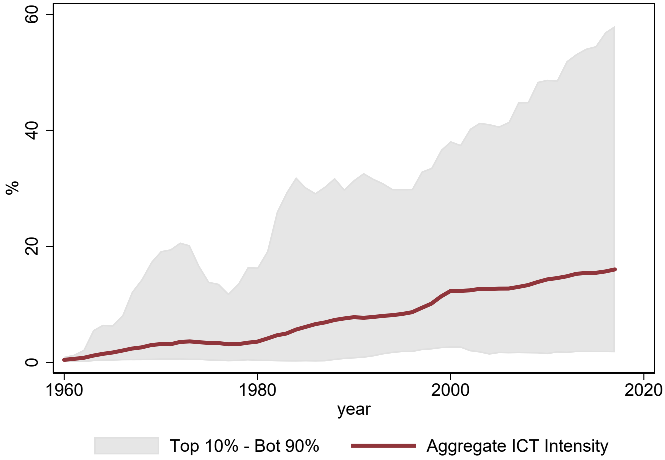
Industry-level ICT intensity

Digitalization Measure: ICT-intensity$=K^{ICT}/K^{total}$



Measuring digitalization

- measure **ICT intensity of 61 industries** as share of capital stock that consists of digital assets (`BEA Detailed Data for Fixed Assets`)
- trace input-output linkages to compute the ICT intensity of **394 final commodities** (`BEA Input-Output Accounts`)
  - final ICT share as weighted mean of ICT share of intermediate inputs and value-added Details
  - use a commodity-by-commodity direct requirements matrix
- link with consumption data to determine the ICT intensity in the **consumption basket** of different households (`CEX`)
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- link with consumption data to determine the ICT intensity in the **consumption basket** of different households (`CEX`)
  - CEX provides info on income and expenditure at the household level
  - ca. 800 detailed product categories, which we match to IO commodities
  - detailed time coverage 1996-2017, historical 1960-2017 by Jaravel & Lashkari (2024)
- link asset data with price data to compute **inflation** at the level of final commodities (`BLS CPI`)
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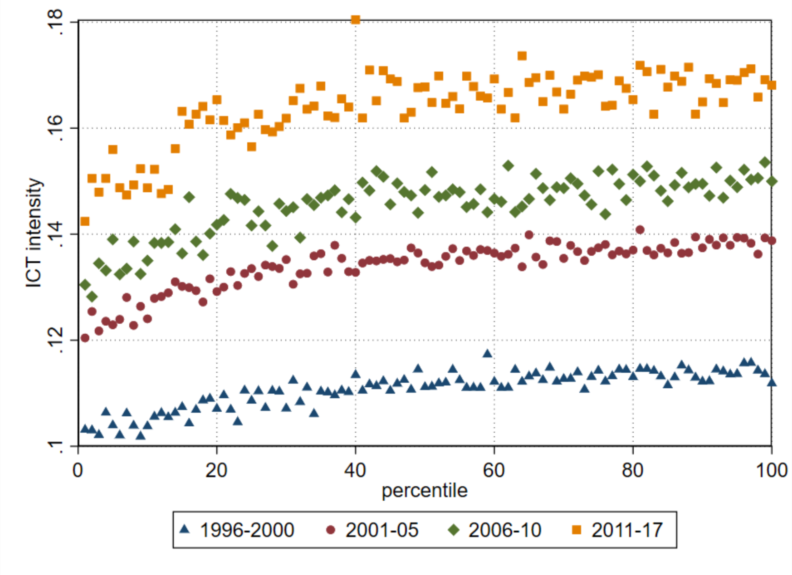
ICT intensity of consumption along the income distribution



Details Historical

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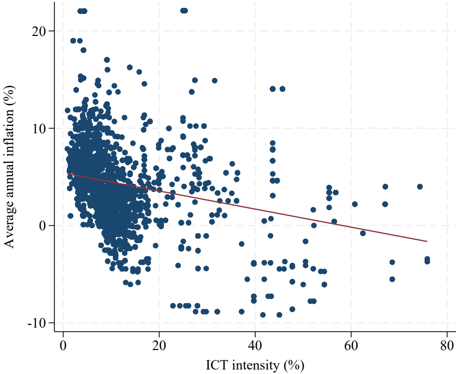
Price Changes and ICT intensity 1960-2017

(a) Decadal $\bar{\pi}$ and ICT intensity of item



Sources: BEA, BLS, Jaravel and Laskari (2024), own calculations

(b) Regression

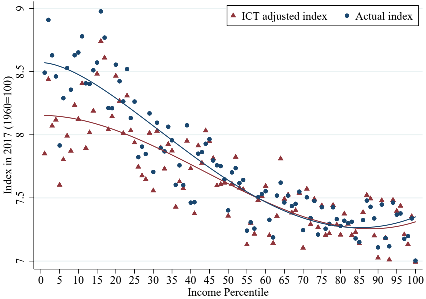
Table 1: Inflation rates and ICT intensity

