Digitalization and Productivity Growth Slowdown in Production Networks

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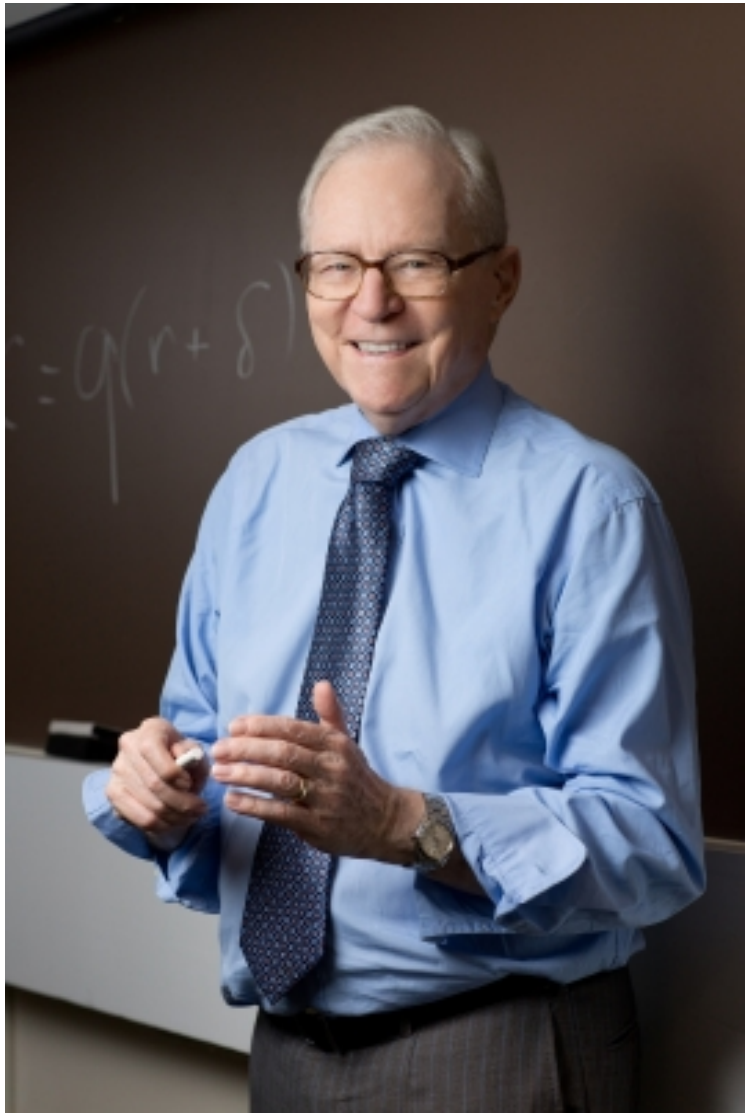
August 2025
EEA Congress - Bordeaux

Tribute: William Baumol & Dale Jorgenson



Motivation

- A production networks perspective on digitalization and the productivity growth slowdown
  1. Digital technologies are often embodied in intermediates (cloud computing, software in automation)
  2. Even for capital, high depreciation rates (40-50%)
  3. Digital-intensive services are central intermediates and capital producers (finance, business services etc.)
- These facts are highly relevant for the future of the productivity growth

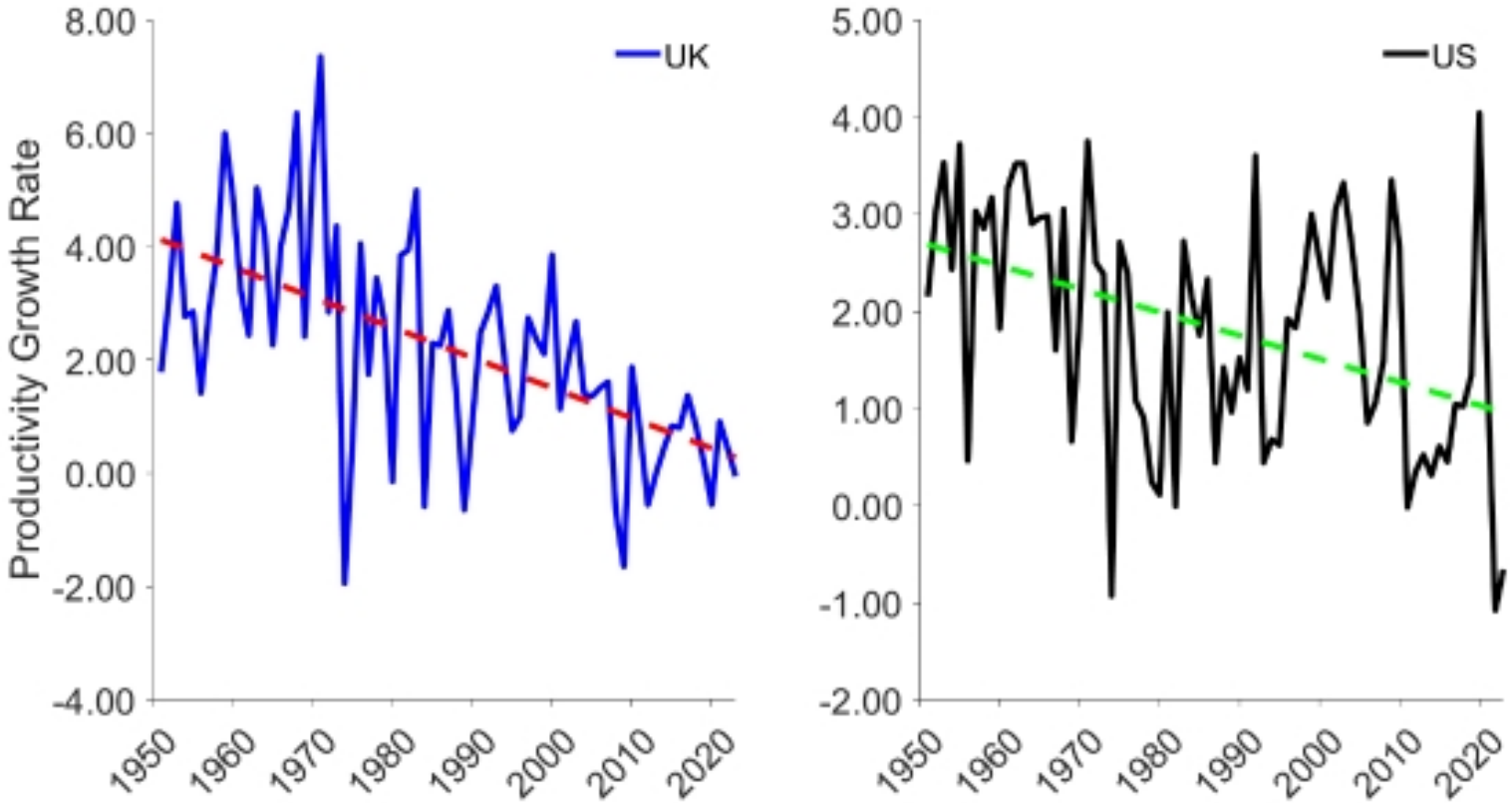
Design

- A comparative analysis of the UK and the US for the last 35 years
- A highly disaggregate model with multiple capital goods and intersectoral linkages
- **Idea**: The slowdown in computer-specific technical change is chiefly responsible for the aggregate productivity growth slowdown

Results

- Decline in the computer-specific technical change accounts for the majority (whole?) of the productivity growth slowdown for the US after 2005
- Many competing alternatives for the UK, but it is primarily a story of IT-specific technical change
- **Structural changes in the IT production**: Diminishing returns/Strong complementarities kick in starting with the early 2000's
- Some cautious implications for the future of the productivity growth

Productivity Growth Slowdown in the UK and US



- **Note**: Productivity growth rate refers to annual labor productivity growth rate.

