# The Case of the Missing Productivity Growth

## (or, Why has Productivity accelerated in the United States but not in the United Kingdom?)

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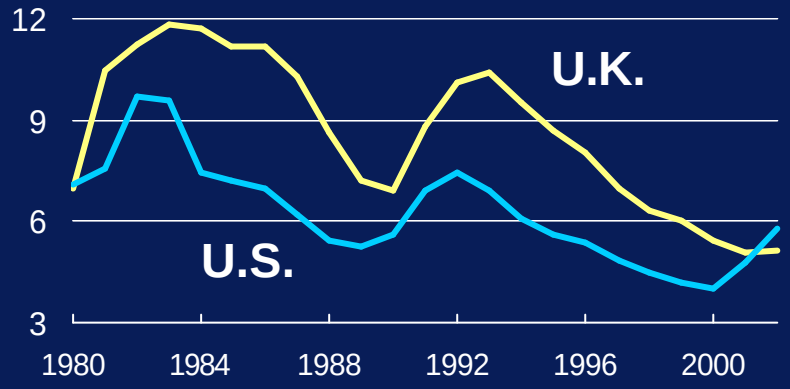
# Strong U.S. and U.K. Macroeconomic Performance in late 1990s

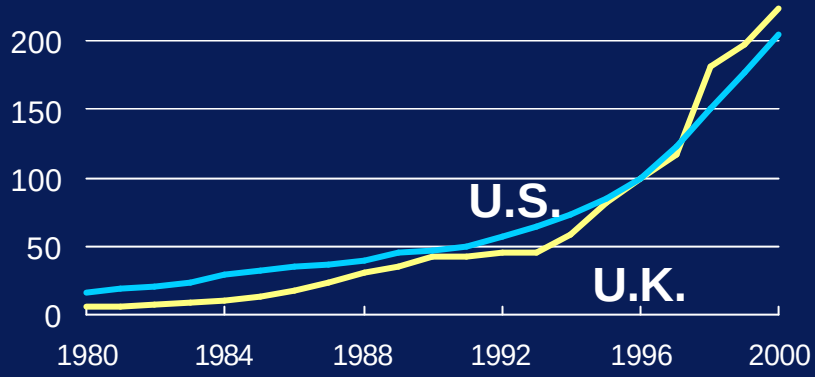
**Unemployment**

(rate)



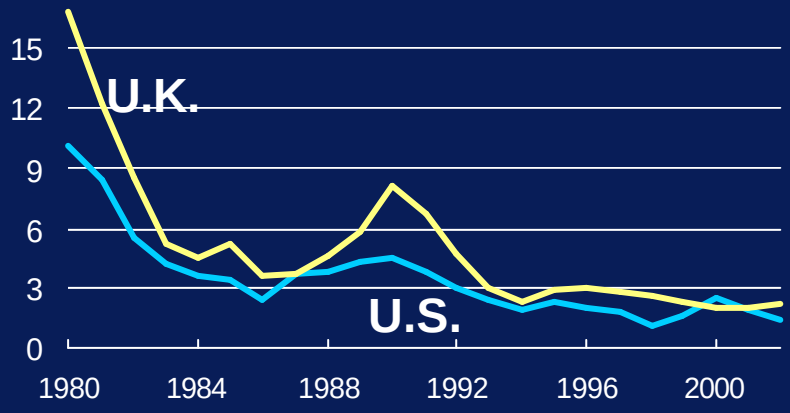

**Aggregate ICT Investment**

(index, 1996 = 100)



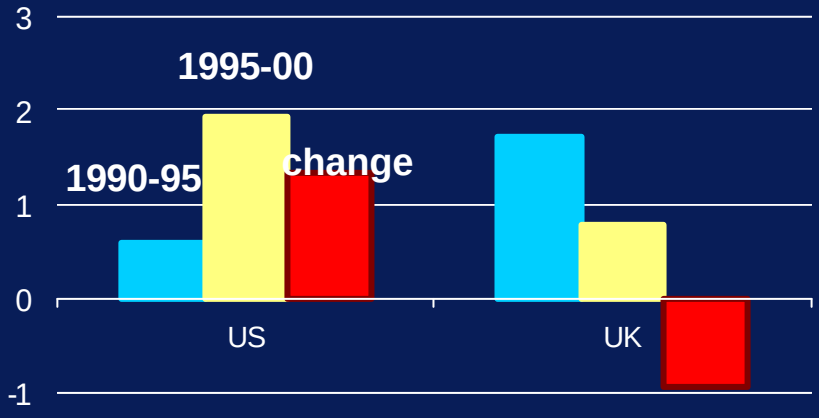

**Inflation**

(percent change)




**Total Factor Productivity**

(percent change, annual rate)



# To understand why no U.K. productivity acceleration, we need to understand, “Why in U.S.?”

- Is U.S. TFP acceleration broader than just the *production* of information and communications technology (ICT)?
- Does U.S. experience support idea that ICT is a ‘General Purpose Technology’?
- Could heavy investment in ‘complementary capital’ explain the low measured TFP growth in the U.K.?

