ICT and Future Productivity
Evidence and Theory of a GPT

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Motivation

- Point of departure: medium-run business cycle models à la Comin & Gertler (2006).
- Key prediction: BC fluctuations of a particular kind of investment (research & development (R&D) $\rightarrow$ adoption) lead total factor productivity (TFP).
- Fernald et al. (2017): the Great Recession 2008 casts doubt on whether this is all of the story.

Argument

This paper

1. Stick aggregate ICT investment (ICT-I) in a VAR and explore how an identified shock to this affects TFP.

   ICT shock = a shock to the productivity of the ICT sector today

   → A shock to ICT leads to substantial TFP increases over the medium-run.

2. Draw on the conclusions of the ICT literature to build a structural model to interpret the results.

   → ICT literature: ICT is a general-purpose technology (GPT).

   ⇒ Estimate a two-sector endogenous growth model to ask whether aggregate data supports this interpretation.

Related literature

1. Medium-run business cycles
   - Comin & Gertler (2006), Bianchi et al. (2014), Moran & Queralto (2017), Guerron & Jinnai (2015)
2. ICT and productivity
   - Jorgenson & Stiroh (1999), Oliner & Stichel (2000), Brynjolffson & Lorin (2000), Stiroh (2002)
3. Identification of news shocks in SVARs
   - Beaudry & Portier (2006), Barsky & Sims (2011)
4. Multi-sector growth models
   - Greenwood, Hercowitz & Krusell (1997), Oulton (2007), Fisher (2006), Whelan (2003)

Roadmap

1. SVAR analysis

We run a SVAR using aggregate, quarterly US data. The data vector is:

$$\mathbf{X_t} = \begin{bmatrix} TFP_t \\ ICTI_t \\ GDP_t \\ C_t \\ RP_t \end{bmatrix} \tag{1}$$

- $RP = \pi^{IT} / \pi^{CPI}$.
- All variables are real (except price indexes) and in log levels (except for RP, which is in growth rates).
- The dataset ranges from 1989:q1 - 2017:q2.

Baseline identification: Cholesky

The ICT shock is assumed to have

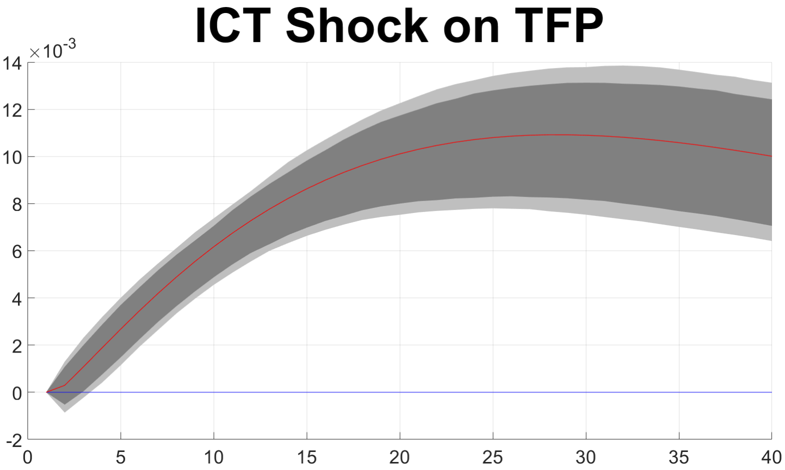
- no impact effect on TFP;
- maximal impact effect on ICT-I.

Why this identification?

- ICT value added is less than 5% of GDP (BEA, April 2018).
  $\rightarrow$ ICT-I increases shouldn't affect TFP on impact.

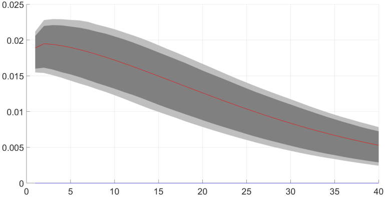
- Prediction of multisector models (GHK): sectoral productivity increase leads to sectoral output becoming cheaper.
  $\rightarrow$ ICT-I should rise after ICT productivity shock.