VARIABLES	(1) 60-17	(2) 60-17	(3) 97-17	(4) 97-17
ICT Intensity	-0.212***	-0.0986***	-0.0550***	-0.0527**
	(0.0258)	(0.0307)	(0.0207)	(0.0216)
Import Share			-0.00387***	-0.00379***
			(0.000722)	(0.000638)
Constant	5.533***	6.555***	2.732***	2.416***
	(0.296)	(0.212)	(0.290)	(0.413)
Observations	3,944	3,944	1,172	1,172
R-squared	0.336	0.520	0.388	0.390
industry FE	yes	yes	yes	yes
year FE	no	yes	no	yes

Note: The table shows the regression of annualized decadal price changes on ICT intensity and the import share at the end of each decade. All variables are measured in %. Columns (1) and (2) are regressions for the full dataset, columns (3) and (4) from 1997. Standard errors clustered at the level of IO commodities in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Inflation inequality and costs 1960-2017

(c) Price index inc percentile, 1960=1



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(d) Compensatory variation

- ICT adjusted index: What if all household had ICT content in consumption as the top 10%, given *smallest* ICT-price relationship in regression (4)
-

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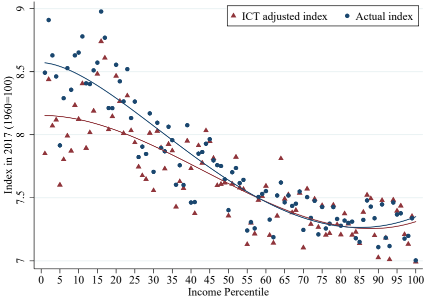
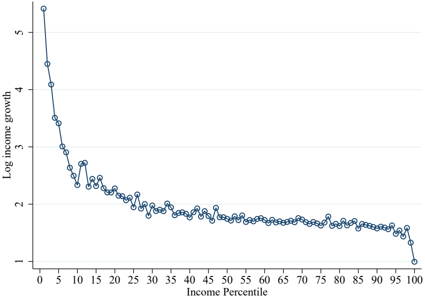


(d) Compensatory variation



- ICT adjusted index: What if all household had ICT content in consumption as the top 10%, given *smallest* ICT-price relationship in regression (4)
- Compensatory variation: how much more income do we need to give households relative to their 1960 income to make them indifferent to price changes between 1960 and 2017?

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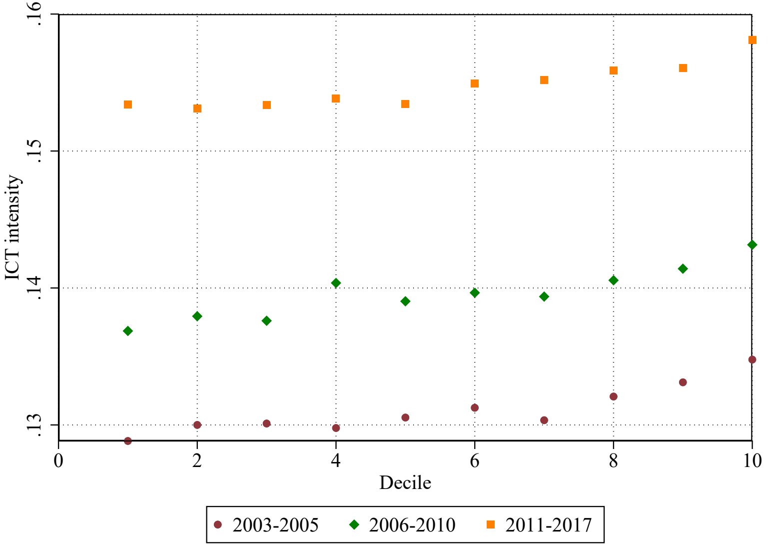
- link ICT intensity of final commodities to activities in a **time use** survey (`ATUS`)
  - ATUS (subsample from CPS) provides information about the time use of individuals
  - more than 400 different activities, matched to final goods and ICT intensity
  - time coverage 2003-2017

ICT intensity of time use along the income distribution



4digit "free" goods

Summary of empirical findings

We have shown using US data that

- High-income households consume more digitalized goods
- They benefit more price changes of ICT intensive goods and services
- They also spend more time with ICT intensive activities
- Effect of digitalization on inequality amplified: U-shaped income polarization together with downward sloping price effect

Summary of empirical findings

We have shown using US data that

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How large is the actual welfare change due to digitalization?

How large is the income vs the price effect?