# Digging deeper into the crime scene: Data for industry growth accounting

- United States
  - BEA industry data on gross output and intermediate inputs
  - BLS industry capital services and hours worked
- United Kingdom
  - New industry dataset with similar data coverage to U.S.
  - Follows U.S. NIPA methodologies to extent possible, e.g., for ICT deflators
- For the top-line figures (but not industry figures) we adjust for labor quality/composition

# U.S. and U.K. TFP Acceleration

(%-point change in average annual value-added TFP growth, 1990-95 to 1995-00)

| | United States | United Kingdom |
|---|---|---|
| **Private non-farm** | **1.3** | **-0.9** |
| **ICT producing** | **5.5** | **6.6** |
| **Non-ICT-producing** | **0.9** | **-1.6** |
| | | |
| ***Selected 1-digit industries*** | | |
| **Finance & Insurance** | **3.0** | **2.0** |
| **Wholesale Trade** | **3.7** | **0.3** |
| **Retail Trade** | **4.5** | **-1.9** |

# Usual suspects we can dismiss

- Cyclical utilization?
  - Little or no evidence it boosts U.S. numbers (Basu, Fernald, Shapiro; Baily-Lawrence; CEA)
  - U.K. economy was booming
- Labor and product market regulation?
  - Inflexibilities widely cited for Continental Europe...
  - …but U.S. and U.K. similar, according to OECD/Card-Freeman/Gust-Marquez

# Petty criminals we release with a stern warning

- Labor quality with falling unemployment? We incorporate a labor quality adjustment
- Traditional convex costs of adjusting investment?
  - Go right way, but with plausible estimates, appear to explain only a modest share of the gap
  - Caveat: Maybe ICT investments have larger adjustment costs? Related to GPT story

# Information technology as General Purpose Technology: Einstein's 'spooky action at a distance?'

- Recent theory and firm-level evidence suggest broad but indirect effects
  - Long and variable lags; effects show up in unexpected places
  - Theory suggests measured TFP growth might slow for a time
    - Many papers in Helpman (1998) note this
    - Greenwood-Yorokoglu and '1974''
  - Empirically: Brynjolfsson and Hitt -- lags of 5 or more years

*"We have lots of information technology. We just don't have any information."*

# Growth accounting with unobserved output and input (investment in, and input from, complementary capital)

- Production function for industries using ICT:

$$Q_{it} \equiv Y_{it} + A_{it} = F\left(Z_{it} G(K_{it}^{ICT}, C_{it}), K_{it}^{NT}, L_{it}\right), \quad i = 1...N$$

- Capital stock $C$ accumulates in usual way:

$$C_{it} = A_{it} + (1 - d_C) C_{it-1}$$

- Under usual assumptions:

$$\Delta TFP = \left[\frac{F_C C}{Y^{NT}}\right] \Delta c - \left[\frac{A}{Y^{NT}}\right] \Delta a + s_G \Delta z$$

# Expressing *unobserved* complementary capital in terms of *observed* ICT capital

- We assume CES form for $G(\ )$:

$$G = [a K^{IT\frac{s-1}{s}} + (1-a) C^{\frac{s-1}{s}}]^{\frac{s}{s-1}}$$

- Implies link between $\Delta c$ and $\Delta k^{ICT}$:

$$\Delta c_t = \Delta k_t^{ICT} + s \Delta p_t^{ICT}$$

- Implies ICT-intensive industries are complementary-intensive:

$$\frac{C}{Y^{NT}} = \left[ \left( \frac{1-a}{a} \right)^s \left( \frac{P_K}{P} \right)^{1-s} \right] s_{K^{ICT}} = b\, s_{K^{ICT}}$$

# Implications for TFP dynamics

- Expressing $\Delta a$ in terms of $\Delta c$; and $\Delta c$ in terms of ICT growth:

$$\rightarrow \Delta TFP = \left[F_C - 1\right] b \tilde{k}_t + \left[\frac{(1-d_C)}{(1+g)}\right] b \tilde{k}_{t-1} + s_G \Delta z,$$

$$\text{where } \tilde{k}_t = s_{K^{ICT}} \left[\Delta k_t^{ICT} + s \Delta p_t^{ICT}\right]$$

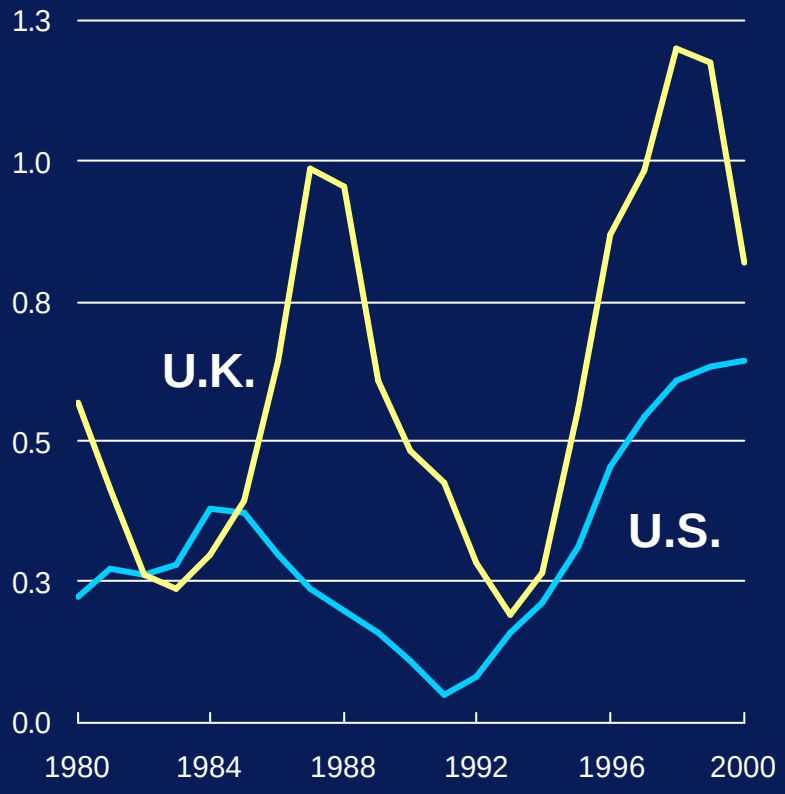
- Alternatively, suppose $\Delta a = g\, s_{I^{ICT}} \Delta i^{ICT} \equiv g\, \tilde{i}$:

$$\rightarrow \Delta TFP = F_C b \tilde{k}_t - gb \tilde{i}_t + s_G \Delta z,$$

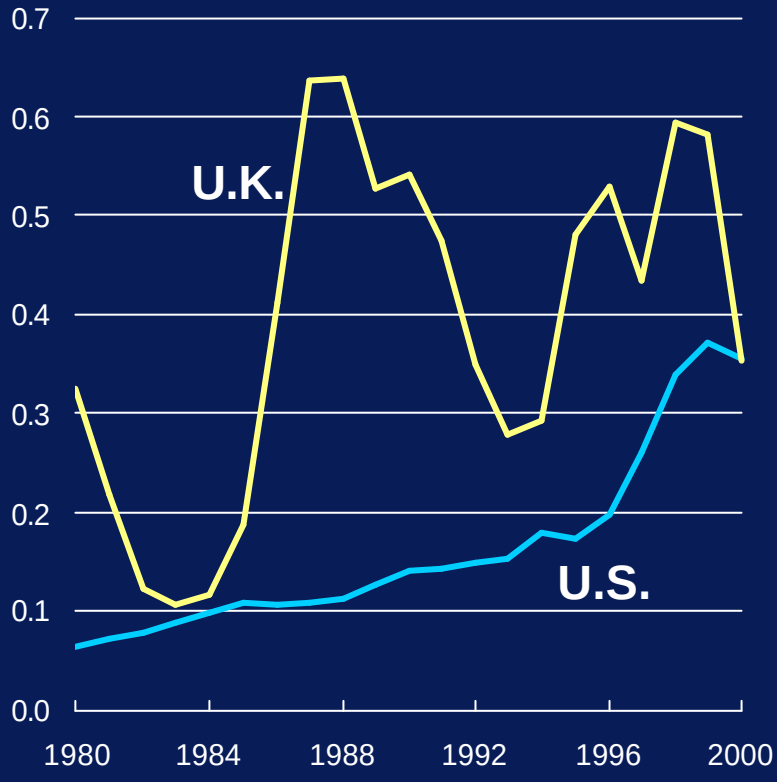
- Theory tells us little about lags, which could be long

# U.K. Share-weighted ICT capital growth $\tilde{k}$ is volatile: Maybe complementary investment is also volatile?

**Computers**




**Software**



# Past industry ICT growth is correlated with late 1990s industry TFP growth in U.S., but not in U.K. (Taking $\tilde{k}_t = s_{K^{IT}} \Delta \ln k$ )

| | United States | United Kingdom |
|---|---|---|
| C | -0.001 | -0.09 |
| | (0.003) | (0.48) |
| $\tilde{k}_{1980–1990}$ | 4.1 | 1.39 |
| | (7.2) | (3.56) |
| $\tilde{k}_{1990–1995}$ | 17.4 | 0.65 |
| | (5.7) | (2.80) |
| $\tilde{k}_{1995–2000}$ | -8.9 | 0.65 |
| | (4.8) | (1.48) |
| Poorly*C | 0.011 | -0.18 |
| | (0.0058) | (0.48) |
| Poorly* $\tilde{k}_{1980–1990}$ | 15.3 | 2.77 |
| | (7.7) | (3.56) |
| Poorly* $\tilde{k}_{1990–1995}$ | -8.1 | -1.60 |
| | (6.6) | (2.80) |
| Poorly* $\tilde{k}_{1995–2000}$ | -10.1 | -2.60 |
| | (5.8) | (1.48) |
| $R^2$ | 0.38 | 0.10 |
| Observations | 49 | 28 |

*Note:* Dependent variable is average TFP growth 1995-2000. Standard errors in parentheses. "Poorly" means "relatively poorly measured", i.e., everything other than mining, manufacturing, transportation, utilities, trade)

# Weak evidence: ICT investment is negatively correlated with TFP acceleration in U.K. but not in U.S

$$(\Delta TFP_{i,1995-2000} - \Delta TFP_{i,1990-1995}) = a\left(\tilde{k}_{i,1995-2000} - \tilde{k}_{i,1990-1995}\right) - b\left(\tilde{i}_{i,1995-2000} - \tilde{i}_{i,1990-1995}\right) + e_i,$$

| | United States | United Kingdom |
|---|---|---|
| $\left(\tilde{k}_{i,1995-2000} - \tilde{k}_{i,1990-1995}\right)$ | **0.21** | **4.41** |
| | **(2.27)** | **(1.02)** |
| $\left(\tilde{i}_{i,1995-2000} - \tilde{i}_{i,1990-1995}\right)$ | **-0.04** | **-1.63** |
| | **(0.75)** | **(0.41)** |
| **$R^2$** | **0.01** | **0.41** |
| **Observations** | **49** | **28** |

# Conclusions: Why no productivity growth in the U.K.?

- First issue we've addressed: *Why* in U.S.?
  - ICT seems like major obvious source of innovation, but most of TFP acceleration is *outside* ICT-producing industries
  - Industry TFP growth associated with ICT capital growth with long lags--consistent with unmeasured complementary investment
- Our story for U.K.: Began accumulating complementary capital intensively in the late 1990s
  - Maybe UK really does have strong underlying productivity
  - Timing fits; other "suspects" seem to have alibis
- Puzzles remain: Why did U.K. start later? Why are negative coefficients on ICT investment so small?
  - Possibly a skills shortage?