Results

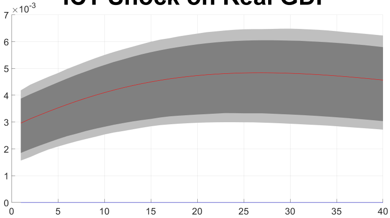


Results II

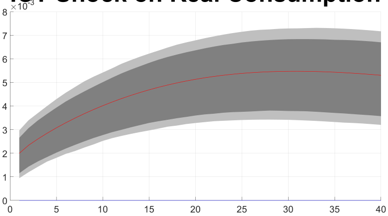
ICT Shock on Real ICT Investment



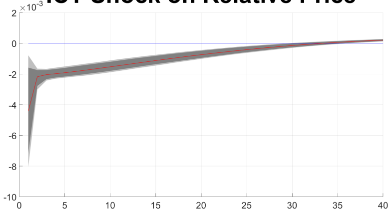
ICT Shock on Real GDP



ICT Shock on Real Consumption



ICT Shock on Relative Price



Results for a larger-scale VAR

Results III

	$h = 1$	$h = 4$	$h = 8$	$h = 16$	$h = 24$	$h = 40$
TFP	0	0.0023	0.0194	0.1088	0.2273	0.3382
ICT-I	0.9997	0.9038	0.7964	0.6320	0.5310	0.4371
Real GDP	0.2620	0.3061	0.3486	0.3936	0.4046	0.3881
Real C	0.1952	0.2638	0.3219	0.3931	0.4188	0.4064
Relative Prices	0.0618	0.0967	0.1276	0.1511	0.1516	0.1467

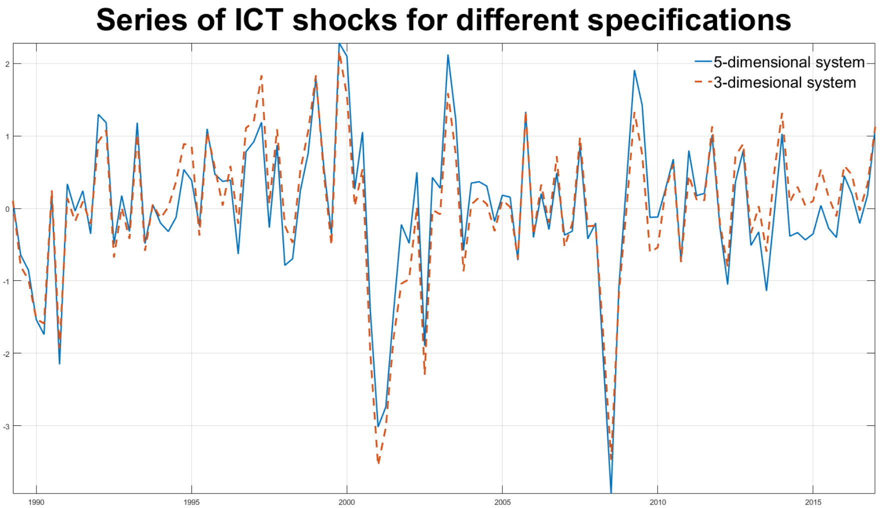
Robustness checks

- Main critique: reverse causality from news about future TFP.

→ Alternative specification filters out news to recover an alternative ICT shock series.

Alternative specification

The two recovered ICT shock series



Interpretation of results

- ICT-shock leads to significant and persistent TFP increases in the medium run.

- ICT literature: it's a general purpose technology (GPT)!

$\rightarrow$ embed in a structural model and estimate whether data favors the GPT-interpretation.

Roadmap

2. Model - in a nutshell

- Belongs to the class of Greenwood, Hercowitz & Krusell (GHK) models.
  (We use isomorphic formulation of Oulton (2007).)

- Key: two sectors with identical production functions

$\rightarrow$ with an externality capturing the GPT-nature of ICT-capital.

- Rest of model perfectly standard.

Two sectors

Consumption-good sector

$$y_t^c(j) = A_t^c \left(k_t^c(j)\right)^a \left(k_t^i(j)\right)^b \left(l_t(j)\right)^{1-a-b}, \quad 0 < a, b < 1 \tag{2}$$

ICT-good sector

$$y_t^i(q) = A_t^i \left(k_t^c(q)\right)^a \left(k_t^i(q)\right)^b \left(l_t(q)\right)^{1-a-b}, \quad 0 < a, b < 1 \tag{3}$$

with

$$A_t^c = \eta_t \; \theta_t^c \; (k_t^i)^\gamma$$

$$A_t^i = \eta_t \; \theta_t^i \; (k_t^i)^\gamma$$

Uses of outputs

Consumption-good sector

$$y_t^c = c_t + i_t^c$$

ICT-good sector

$$y_t^i = i_t^i$$

TFP in the model

Impulse-response matching - does data support $\gamma > 0$?