Modelling Digitalization

- Decline in the relative price of digital capital amplified by network effects

$$\begin{matrix}\text{Digital-intensive intermediate producers} \\ \\ \text{Digital-intensive capital goods producers}\end{matrix} \quad \Rightarrow \quad \text{All Industries}$$

- 75% of aggregate productivity growth is driven by sectoral patterns (Foerster et al. 2022)
- Even for a general purpose technology, digitalization has strong sectoral underpinnings

A Classification of Digital-Intensive Industries

- Digital Capital (a.k.a ICT Capital)
  1. Computer Hardware
  2. Communications Equipment
  3. Software (Pre-Packaged, Custom and Own Account)
- Capital types that rely on digital technologies are out (medical instruments, office equipment, etc.)
- Also do not account for digital share in intermediates
- The share of digital capital in total industrial output: $\sim 3.30\%$ (Median) for the UK and $\sim 2.10\%$ for the US
- **Digital-Intensive Industries**: Above Median

A Ranking of Industries by Digital-Intensity: US

Industry	Digital-Intensity
Broadcasting and Telecommunications	0.295
Data Processing	0.250
Legal Services	0.078
Wholesale Trade	0.065
Miscellaneous Professional, Scientific and Technical Activities	0.065
Food Services and Drinking Places	0.010
Rail Transportation	0.007
Hospitals and Nursing and Residential Care	0.007
Arts and Entertainment	0.004
Real Estate	0.004

A Taxonomy of Digital-Intensive Industries

- **Digital-Intensive Industries**

  Service industries that primarily produce intermediates and capital goods

- **Digital Services**: Wholesale and retail trade, finance, business services, information...

  Stagnant Services: Education, health, food and accommodation....

- Highly relevant in many contexts: productivity growth, capital intensity, trade

- **Capital Goods-Producing Manufacturing Industries**

  They show an above average digital intensity

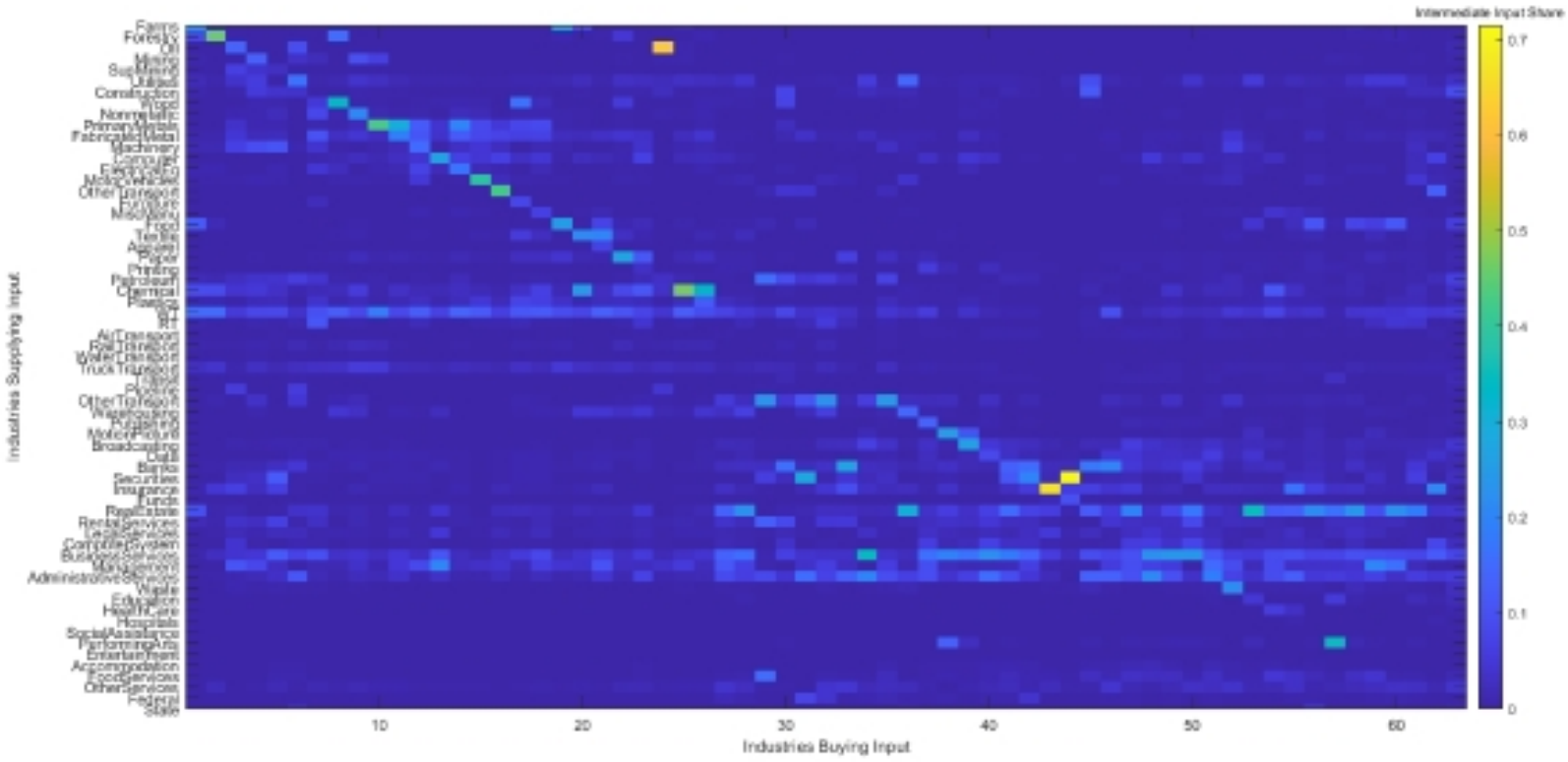
Motivation - Stylized Facts on Digital Services

- **Fact#1:** They are highly central in production network

Centrality in the Production Network of the US - 2021

Industry	Outdegree
Miscellaneous Professional, Scientific, and Technical Services	5.50
Wholesale Trade	4.21
Administrative and Support Services	3.85
Management of Companies and Enterprises	2.49
Accommodation	0.14
Amusements, Gambling, and Recreation Industries	0.03
Hospitals and Residential Care Facilities	0.01
Social Assistance	0.01