Miscellaneous extra stuff follows

# Growth accounting with unobserved output and input (investment in, and input from, complementary capital)

- Production function for industries using ICT:

$$Q_{it} \equiv Y_{it} + A_{it} = F\left(Z_t\, G(K_{it}^{IT}, C_{it}), K_{it}^{NT}, L_{it}\right), \quad i = 1...N$$

- Capital stock C accumulates in usual way:

$$C_{it} = A_{it} + (1 - d_C) C_{it-1}$$

- Differentiating production function; assuming CRS and perfect competition; and rearranging:

$$\Delta TFP = \left[\frac{F_C C}{Y^{NT}}\right]\Delta c - \left[\frac{A}{Y^{NT}}\right]\Delta a + s_G \Delta z$$

# Expressing *unobserved* complementary capital in terms of *observed* ICT capital

- We assume CES form for $G(\ )$:

$$G = [a\,K^{IT\,\frac{s-1}{s}} + (1-a)C^{\frac{s-1}{s}}]^{\frac{s}{s-1}}$$

- Implies link between $\Delta c$ and $\Delta k^{IT}$:

$$\Delta c_t = \Delta k_t^{IT} + s\,\Delta p_t^{IT}$$

- Implies ICT-intensive industries are complementary intensive:

$$\frac{C}{Y^{NT}} = \left[\left(\frac{1-a}{a}\right)^{s}\left(\frac{P_K}{P}\right)^{1-s}\right] s_{K^{IT}} = b\,s_{K^{IT}}$$

# Implications for TFP dynamics

- Expressing $\Delta a$ in terms of $\Delta c$, and substituting ICT for $\Delta c$ :

$$\rightarrow \Delta TFP = \left[F_C - 1\right] b \tilde{k}_t + \left[\frac{\left(1-d_C\right)}{\left(1+g\right)}\right] b \tilde{k}_{t-1} + s_G \Delta z,$$

$$\text{where } \tilde{k}_t = s_{K^{IT}} \left[\Delta k_t^{IT} + s \Delta p_t^{IT}\right]$$

- Alternatively, suppose $\Delta a = g\, s_{I^{ICT}} \Delta i^{ICT} \equiv g\, \tilde{i}$:

$$\rightarrow \Delta TFP = F_C b \tilde{k}_t - gb \tilde{i}_t + s_G \Delta z,$$

- Theory tells us little about lags, which could be long

# Past industry ICT growth is correlated with late 1990s industry TFP growth in U.S., but not in U.K. (Taking $\tilde{k}_t = s_{K^{IT}} \Delta k_t^{IT}$)

| | United States | United Kingdom |
|---|---|---|
| C | -0.001 | -0.26 |
| | (0.003) | (0.33) |
| $\tilde{k}_{1980-1990}$ | 16.5 | -3.0 |
| | (5.0) | (4.1) |
| $\tilde{k}_{1990-1995}$ | -3.4 | -1.0 |
| | (5.7) | (2.5) |
| $\tilde{k}_{1995-2000}$ | -2.4 | 1.6 |
| | (3.8) | (1.7) |
| Poorly*C | 0.012 | 0.03 |
| | (0.005) | (0.33) |
| Poorly* $\tilde{k}_{1980-1990}$ | 2.7 | -7.4 |
| | (6.9) | (4.1) |
| Poorly* $\tilde{k}_{1990-1995}$ | 13.3 | -1.2 |
| | (7.0) | (2.5) |
| Poorly* $\tilde{k}_{1995-2000}$ | -16.8 | 6.6 |
| | (6.0) | (1.7) |
| $R^2$ | 0.54 | 0.20 |
| Observations | 49 | 27 |

Note: Dependent variable is average TFP growth 1995-2000. Standard errors in parentheses.

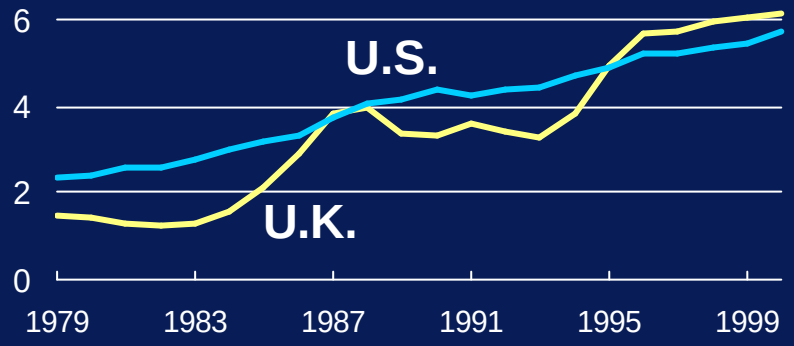
# Using robust standard errors for U.S.

| | $TFP_{1995\text{-}2000}$ (All non-ICT industries) |
|---|---|
| C | 0.003 |
| | (0.004) |
| $\tilde{k}_{1980-1990}$ | -5.2 |
| | (8.1) |
| $\tilde{k}_{1990-1995}$ | 19.0 |
| | (5.3) |
| $\tilde{k}_{1995-2000}$ | -9.7 |
| | (4.6) |
| Poorly*C | 0.007 |
| | (0.005) |
| Poorly* $\tilde{k}_{1980-1990}$ | 24.6 |
| | (8.5) |
| Poorly* $\tilde{k}_{1990-1995}$ | -9.8 |
| | (6.2) |
| Poorly* $\tilde{k}_{1995-2000}$ | -9.4 |
| | (5.7) |
| $R^2$ | 0.44 |
| Observations | 47 |