Estimate three parameters: $\Omega = (\gamma,\ \sigma_\iota^2,\ \rho_\iota)$ with

- σ_ι^2 = the variance of an ICT technology shock
- ρ_ι = the persistence of the same shock
- γ = the size of the spillover effect of ICT capital on TFP

and calibrate the rest. Calibration

We estimate Ω as

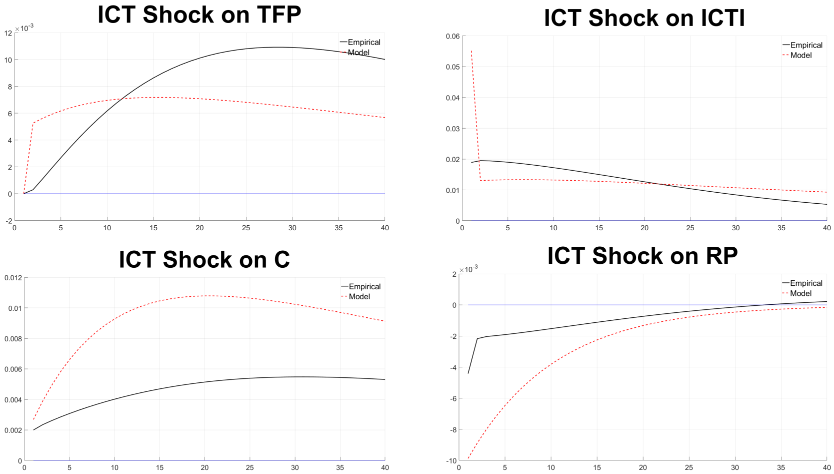
$$\min_{\Omega} \left[\hat{\Psi} - \Psi(\Omega)\right]' \Lambda \left[\hat{\Psi} - \Psi(\Omega)\right] \tag{4}$$

- $\Psi(\Omega)$ = mapping from Ω to the theoretical impulse responses
- $\hat{\Psi}$ = the empirical impulse responses of an ICT shock to TFP, ICTI, C and RP

IR-matching results I

Symbol	Economic Interpretation	Estimated Value
σ_ι^2	Variance of ICT technological shock	0.01
ρ_ι	Persistence of ICT technological shock	0.9
γ	Size of spillover of ICT capital on TFP	0.5881

IR-matching results II



Conclusion

- SVAR analysis uncovered interesting pattern between ICT productivity and TFP.

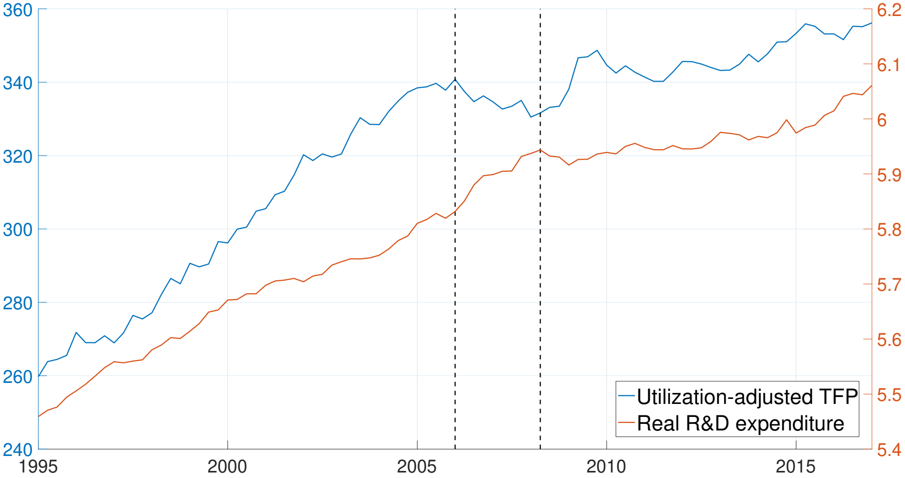
  $\rightarrow$ An ICT shock leads to delayed but persistent TFP increases.