Production Network: US



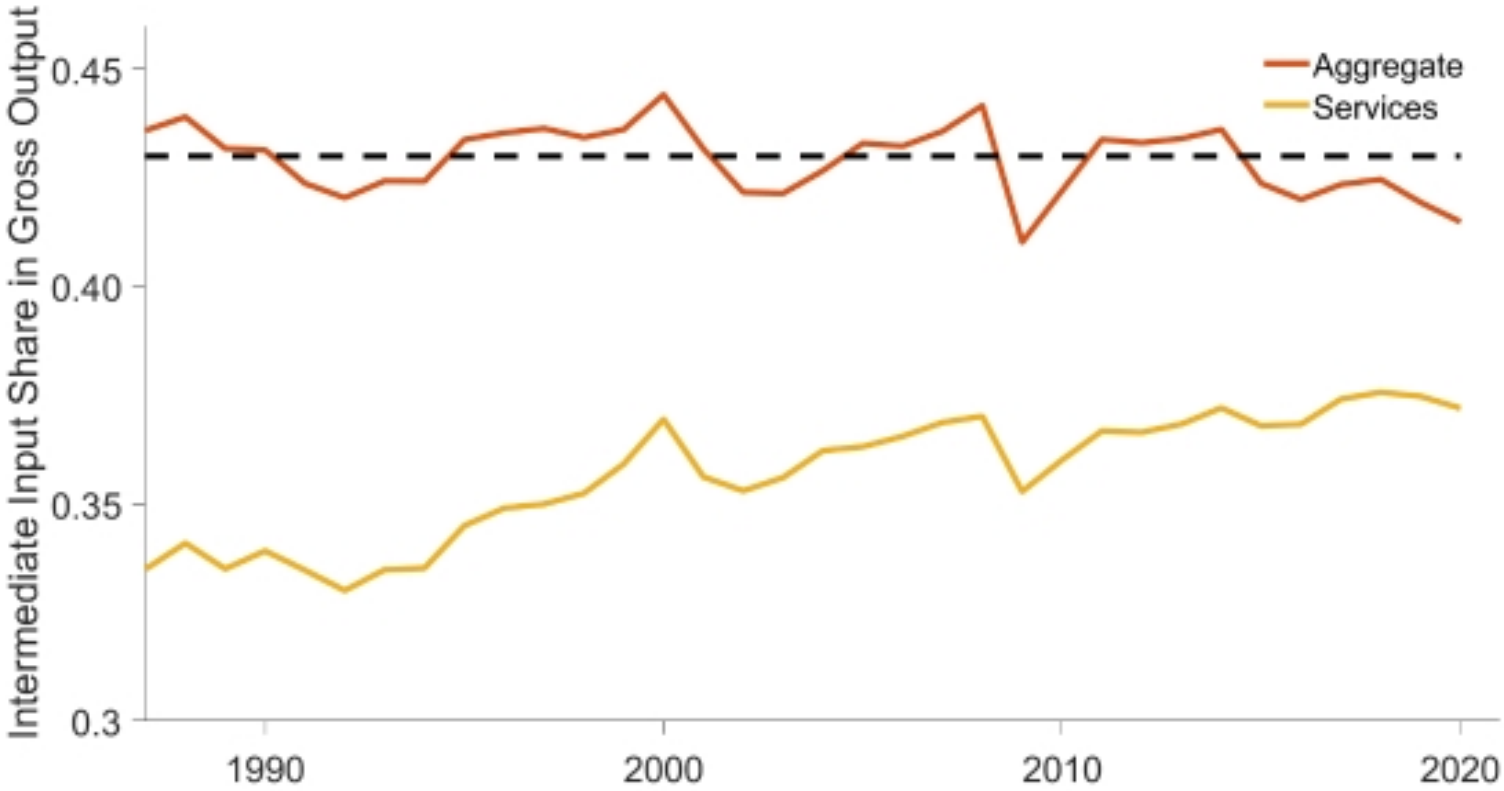
- **Source**: BEA IO Tables.

UK

Motivation - Stylized Facts on Digital Services

- **Fact#2:** Services have been getting more intermediates intensive; Digital Services drive this change

Structural Change in Production Networks: US



- **Source**: BEA-BLS Industry-Level Production Account.

Motivation - Stylized Facts on Digital Services

- **Fact#3:** Aggregate productivity growth closely follows productivity patterns in digital services

Labor Productivity Growth Across Sectors: US

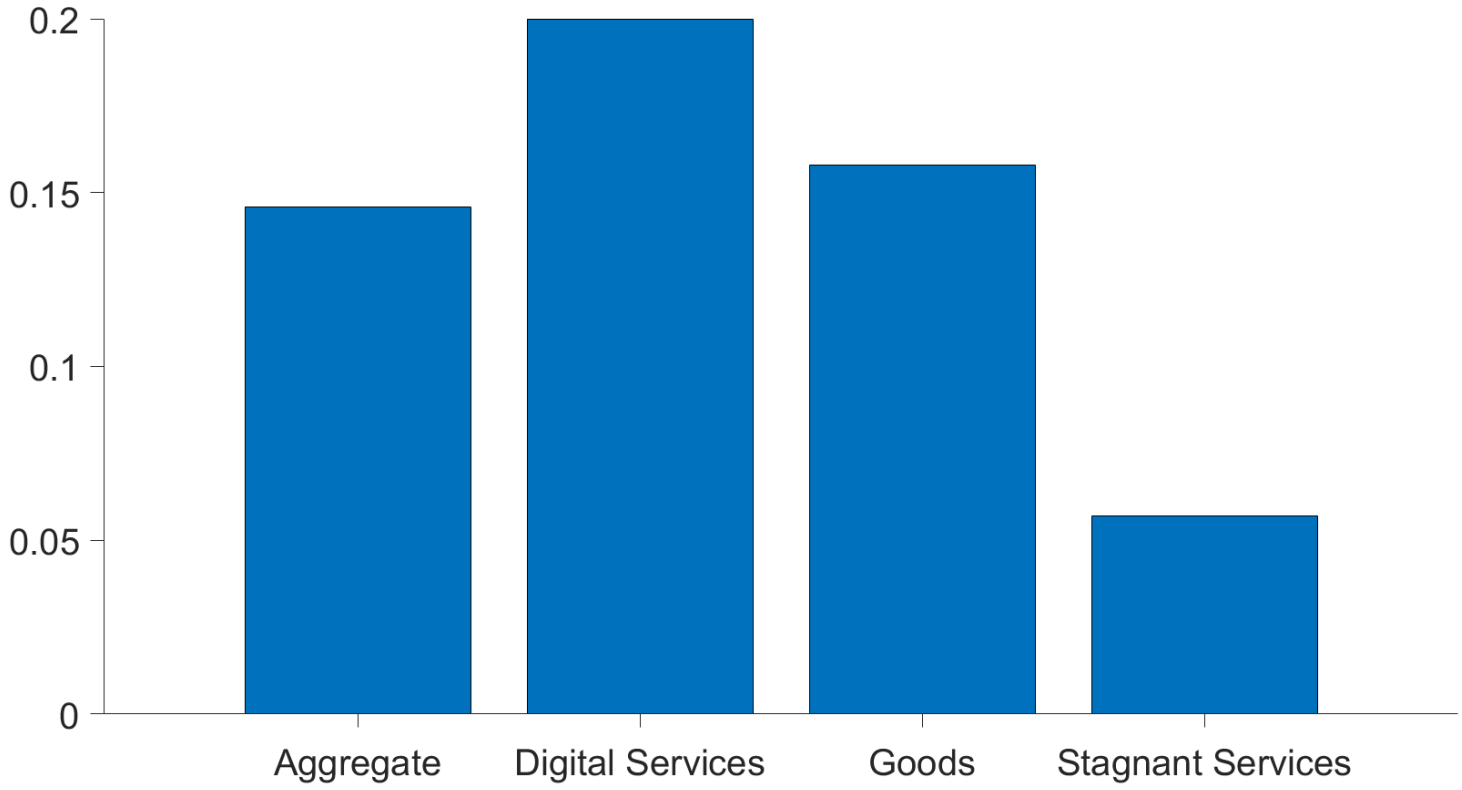
	1995-2005	2005-2020	Difference
Aggregate	2.40	0.98	-1.42
Goods	3.75	1.61	-2.14
Digital Services	2.74	1.26	-1.48
Stagnant Services	1.16	0.39	-0.78

- **Source**: EUKLEMS & INTANProd

Motivation - Stylized Facts on Digital Services

- **Fact#4:** Digital services are the most equipment and software-intensive sub-sector of the aggregate economy and ***capital deepening accounts for almost the whole productivity growth in these industries.***

Equipment-Software Intensity: US



- **Note**: Numbers show the equipment/software share in sectoral output.