# Shares in Value-Added Output

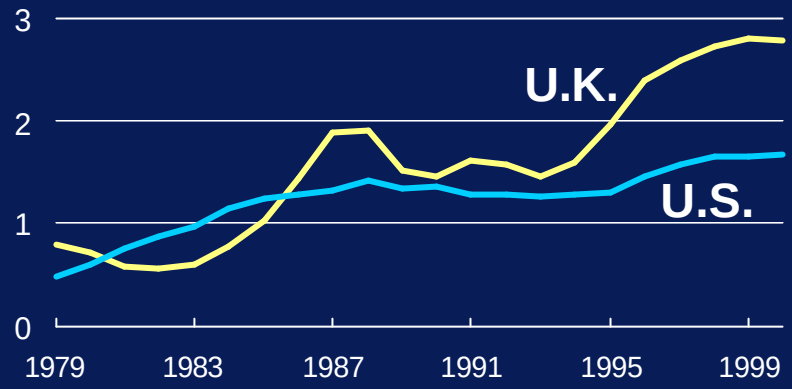
**Total Share in Value-Added**

(percent)



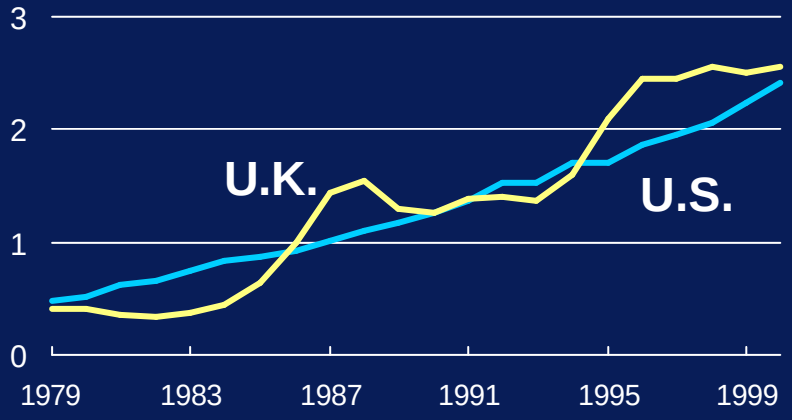

**Computer Share in Value-Added**

(percent)



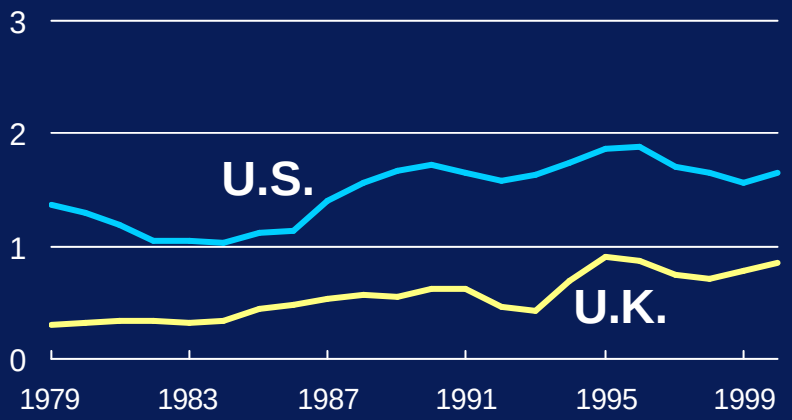

**Software Share in Value-Added**

(percent)




**Telecom Share in Value Added**

(percent)



# Ratio of UK ICT Stocks Per Capita, 1992-2000

## Total Share in Value-Added

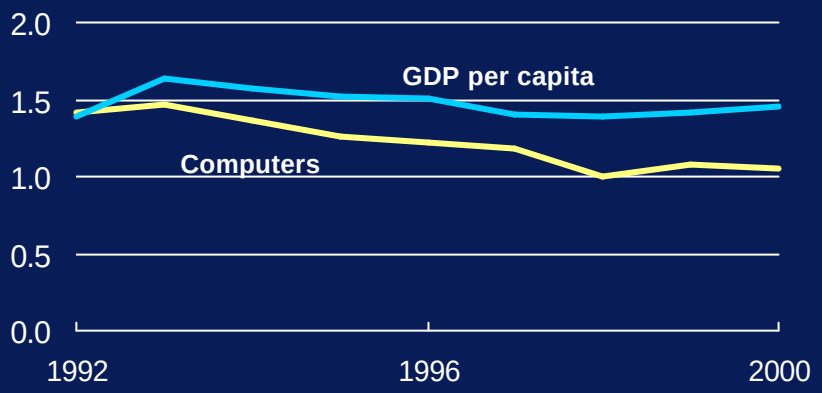
(ratio UK:US)

U.S.

U.K.

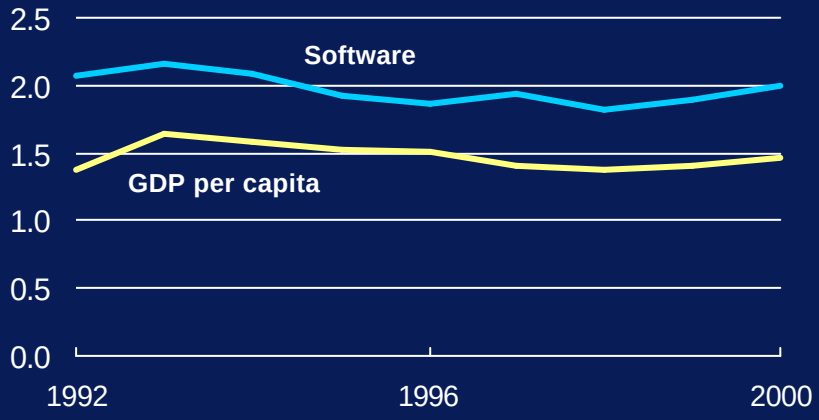
## Computers

(ratio UK:US)