- Two-sector structural model with a spillover from ICT-capital can rationalize results.

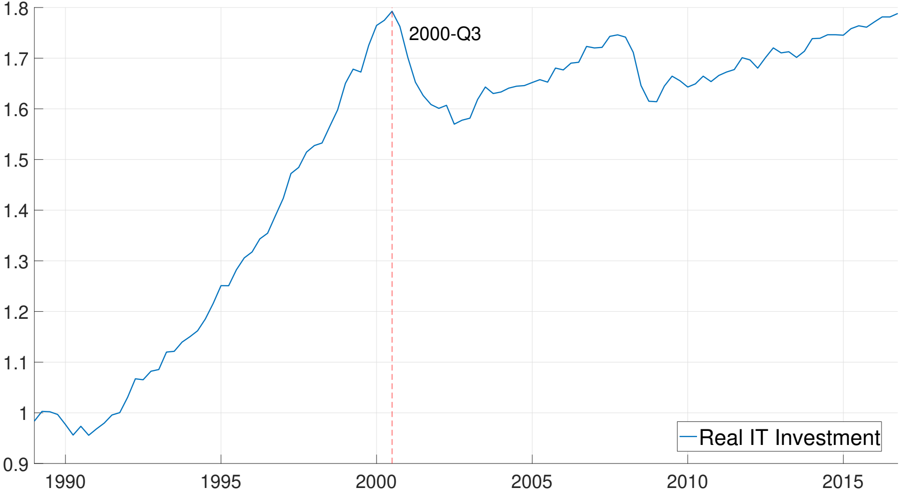
  $\rightarrow$ Estimation of the model suggests that data supports the GPT-interpretation of ICT.

THANK YOU!

Wrong timing



Fernald et al. (2017): "R&D and adoption can't be the whole story".


1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
1990
1995
2000
2005
2010
2015
2000-Q3
Real IT Investment

Return

Notation in detail

The reduced-form VAR is

$$y_t = B(L)y_{t-1} + i_t$$

Mapping between innovations i_t to structural shocks s_t

$$A_0 s_t = i_t$$

$\rightarrow$ structural-form VAR is

$$A_0^{-1} y_t = C(L)y_{t-1} + s_t$$

where $C(L) = A_0^{-1}B(L)$ and $s_t = A_0^{-1}i_t$, and the impact matrix A_0 satisfies $\Sigma = A_0 A_0'$.

For any arbitrary orthogonalization $\tilde{A}_0 \; : \; \Sigma = \tilde{A}_0 \tilde{A}_0'$, a rotation using an orthogonal matrix D ($DD' = I$) allows us to back out impact matrix as $A_0 = \tilde{A}_0 D$.

$\rightarrow$ The matrix of impact responses to all shocks is:

$$\Pi(0) = \tilde{A}_0 D$$

Specifically, denoting the responses of variable i to shock j, it is

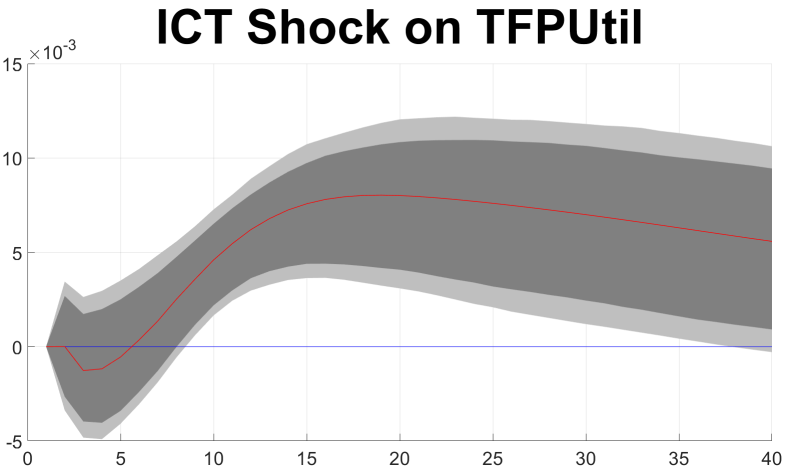
$$\Pi_{i,j}(0) = e_i' \tilde{A}_0 D e_j$$

where e_k is a selector column vector.
Denote $\gamma_j := De_j$, a specific column of D.