Productivity Growth in Digital Services: US, 1947-2014

- Almost entirely capital deepening

	Labor Productivity Growth	Capital Deepening	Percentage
Wholesale Trade	3.08	1.78	57.72%
Retail Trade	2.08	0.81	38.98%
Information	3.26	2.46	75.24%
Finance	1.56	1.83	117.87%
Business Services	1.87	1.91	102.14%
Administrative and Support Services	1.30	1.24	95.18%

- **Source**: WORLD KLEMS

Main Idea

- Capital embodied technical change is the engine of growth in digital services
- Decline in the relative price of computers slows down
- $\Rightarrow$ It affects productivity growth negatively in digital services
- Network structure amplifies these effects

Slowdown in Computer-Specific Technical Change

	1995-2005	2005-2021
Equipment	-4.51	-2.02
Computers and Peripheral Equipment	-20.56	-5.28
Communication Equipment	-8.09	-9.13
Structures	2.49	1.29
Software	-4.17	-3.09
R&D	-0.16	0.50

- **Notes**: Numbers show the changes in the prices of different capital types relative to consumption. Data source is BEA.

A Model of Digitalization in Production Networks

- Three main sectors
  1. Goods (G)
  2. Digital Services (D)
  3. Stagnant Services (S)

- 60 industries, 30 types of capital

Production Side

$$Q_{jt} = A_{jt}\left[\left[(1-\mu_j)^{\frac{1}{\epsilon_{Qj}}} L_{jt}^{\frac{\epsilon_{Qj}-1}{\epsilon_{Qj}}} + \mu_j^{\frac{1}{\epsilon_{Qj}}} M_{jt}^{D\,\frac{\epsilon_{Qj}-1}{\epsilon_{Qj}}}\right]^{\frac{\epsilon_{Qj}}{\epsilon_{Qj}-1}}\right]^{\alpha_j}\left[\left(\frac{K_{jt}}{\phi_{jk}}\right)^{\phi_{jk}}\left(\frac{M_{jt}^{G}}{\phi_{jg}}\right)^{\phi_{jg}}\left(\frac{M_{jt}^{S}}{\phi_{js}}\right)^{\phi_{js}}\right]^{(1-\alpha_j)}$$

ϵ_{Qj} : Elasticity of substitution between digital services and labor

$\epsilon_{Qj} > 1$ for many service industries

$$K_{jt} = \prod_{k=1}^{N_k}\left(\frac{K_{jt}^{k}}{\beta_{kj}}\right)^{\beta_{kj}}$$

$$K_{jt+1}^{k} = (1-\delta_k)K_{jt}^{k} + X_{jt}^{k}$$

Production Side

$$M_{jt}^{x} = A_{jt}^{x} \prod_{i=1}^{N_x} \left(\frac{M_{ij,t}^{x}}{\phi_{ij}^{x}} \right)^{\phi_{ij}^{x}} \quad for \quad x \in \{D, G, S\}$$

A_{jt}^{x} : Exogenous intermediates-biased technical change

Imported intermediate goods or mismeasurement

$$X_{jt}^{k} = A_{jt}^{k} \prod_{i=1}^{N} \left(\frac{x_{ij,t}^{k}}{\omega_{ij}^{k}} \right)^{\omega_{ij}^{k}}$$

Computer and Electronic Products

Demand Side

$$\sum_{t=0}^{\infty} \beta^t \log C_t$$

where

$$C_t = \sum_{j=1}^{N} \left[\theta_j{}^{\frac{1}{\epsilon_c}} C_{j,t}{}^{\frac{\epsilon_c - 1}{\epsilon_c}} \right]^{\frac{\epsilon_c}{\epsilon_c - 1}}$$

ϵ_c : Elasticity of substitution between different industries in consumption

$$Q_{jt} = C_{jt} + \sum_{i=1}^{N} M^D_{ji,t} + \sum_{i=1}^{N} M^G_{ji,t} + \sum_{i=1}^{N} M^S_{ji,t} + \sum_{k=1}^{N_k} \sum_{i=1}^{N} X^k_{ji,t} \quad (\textit{Resource Constraint})$$

Counterfactuals

- Keep TFP growth intact in a couple of industries after 2005. Keep production technology same in the computers industry
- Computer and Electronic Products, Software, Scientific Research and Development, Equipment/Machinery, Finance
- **US**: The productivity slowdown in the computers industry accounts for the majority of the aggregate productivity growth slowdown after 2005
- **UK**: Many industries are responsible. Chiefly, IT. Equipment/Machinery, Scientific R&D, Finance are also important.

Counterfactuals: US

	Data	**Model**
LPG (1995-2005)	2.40%	2.26%
LPG (2005-2020)	0.98%	1.04%
Exogenous TFP Growth in Computers Capital		1.27%
TFP Growth in Computers Industry		1.52%
Change in Production Function in Computers (Further Decline in TFP Growth in Computers Industry)		2.02%

Counterfactuals: UK

	Data	Model
LPG (1995-2007)	1.84%	1.84%
LPG (2007-2019)	0.42%	0.37%
Computer, Electronic and Optical Products		0.85%
Software, IT&Data Services		1.09%
Computers+Software		**1.56%**
Scientific R&D		0.66%
Finance		1.28%
Equipment&Machinery ex. Computers		**1.29%**