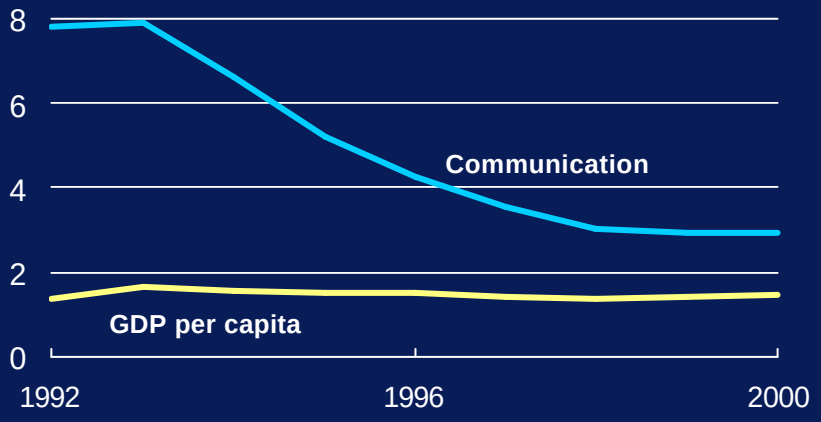

## Software

(ratio UK:US)



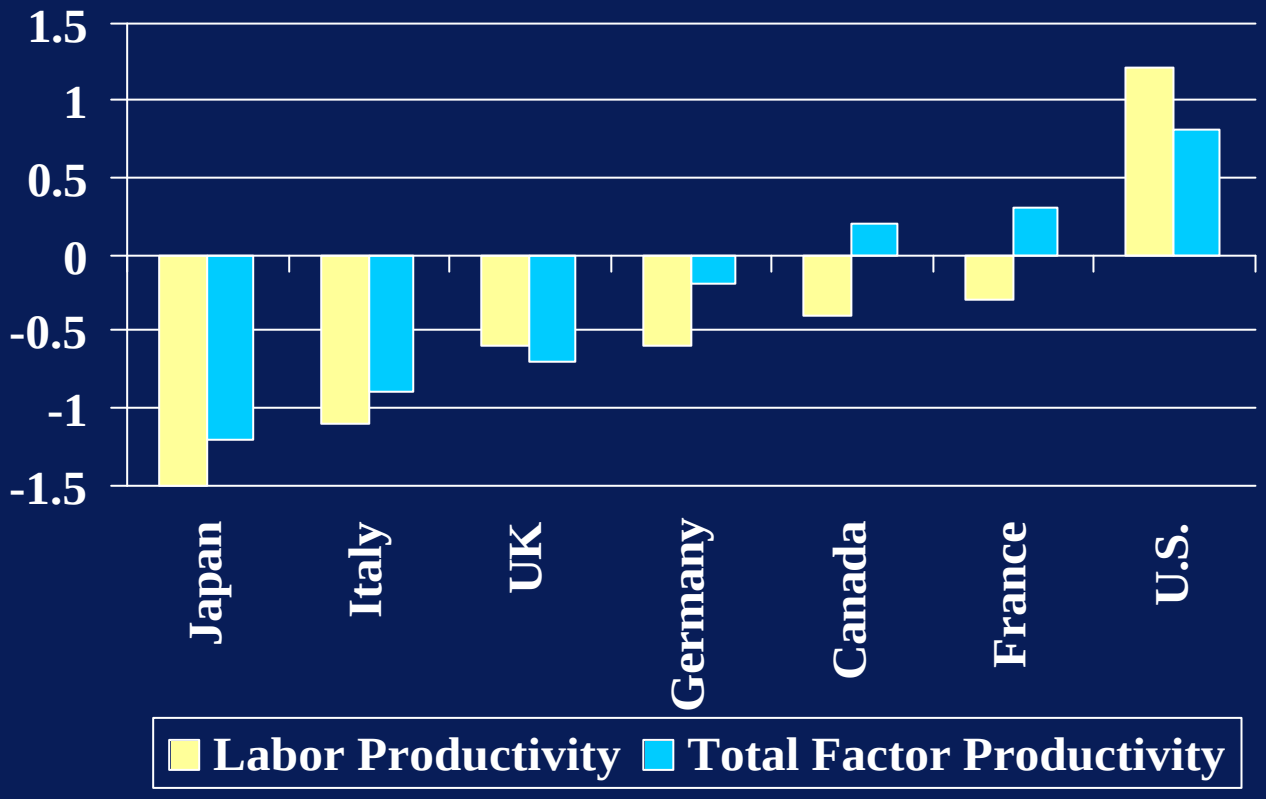

## Communication

(ratio UK:US)



# Productivity accelerated in U.S. in late 1990s, but slowed in most other G-7 countries

Percentage point change in annual labor and total factor productivity growth from 1980-95 to 1995-2000.

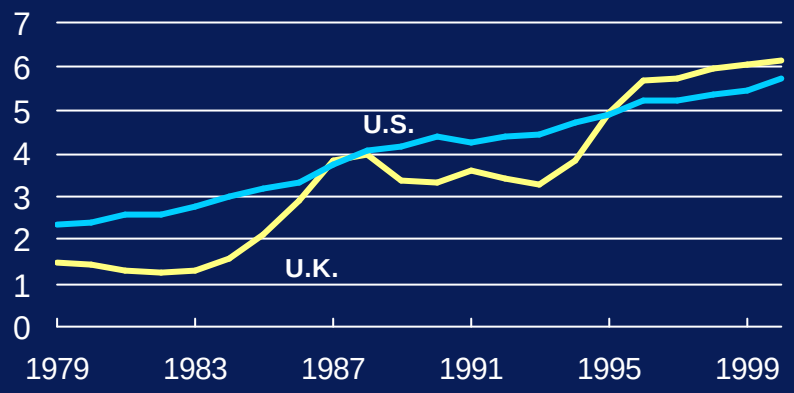



(Note: This chart originally appeared in the 2001 Economic Report of the President. Data from Gust and Marquez