$\rightarrow$ Assess via a structural model

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1. Data analysis
2. Model
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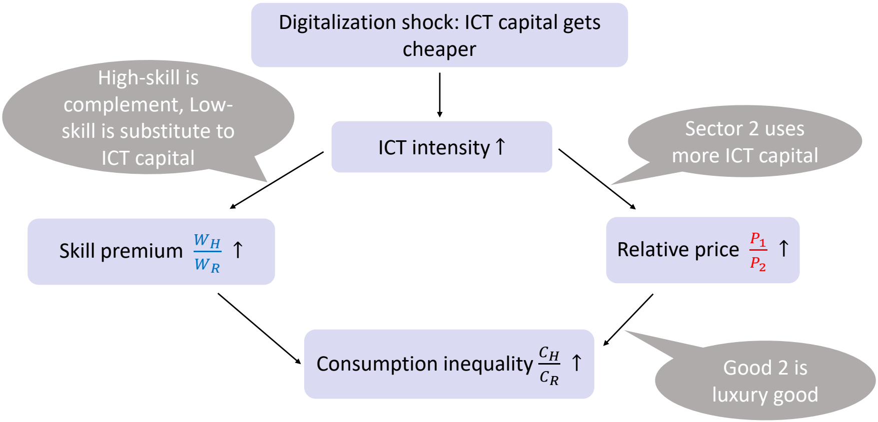
Model Overview

- two types of capital: **ICT and non-ICT capital**
- **two sectors**: sector 2 uses ICT capital more intensively than sector 1
- three types of labor: **high-skill, manual and routine work**; can work in either sector
- Households have different skills and sort into sectors depending on wage
- high-skill labor is complementary to ICT capital, routine labor substitutable
- **non-homothetic preferences**: the richer a household, the larger the share of ICT-goods in consumption basket (PIGL preferences)
- digitalization works through an increase in the rate of transformation of output into ICT capital.

Model Overview



Production

Inner nest: Routine labor H_i and ICT capital ICT_i produce automated work (AW):

$$AW_i = \left[\phi_i R_i^{\frac{\eta_i - 1}{\eta_i}} + (1 - \phi_i) ICT_i^{\frac{\eta_i - 1}{\eta_i}}\right]^{\frac{\eta_i}{\eta_i - 1}},$$

Middle nest 1: AW and high-skill work H_i produce specialized work (SW):

$$SW_i = \left[\gamma_i H_i^{\frac{\epsilon_i - 1}{\epsilon_i}} + (1 - \gamma_i) AW_i^{\frac{\epsilon_i - 1}{\epsilon_i}}\right]^{\frac{\epsilon_i}{\epsilon_i - 1}},$$

Middle nest 1: SW and manual work M_i produce total work (TW):

$$TW_i = M_i^{\psi_i} SW_i^{1 - \psi_i}$$

Outer nest: Total work and non-ICT capital produce final output:

$$Y_i = K_i^{\alpha_i} TW_i^{1 - \alpha_i} = K_i^{\alpha_i} M_i^{(1 - \alpha_i)\psi} SW_i^{(1 - \alpha_i)(1 - \psi)}$$

Investment

ICT investment is generated from good 2, non-ICT investment from good 1:

$$Y_1 = C_1 + Inv_K \qquad Y_2 = C_2 + \mu Inv_{ICT}$$

- digitalization: decline in μ (ICT capital produced more efficiently) (Eden and Gaggl, 2018; Karabarbounis and Neiman 2019)

Capital formation:

$$K' = (1 - \delta_K)K + Inv_K \qquad ICT' = (1 - \delta_{ICT})ICT + Inv_{ICT}$$

Households: Occupational Choice

- two types of households high-skill and low-skill, time-varying sizes $\bar{H}$ and $\bar{L}$
- Households can work in any sector and can switch sectors at no cost
- as in Jaimovich et al. (2020), low-skill households work in either R or M occupations
- Each low-skill household j is endowed with two idiosyncratic productivity parameters λ_{Rj},λ_{Mj} drawn from a joint distribution $\Gamma(\lambda_R, \lambda_M)$

A household chooses to work in M if

$$\lambda_{Rj} W_R \leq \lambda_{Mj} W_M$$

- H households are all identical and allocate to the H tasks

Households: Preferences

- Price Independent Generalized Linearity (PIGL) preferences (Boppart, 2014): flexible framework for non-homothetic preferences
- Indirect utility function

$$V(P_1, P_2, e_j) = \frac{1}{\rho}\left(\frac{e_j}{P_2}\right)^{\rho} - \frac{\nu}{\theta}\left(\frac{P_1}{P_2}\right)^{\theta} - \frac{1}{\rho} + \frac{\nu}{\theta}$$

  - e_j is expenditure, $j \in \{H, R, M\}$
  - ρ controls the income effect, θ the relative price effect, ν average expenditure shares.
- nests other types of preferences: Cobb Douglas if $\theta = \rho = 0$, $\rho = 0$ homothetic preferences

Household budgets

- Exogenous mass of high-skill ($\bar{H}$) and low-skill households ($\bar{L}$)
- High-skill households own all the capital. Low-skill households are hand-to-mouth. data

High-skill budget constraint:

$$\underbrace{C_{1,H} P_1 + C_{2,H} P_2}_{=e_H} + I_K P_1 + I_{ICT} P_2 = \bar{H}\, W_H + K\, R_K + IT\, R_{ICT}$$