Structural Change in the Computers Production

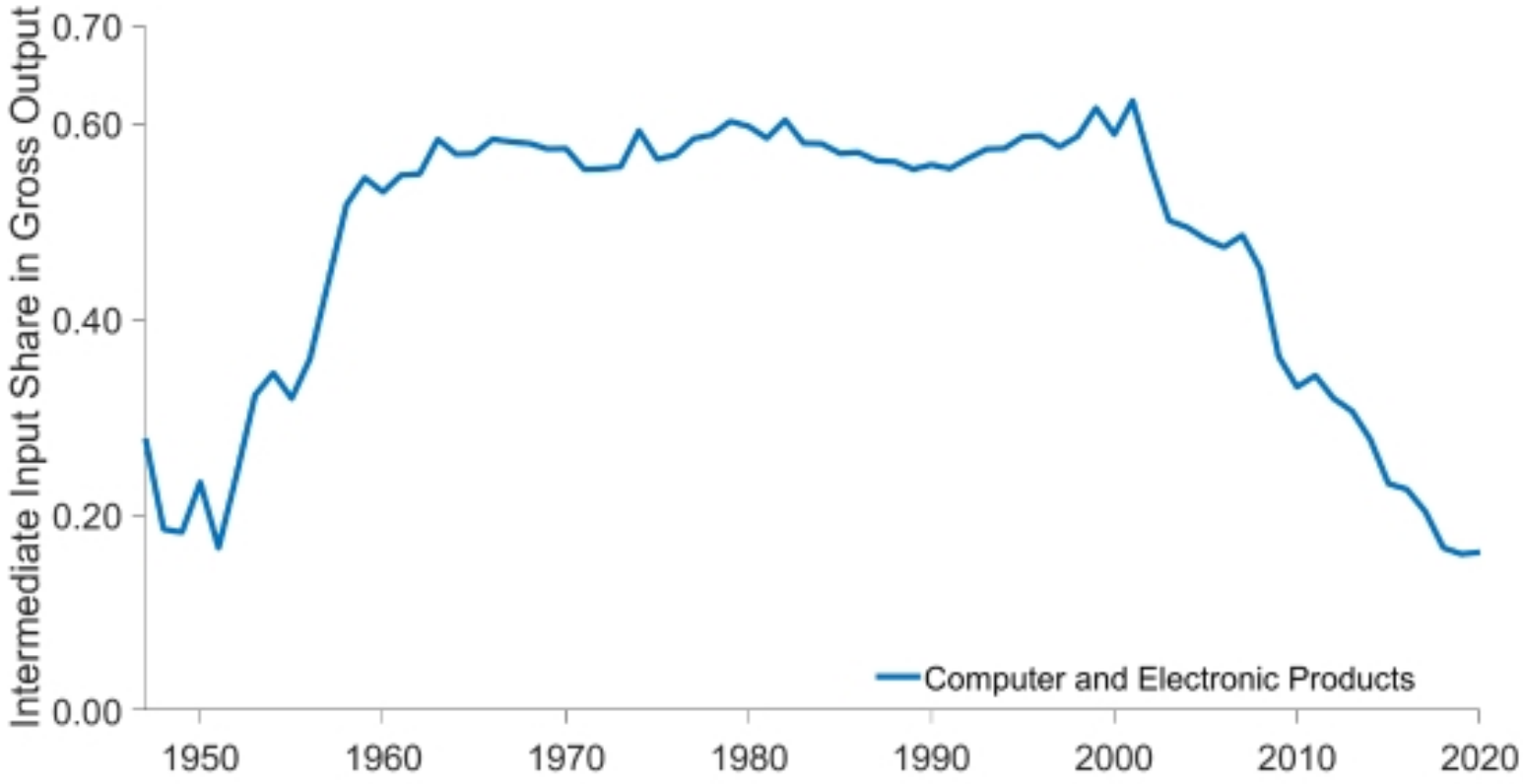
1. Computer Systems Design accounts for a larger share of the production of computers (Software is eating the world!)
2. Services account for a larger share of intermediates used in the computers sector
3. Computers sector has been getting tremendously value-added intensive!

Computers and Peripheral Equipment Production

	1997	2021
Computer and Electronic Products	74%	46%
Computer Systems Design and Related Services	7%	34%