# Production cost shares of ICT capital: U.S. and U.K.

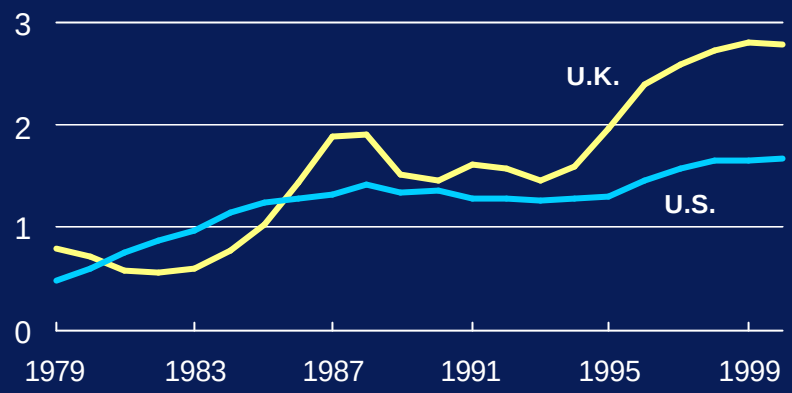
**Total Share in Value-Added**

(percent)



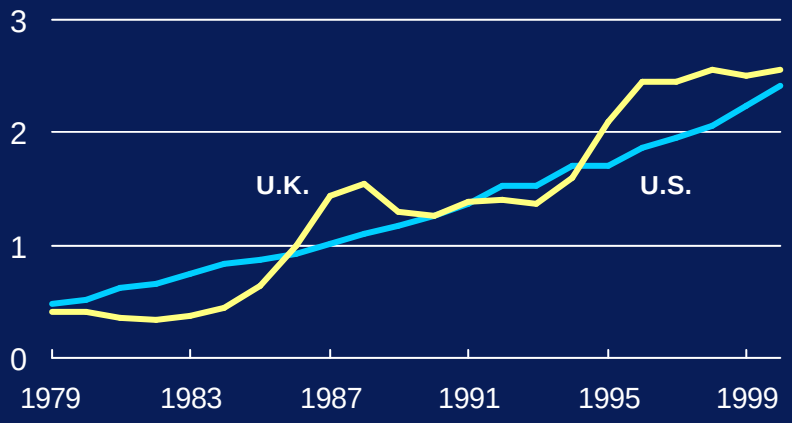

**Computers**

(percent)



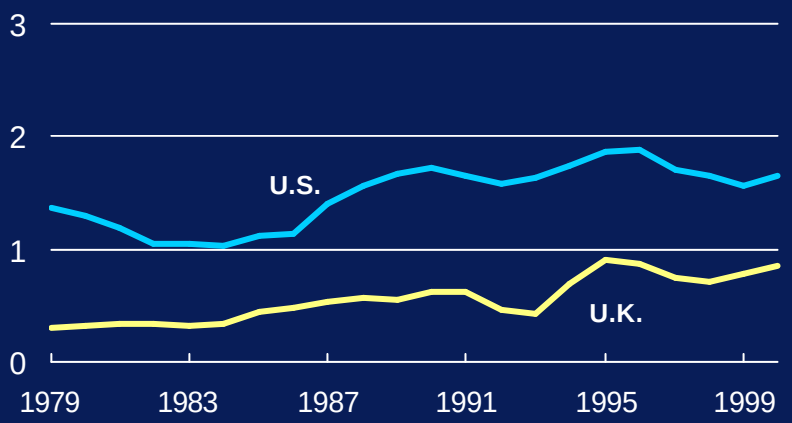

**Software**

(percent)