Low-skill budget constraint, j sorts into $i \in \{R, M\}$:

$$\underbrace{C_{1,j} P_1 + C_{2,j} P_2}_{=e_j} = \lambda_{ij}\, W_i$$

First order conditions

- Intratemporal optimization: Marshallian demands

$$C_{1,j} = \nu \frac{e_j}{P_1} \left(\frac{P_2}{e_j}\right)^{\rho} \left(\frac{P_1}{P_2}\right)^{\theta}; \quad C_{2,j} = \frac{e_j}{P_2} \left(1 - \nu \left(\frac{P_2}{e_j}\right)^{\rho} \left(\frac{P_1}{P_2}\right)^{\theta}\right)$$

The elasticity of substitution depends on expenditure

$$\sigma_j = 1 - \theta - \frac{\nu \left(\frac{P_1}{P_2}\right)^{\theta}}{\left(\frac{e_j}{P_2}\right)^{\rho} - \nu \left(\frac{P_1}{P_2}\right)^{\theta}} (\theta - \rho).$$

- Intertemporal optimization of H-households: Euler equations

$$\left(\frac{P_2'}{P_2}\right)^{\rho} \left(\frac{e_H'}{e_H}\right)^{1-\rho} = \beta \frac{\mu'(1 - \delta_{ICT}') + R_{ICT}'}{\mu},$$

$$\left(\frac{P_2'}{P_2}\right)^{\rho} \left(\frac{e_H'}{e_H}\right)^{1-\rho} = \beta \left((1 - \delta_K') + R_K'\right),$$

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Industry classification

BEA industries are classified into sector 1 (non-ICT) and 2 (ICT) via k-means clustering

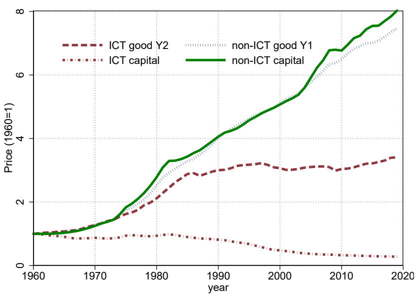
- Sector 2 covers 10 industries mainly related to computer manufacturing, information services, finance and management. details
- In 1996-98 these sectors cover

Data in %	Sector 1	Sector 2
ICT intensity	9%	40%
Value added share	82%	18%
Cons. Expenditure share	91%	9%
Labor share	50%	70%
Cognitive employment share	59%	79%

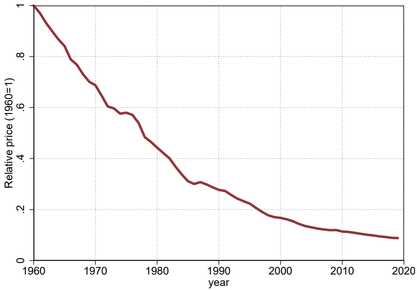
Progress in digital technology

Progress in digital technology is measured by μ (price of ICT capital/price of ICT intensive good) $\rightarrow$ feed this into the model as exogenous shock

(e) Individual price series



(f) μ



Calibration

We calibrate the parameters of the production function using the **method of simulated moments**.

Moments to match (% change between 1960 and 2017):

- skill premium (ACS)
- relative consumption prices (NIPA)
- ICT intensity (BEA)
- labor share (NIPA, Elsby et al., 2013)
- rate of return to ICT capital (Karabarbounis and Neiman, 2014)
- Relative consumption
- difference in cons exp share for good 2 top 10 bottom 10
- increase in average cons exp share of good 2

We set 1960 as pre-digitalization steady state and feed in changes in the price of ICT capital between 1960 and 2017

Calibrated parameters

Table 1: Calibrated parameters

Symbol	Value	Description	Source
Inner nest			
ϕ_1	0.896	Weight of R in 1	calibrated
ϕ_2	0.687	Weight of R in 2	calibrated
$\eta_1 = \eta_2$	2.170	El. of Subst between R and ICT	calibrated
Middle nest 1			
γ_1	0.548	Weight of H in sector 1	calibrated
γ_2	0.217	Weight of H in sector 2	calibrated
$\epsilon_1 = \epsilon_2$	0.651	El. of Subst betw H and AW	calibrated
Middle nest 2			
ψ_1	0.143	Income share of M in sector 1	ACS and EHS
ψ_2	0.021	Income share of M in sector 2	ACS and EHS
Final Production			
α_1	0.45	Capital share in sector 1	BEA
α_2	0.18	Capital share in sector 2	BEA
δ_{ICT}	0.14	Depreciation rate ICT capital	BEA
δ_K	0.06	Depreciation rate non-ICT capital	BEA
Preferences			
ν	0.580	Expenditure share parameter good 1	calibrated
θ	-0.042	Substitution parameter	calibrated
ρ	0.117	Income elasticity parameter	calibrated
β	0.97	Discount factor	

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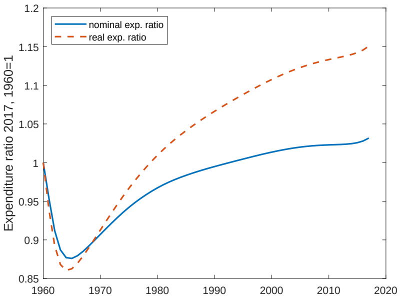
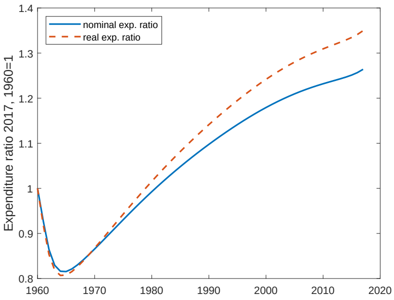
Consumption inequality