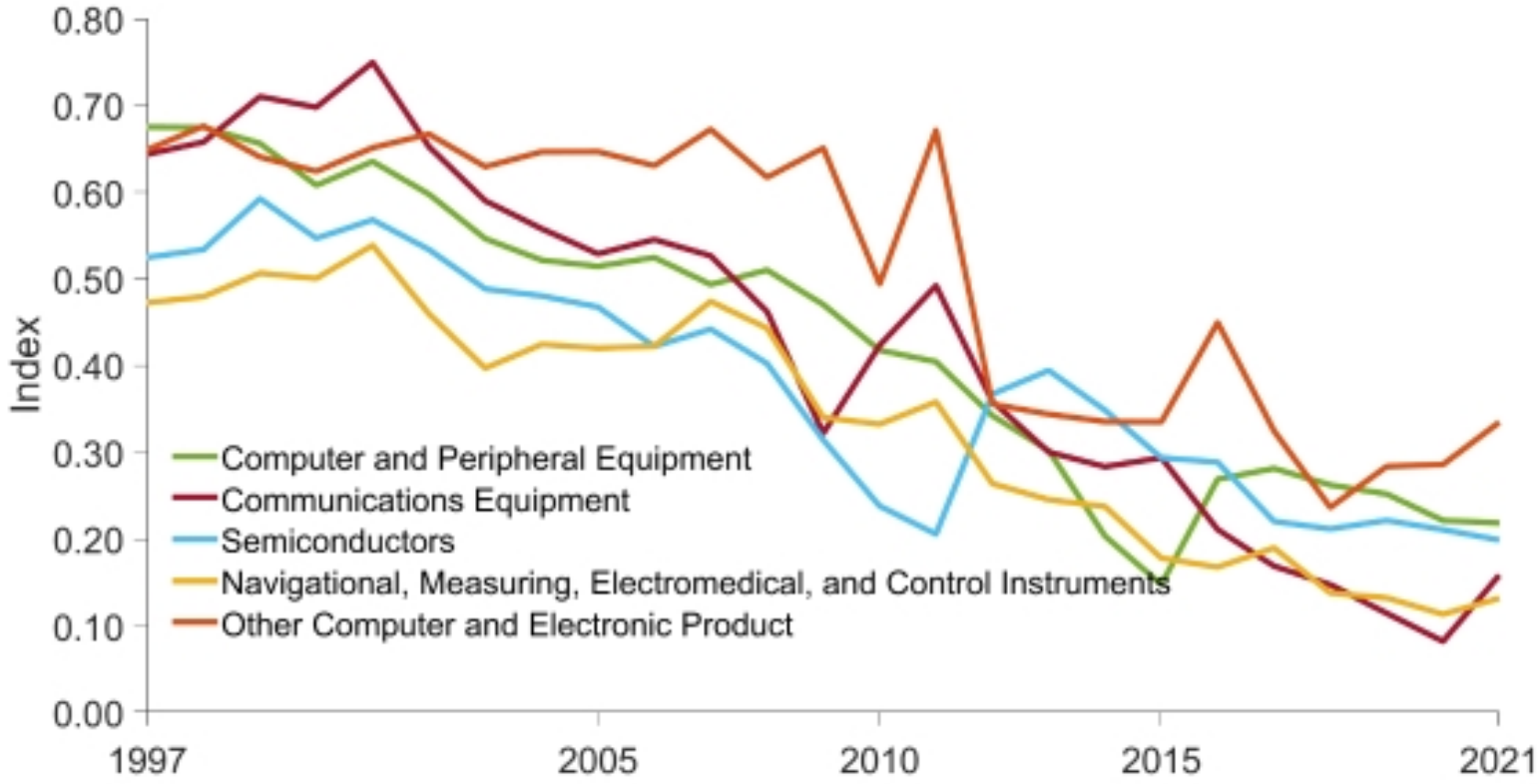
- **Source**: BEA Bridge Tables

Cost Share of Intermediate Inputs in Computers Industry



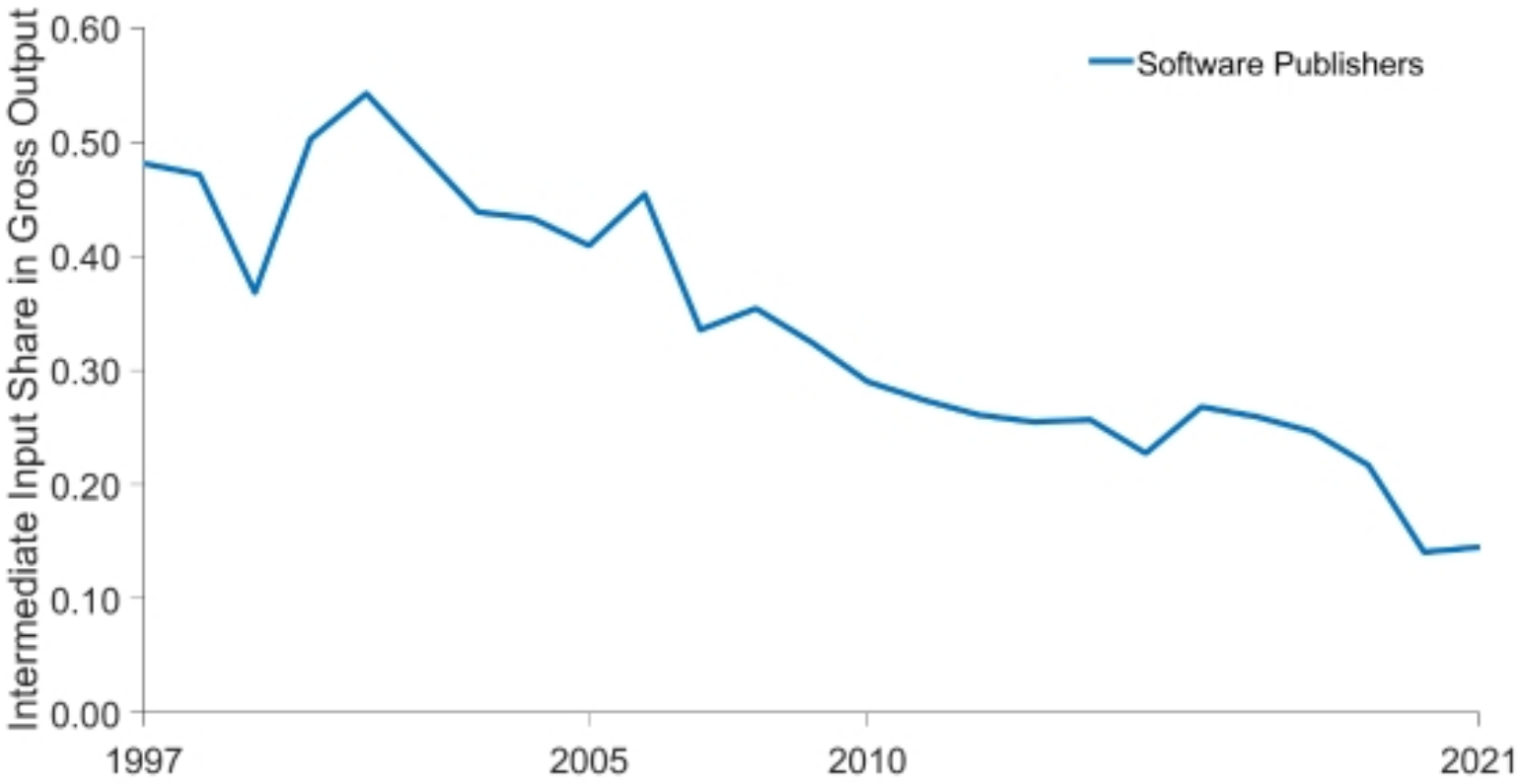
- **Source**: BEA-BLS Integrated Experimental Industry Production Account.

Cost Share of Intermediate Inputs in Sub-Industries



- **Source**: BEA.

Cost Share of Intermediate Inputs in Software



- **Source**: BEA.

Digital Technology Production

- ***Perfect complementarity in all digital-technology producing industries, without exception***
- Without a change in the production function of the computers industry, it is not possible to generate an aggregate slowdown in the productivity growth
- Around 75% of the slowdown in computer-specific technical change can be attributed to this change in production function
- Diminishing returns: Labor and R&D costs weigh in
- Something referred in Baumol et al. (1985)

Unbalanced Growth Revisited: Asymptotic Stagnancy and New Evidence: Baumol, Blackman, and Wolff (1985)

We have also introduced into the model a type of activity we call asymptotically stagnant—economic enterprises which seem among the most high tech and progressive one can imagine. They contain both a technologically sophisticated component and a relatively irreducible labor-intensive component. Starting out as innovative activities dominated by their very productive technological side, as the labor component assumes an ever larger share of total cost (because the progressive component is innovating itself out of its cost-dominating position), ultimately the activity assumes all the characteristics of the stagnant services. Empirical data on two such activities—TV broadcasting and electronic computation—are also consistent with the model's predictions. This suggests that the progressivity of such activities may well prove transitory and somewhat illusory. In sum, the cost disease of the stagnant services may affect more of the economy than was previously thought.

Electronic Computation: Baumol, Blackman, and Wolff (1985)

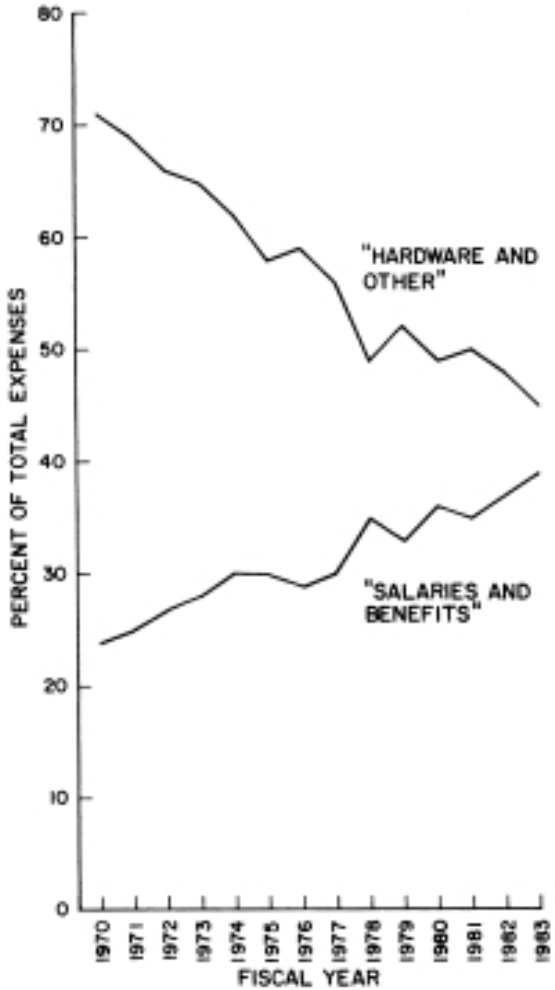


FIGURE 1. LABOR COSTS VS. HARDWARE COSTS AS A PERCENTAGE OF TOTAL COSTS, PRINCETON UNIVERSITY COMPUTER CENTER, 1970–83

Broadcasting: Baumol, Blackman, and Wolff (1985)