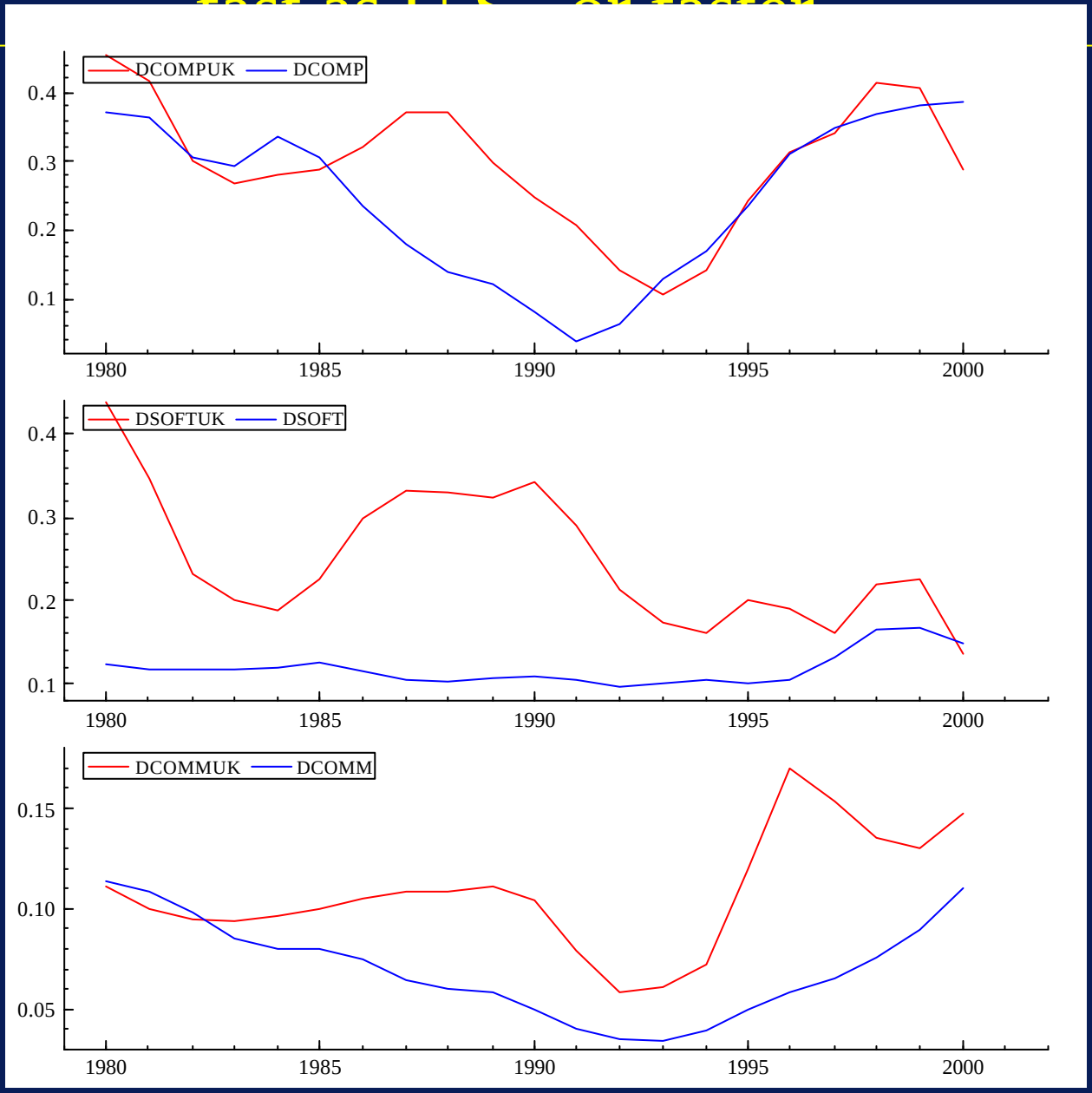



**Communications**

(percent)



# Data: U.K. ICT capital has been growing as fast as U.S., or faster



# Empirical specification suggested by theory

- [Cut this slide, after reformatting tables to include estimating equation!!]

$$\Delta p_i^{95-00} = c_i + a\tilde{k}_i^{95-00} + b\tilde{k}_i^{90-95} + b\tilde{k}_i^{80-90} + e_i$$

$$\tilde{k} = \mathbf{s}_{\mathrm{K}_{\mathrm{COMPUTERS+SOFTWARE}}} \Delta \ln k_{COMP+SOFTWARE}$$

# Share-weighted computer/software capital growth and late 1990s industry TFP growth: Taking $\tilde{k}_t = s_{K^{IT}} \Delta k_t^{IT}$

| | United States | United Kingdom |
|---|---|---|
| C | -0.001 | -0.26 |
| | (0.003) | (0.33) |
| $\tilde{k}_{1980-1990}$ | 16.5 | -3.0 |
| | (5.0) | (4.1) |
| $\tilde{k}_{1990-1995}$ | -3.4 | -1.0 |
| | (5.7) | (2.5) |
| $\tilde{k}_{1995-2000}$ | -2.4 | 1.6 |
| | (3.8) | (1.7) |
| Poorly*C | 0.012 | 0.03 |
| | (0.005) | (0.33) |
| Poorly* $\tilde{k}_{1980-1990}$ | 2.7 | -7.4 |
| | (6.9) | (4.1) |
| Poorly* $\tilde{k}_{1990-1995}$ | 13.3 | -1.2 |
| | (7.0) | (2.5) |
| Poorly* $\tilde{k}_{1995-2000}$ | -16.8 | 6.6 |
| | (6.0) | (1.7) |
| $R^2$ | 0.54 | 0.20 |
| Observations | 49 | 27 |

Note: Regressions are weighted least squares, using industry shares in total output. Standard errors in parentheses.

# U.S. regressions suggest past ICT growth is correlated with late 1990s TFP acceleration

| | $TFP_{1995\text{-}2000}$ (All non-ICT industries) | $TFP_{1995\text{-}2000}$ (Excluding Wholesale/Retail) | $TFP_{1995\text{-}2000}$ (Excluding All 'Influential') |
|---|---|---|---|
| C | -0.001 | -0.0006 | -0.002 |
| | (0.003) | (0.004) | (0.003) |
| $\tilde{k}_{1980-1990}$ | 16.5 | 4.5 | 9.3 |
| | (5.0) | (5.1) | (4.5) |
| $\tilde{k}_{1990-1995}$ | -3.4 | 9.5 | 10.0 |
| | (5.7) | (5.7) | (5.2) |
| $\tilde{k}_{1995-2000}$ | -2.4 | -6.5 | -7.9 |
| | (3.8) | (3.5) | (3.4) |
| Poorly*C | 0.012 | 0.012 | -- |
| | (0.05) | (0.05) | |
| Poorly* $\tilde{k}_{1980-1990}$ | 2.7 | 14.6 | -- |
| | (6.9) | (6.5) | |
| Poorly* $\tilde{k}_{1990-1995}$ | 13.3 | 0.5 | -- |
| | (7.0) | (6.6) | |
| Poorly* $\tilde{k}_{1995-2000}$ | -16.8 | -12.6 | -- |
| | (6.0) | (5.2) | |
| $R^2$ | 0.54 | 0.45 | 0.16 |
| Observations | 49 | 47 | 41 |

Standard errors in parenthesis. TFP variables are average growth rates over the 1995-2000 period. Acceleration regressions are difference between average TFP 1995-2000 and average TFP 1990-1995. Regressors are averages over the shown sample period. All industry list and well-measured industries exclude ICT-producing industries.