- Nominal changes in line with literature Meyer and Sullivan (2023)
- When deflating with percentile-specific Törnqvist indexes, differences in consumption inequality get amplified

(a) 90-10 ratio

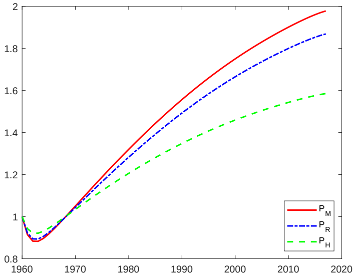


(b) 90-50 ratio

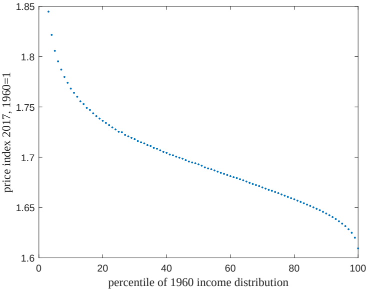


Inflation inequality

(c) Inflation by group



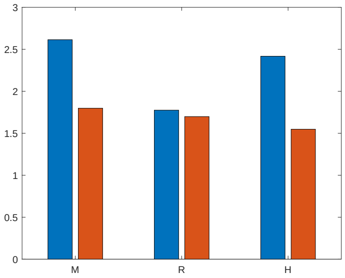
(d) Inflation by percentile group



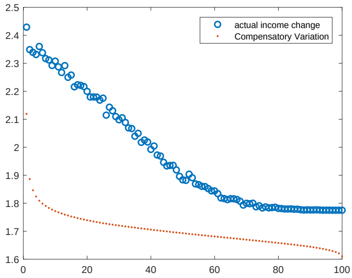
- low-skill price index increases more than high-skill price index
- substantial divergence of price indices along the income distribution

Compensatory income vs. actual income, relative to 1960:

(e) CV by group



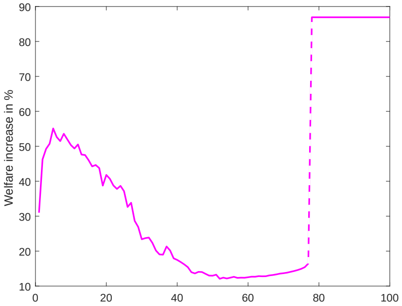
(f) CV by percentile group



- CV: how much additional income do households need relative to their 1960 income to be indifferent to the price increase 1960-2017?
- U-shaped income polarization vs downward sloping inflation costs
- the price effect partly offsets income gains for the poor and amplifies those gains for the rich

Overall welfare effects

- Subtract compensatory income from actual income
- U-shape becomes a J-shape: income gains at top 23% are amplified, at bottom reduced
- Routine workers are hardly better off



Conclusion

- This paper contributes to the debate on digitalization and inequality, focusing on consumption
- Two channels: Income effect vs. price effect. We show empirically that the **price effect works in the same direction as the income effect, benefiting the rich**'
- Part of income gains for the poor are **partly offset by higher inflation rates** for the poor
- Overall welfare effects are not U-shaped, but rather J-shaped

Thank you!

For further comments, contact me at
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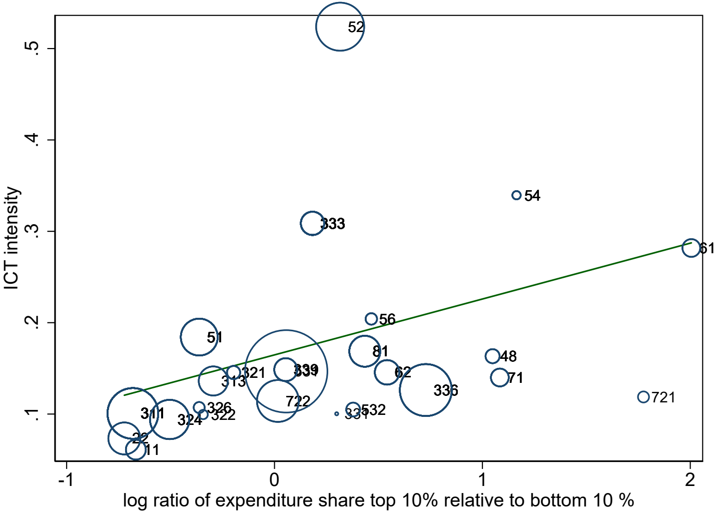
ICT assets

The BEA provides data on 96 different types of assets, of which 16 are IT assets (see Eden and Gaggl, 2018):