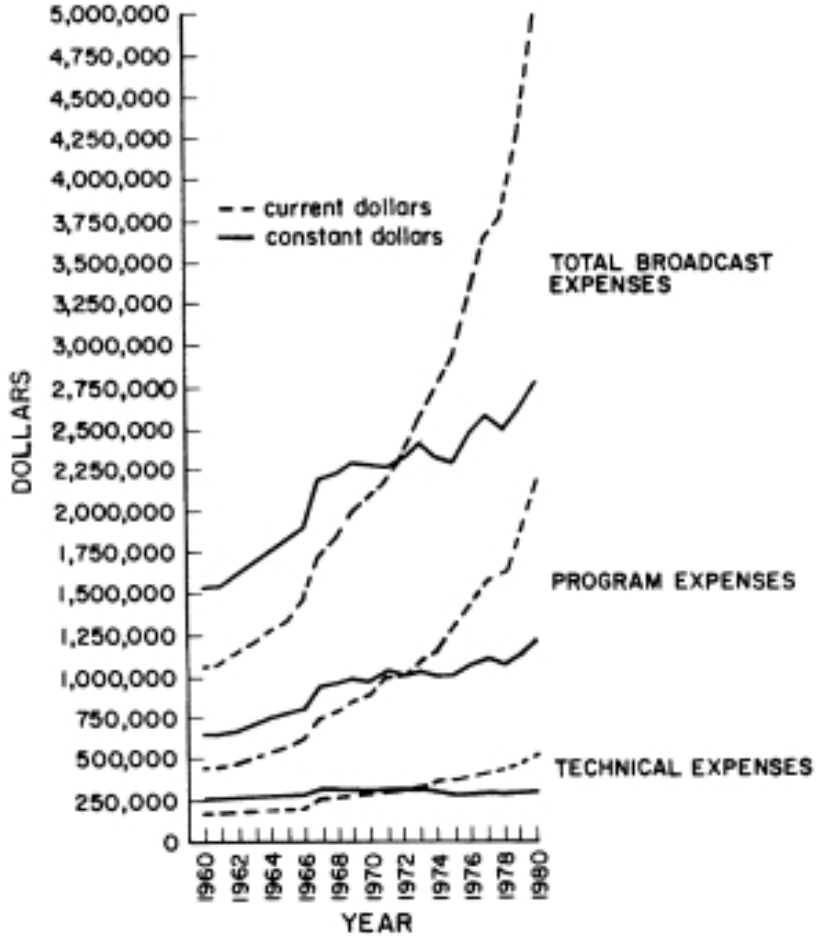


FIGURE 2. BROADCASTING EXPENSES PER AVERAGE TELEVISION STATION[a]

Good News

- Increasing intermediate inputs intensity in services
- Technical change becomes services-biased through capital goods production
- Productivity growth in bottleneck industries improve over time (e.g. finance, business services, administrative and support services)
- Digital technologies diffuse easily in comparison to historical standards
- Exponential growth in digital technologies (up to a certain point)
- Amplification through network effects

Bad News

- High depreciation rate of digital technologies
- Not much persistence, as capital embodied technical change is the engine of growth
- More seriously, perfect complementarity/diminishing returns in digital technology production. Super-fast transition dynamics.
- AI also faces diminishing returns - driven by constraints on data, energy, water, and chips
- Most likely, another period of high productivity growth will not last long

A Ranking of Industries by Digital-Intensity: UK

Industry	**Digital-Intensity**
Telecommunications	0.295
Financial and Insurance Activities	0.133
Computer Programming and Consultancy; Information Service Activities	0.109
Wholesale Trade	0.088
Professional, Scientific and Technical Activities	0.079
Education	0.016
Human Health Activities	0.015
Construction	0.006
Real Estate	0.003

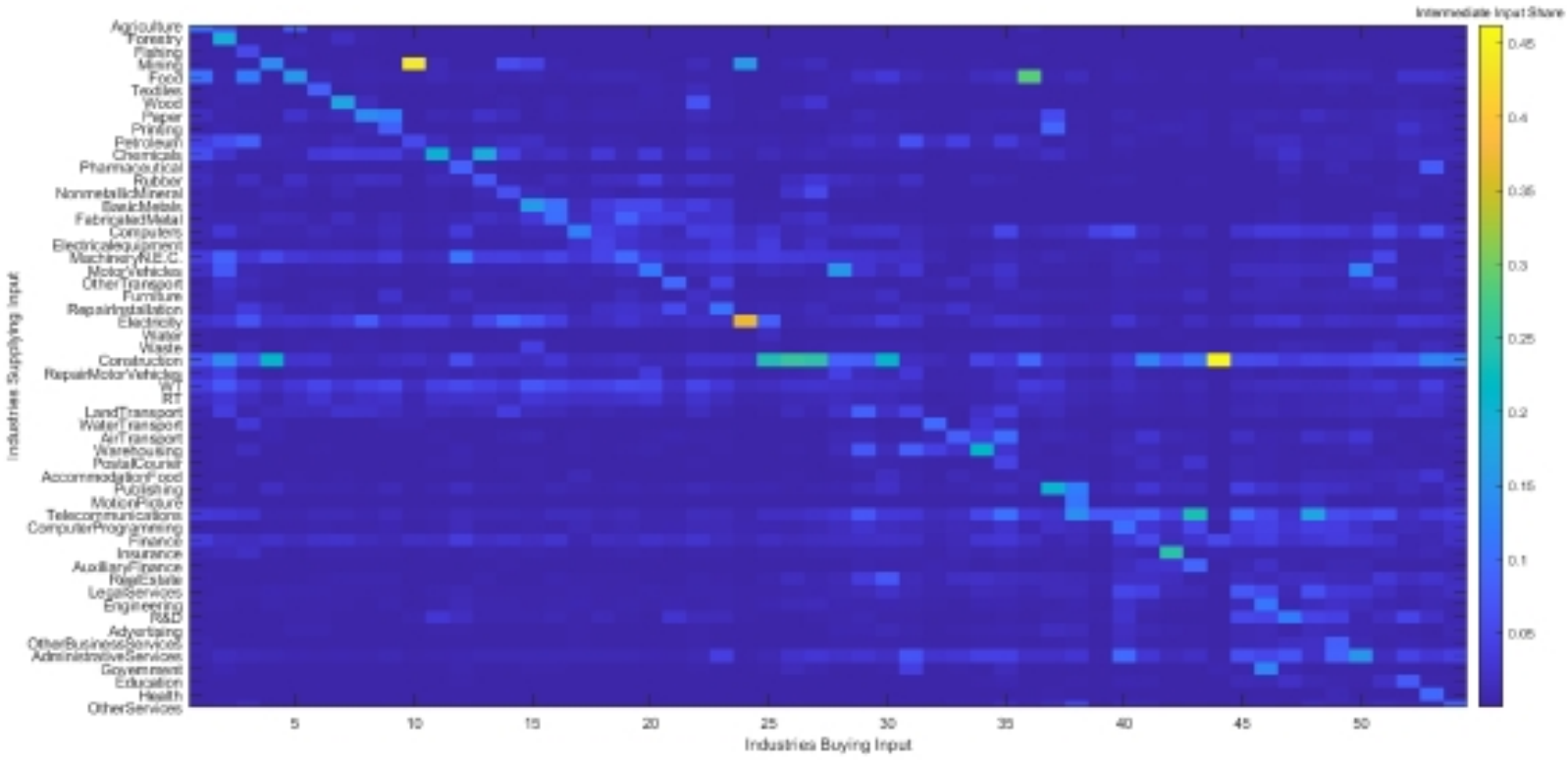
Return

Centrality in the Production Network of the UK - 2019

Industry	Outward Degree
Wholesale Trade	5.44
Administrative and Support Services	3.70
Financial Services	2.80
Legal and Accounting Activities; Management Consultancy	2.13
Retail Trade	1.51
Human Health and Social Work Activities	0.25
Manufacture of Furniture	0.11
Manufacture of Textiles	0.09
Fishing and aquaculture	0.02