- mainframes, PCs, printers, terminals, tap drives, storage devices etc.
- intellectual property products, such as software, computer systems design

back

ICT intensity of vs. relative expenditure shares in 2017



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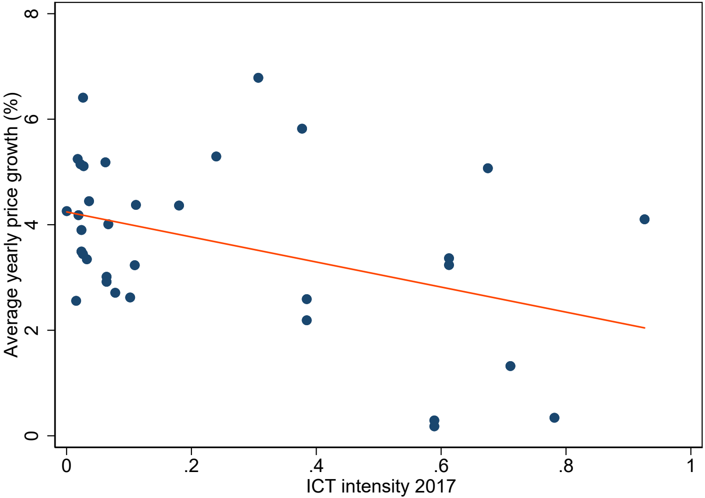
ICT intensity and prices- industry level



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ICT intensive industries

Industry code	Industry name
3340	Computer and electronic products manufacturing
5110	Publishing industries
5140	Data processing, internet publishing, and other information services
5230	Securities, commodity contracts, investments, and related activities
5240	Insurance carriers and related activities
5250	Funds, trusts, and other financial vehicles
5411	Legal services
5412	Accounting and bookkeeping services
5415	Computer systems design and related services
5500	Management of companies and enterprises

back

Inflation along the distribution and products

year	π_t		π_t^{ICT}		$\pi_t^{ICT,fixed}$		Δ^{ICT}	
	1st	10th	1st	10th	1st	10th	1st	10th
1996	-	-	-	-	-	-	-	-
1997	0.9	1	2.2	2	2.2	2	0	0
1998	1	1.2	0.8	0.9	0.8	0.9	0	0
1999	2.6	2.6	1	0.8	1	0.8	0	0
2000	3.1	3	2	1.5	1.9	1.7	0.1	-0.2
2001	0.9	1	4.9	4.4	5	4.5	-0.1	-0.1
2002	2.2	2.3	5.5	4.8	5.7	4.8	-0.2	0
2003	1.3	1.4	2.7	2.4	2.8	2.2	-0.1	0.2
2004	3.4	3.1	2.8	2.5	2.6	2.2	0.2	0.3
2005	3.3	2.9	1.5	1.4	1.6	1.5	-0.1	-0.1
2006	2.2	2.4	0.4	-0.2	1.1	1.1	-0.7	-1.3
2007	4.6	4	0.4	-0.3	1.2	1.5	-0.8	-1.8
2008	-1.4	-0.5	-0.7	0.7	0.9	3	-1.6	-2.3
2009	3.6	3.2	0.9	-0.4	0.5	2.5	0.4	-2.9
2010	1.7	1.5	1.8	0.6	0.4	2.2	1.4	-1.6
2011	3.5	3.1	1.6	1.2	0.9	2.3	0.7	-1.1
2012	1.6	1.8	2.4	1.5	0.8	2.9	1.6	-1.4
2013	1.3	1.4	1.6	1	0.4	2.1	1.2	-1.1
2014	0.1	0.4	1.6	1.4	0.2	2.4	1.4	-1
2015	-0.3	0.4	2.6	2.5	0.5	3.2	2.1	-0.7
2016	1.3	1.8	2.6	3	0.7	3.7	1.9	-0.7
2017	1.9	1.7	2.1	0.6	-0.2	3	2.3	-2.4

back

Compensatory Variation with the data

Suppose you have utility over goods C_i $i \in 1, 2, ..., N$

$$U\left(\{C_i\}_i^N\right)$$

The agent has income I and faces prices $\{p_i\}_i^N$.

Suppose prices change $\{dp_i\}_i^N$. the compensatory variation then asks how much additional income is needed to ensure the same utility level

$$V\left(I + EV, \{p_i\}_i^N\right) = V\left(I, \{p_i + dp_i\}_i^N\right)$$

which is approximately

$$V\left(I, \{p_i\}_i^N\right) + \frac{dV}{dI}EV = V\left(I, \{p_i\}_i^N\right) + \frac{dV}{dp_i}\Delta p_i$$