Return

Production Network: UK



- **Source**: ONS

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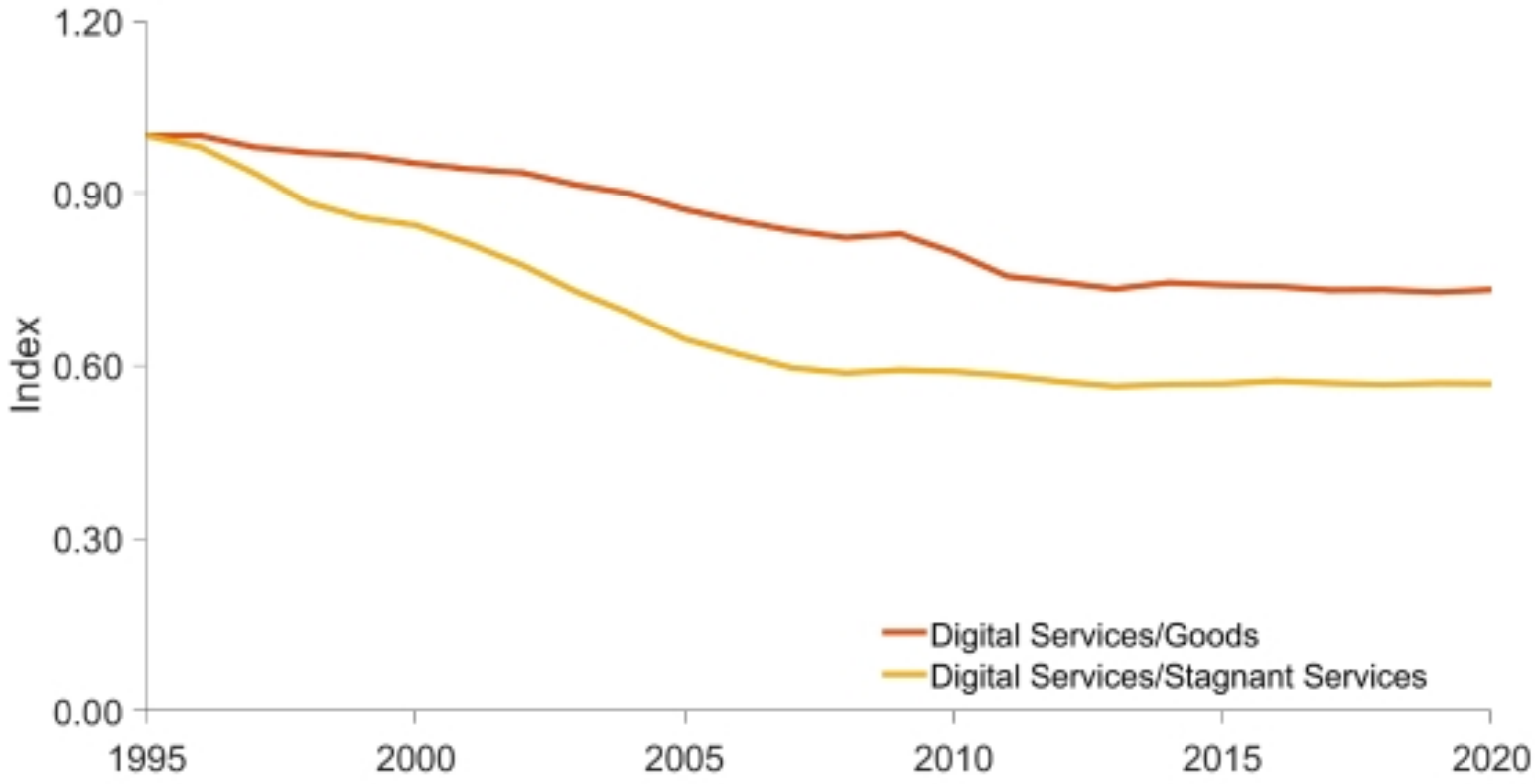
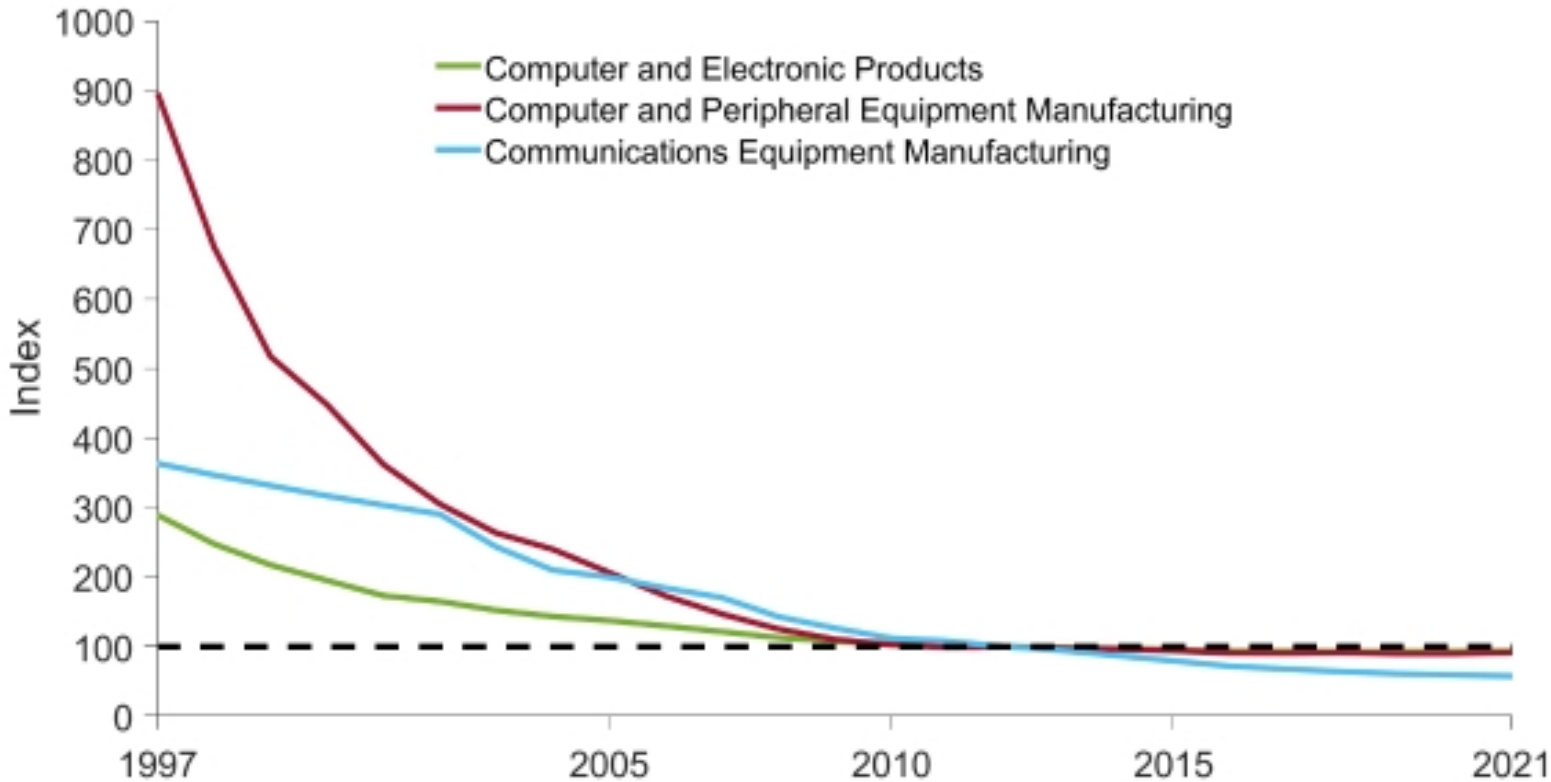
Relative Rental Price of Capital Across Sectors: UK



- **Note**: The variable is normalized to 1 in 1995.

Return

Example: Computer and Electronic Products



- **Note**: The variables are normalized to 100 in 2012.

Return