Recall Roy's identity that gives us an expression for demand x_i of good C_i:

$$-x_i = \frac{dV/dp_i}{dV/dI}$$

Plug this into the approximation above:

$$EV = -x_i \Delta p_i = -x_i p_i \frac{\Delta p_i}{p_i}$$

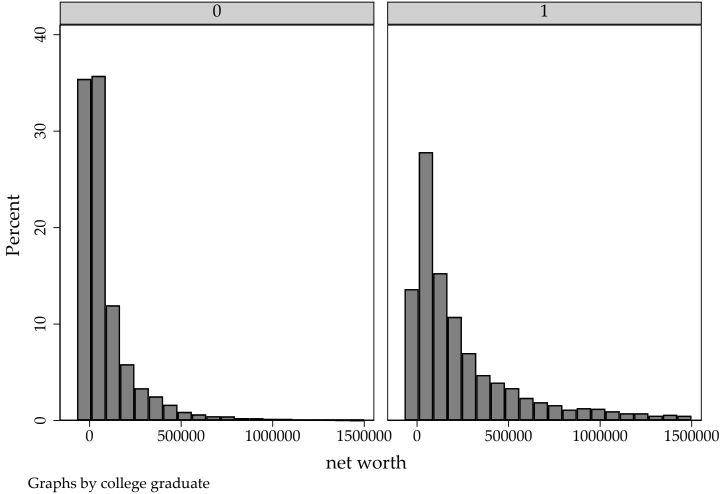
which states that EV is equal to nominal expenditures times the percentage change of prices. Logic extends when all prices change

$$EV = -\sum_i p_i x_i \frac{\Delta p_i}{p_i}$$

Divide this by initial income and compare with the actual income growth

back

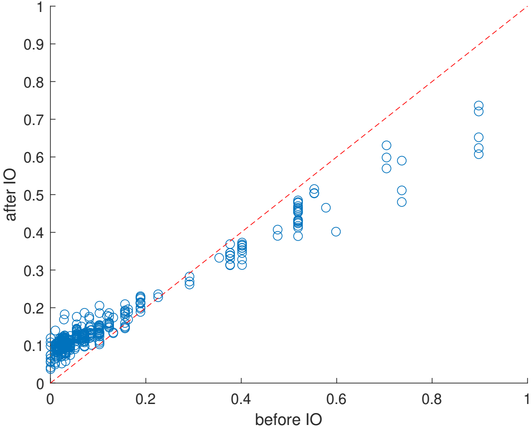
Net worth distribution by education level



Source: SCF, data for 1998-2013 for net worth <1.5mio. USD. back

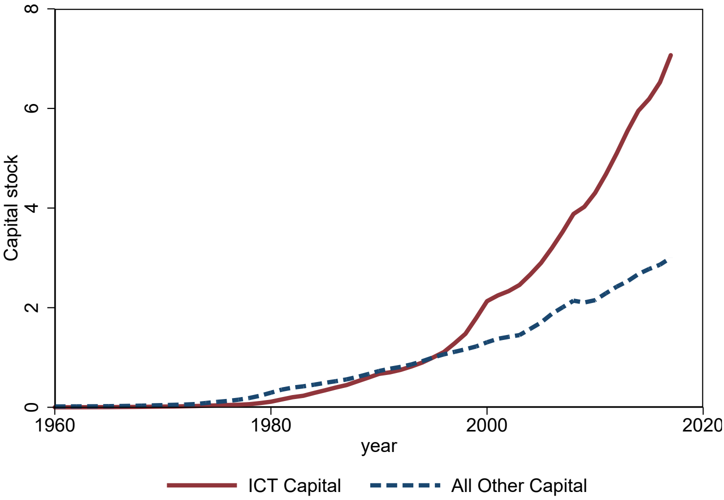
Considering the Input-output structure

ICT intensities for 2012



61 industries before IO, 394 industries after IO back

Aggregate ICT- and non-ICT capital (1995=1)



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Inflation and ICT intensity

Table 2: Average annual inflation rate and ICT intensity

Variables	(1) π_{2017}	(2) π_{2012}	(3) π_{2012}
ICT intensity	-4.220***	-6.136***	-5.152***
	(1.476)	(1.786)	(1.702)
Trade share			-2.835***
			(0.497)
Constant	1.273***	1.422***	2.156***
	(0.298)	(0.333)	(0.341)
Observations	300	281	281
R-squared	0.017	0.037	0.209

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

back

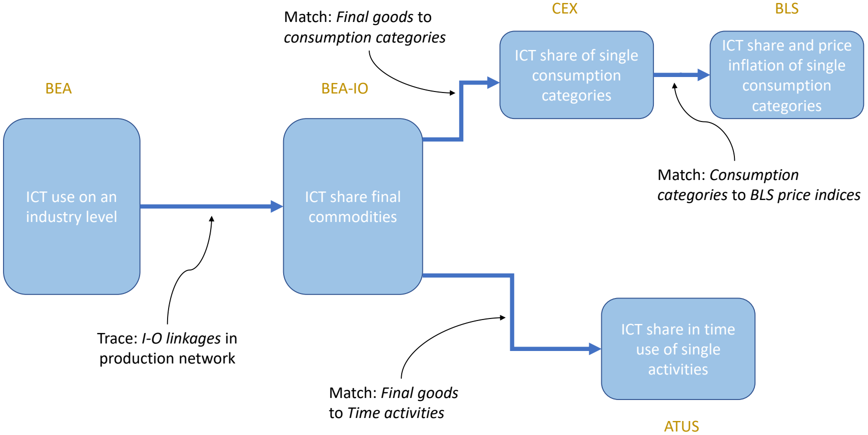
Inflation and ICT intensity

Back of the envelope calculation:

- Difference in ICT intensity between 1st and 100th percentile of the income distribution: approx. 2ppt
- Slope coefficient on regression of annual inflation on ICT intensity: -4.22
- The ICT-predicted difference in annual inflation is $0.02 \times 4.22/100 = 0.000844$
- Over 22 years, this amounts to $(1 + 0.000844)^{22} = 1.0187$

back

Overview: Input-based Measurement of Digitalization

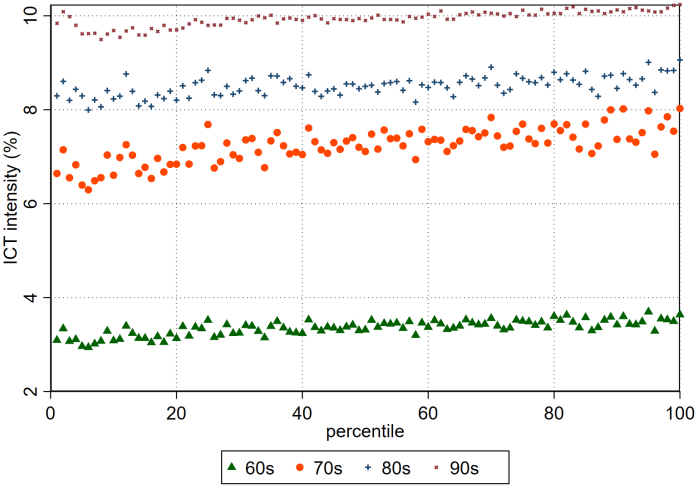


back

ICT intensity vs. relative expenditure shares in 2017

back

Historical ICT-share in Consumption



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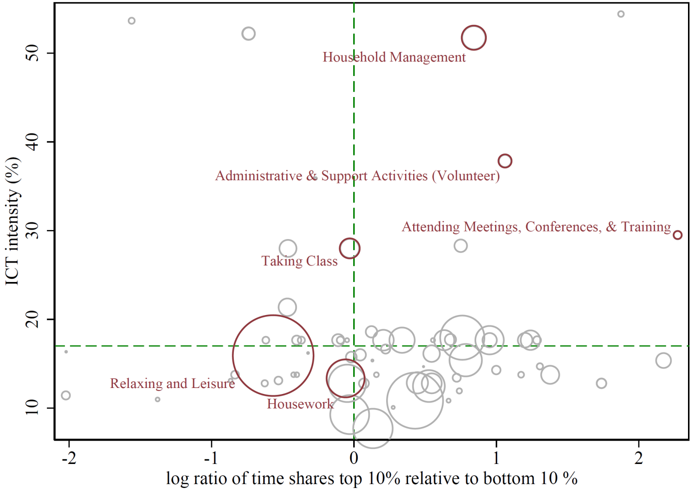
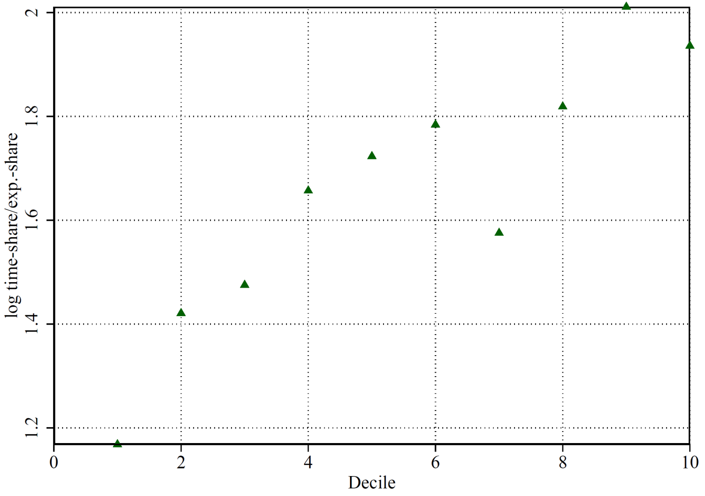
ICT intensity vs relative share in time use



4 digit activity codes back

"Free" digital activities



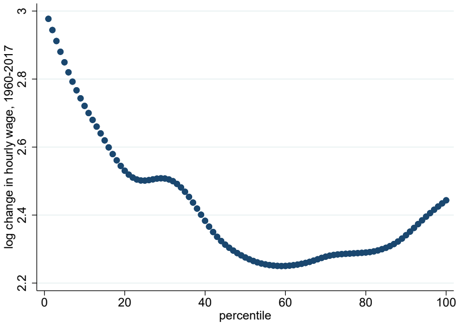
Near zero marginal costs goods ("free digital good"). Time-share/expenditure share for this category. back

Motivation

Automation leads to **income** polarization: routine jobs lose, low-skill manual and high-skill cognitive jobs gain.

Autor, Katz & Kearney (2008), Autor and Dorn (2013), Goos, Mannings & Salomons (2009), Michaels, Natraj & van Reenen (2014)

Figure 1: income growth, 1960-2017



Source: ACS, Census.

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