$\rightarrow$ $\tilde{A}_0 \gamma_j$ =the vector of impact responses of all variables to shock j.

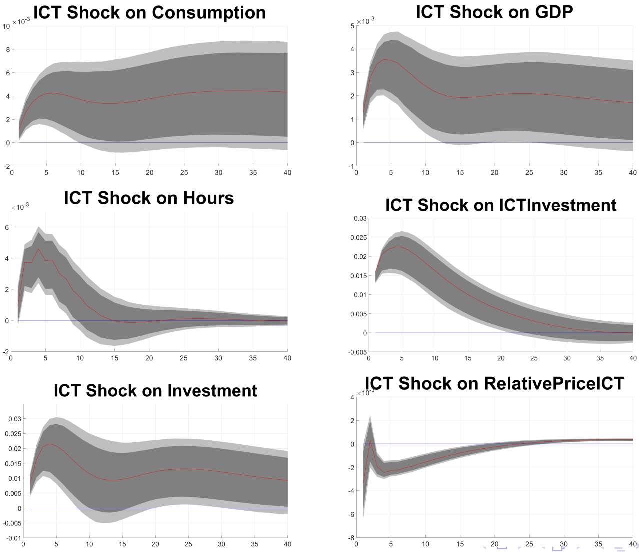
Return

IRFs for a larger-scale VAR I (2 lags)



Return

IRFs for a larger-scale VAR II (2 lags)



Controlling for news

Step 1 - Identification of γ_{news}

$$\max_{\gamma_{news}} \Omega_{1,news}(h) = \frac{\sum_{t=0}^{h} e_1' B^t \tilde{A}_0 \gamma_{news} \gamma_{news}' \tilde{A}_0' B'^t e_1}{e_1' (\sum_{\tau=0}^{H} B^t \Sigma B'^t) e_1}$$

subject to

$$\Pi_{1,news}(0) = 0,$$
$$\Pi_{6,news}(0) = \Pi_{6,news}(1) = \Pi_{6,news}(2) = 0, \quad \text{and}$$
$$\gamma_{news} \gamma_{news}' = 1.$$

Controlling for news

Step 2 - Identification of γ_{ICT}

$$\max_{\gamma_{ICT}} \Pi_{2,ICT}(0) = e_2' \tilde{A}_0 \gamma_{ICT}$$

subject to

$$\Pi_{1,ICT}(0) = 0,$$
$$\gamma_{news}\gamma_{ICT}' = 0, \quad \text{and} \quad \gamma_{ICT}\gamma_{ICT}' = 1.$$

Return

Robustness checks for the news specification

- Different variables
  - Add the Michigan index of consumer confidence (expected business conditions 5 years ahead)
  - Replace IT prices with capital prices (following Comin & Gertler)
  - Replace CPI inflation with PCE inflation
- Different horizons at which we impose the restriction on relative prices for the news shock
  $\rightarrow$ ran 6, 8, 10, 12 and 16 quarters.
- Increase the number of lags (2)
- Check whether VAR is information-sufficient to identify the news shock (Forni-Gambetti test) (p-val of 12%)

TFP in the model

Can be computed 2 ways:

1) $TFP_t = (1-w)TFP_t^c + wTFP_t^i$

2) $g_{TFP} = g_{GDP} - ag_{k^c} - bg_l - (1-a-b)g_{k^i}$

where for a variable X, $g_x := \ln\left(\frac{X_t}{X_{t-1}}\right)$.

In the model, the latter is equivalent to

$$g_{TFP} = g_\eta + wg_{\theta^c} + (1-w)g_{\theta^i} + \gamma g_{k^i} \tag{5}$$

Return

GDP and relative prices in the model

GDP is

$$GDP_t = (1-w)y_t^c + w y_t^i \quad \text{where} \quad w = \frac{p_t y_t^i}{y_t^c + p_t y_t^i}$$

with

$$p_t = \frac{p_t^i}{p_t^c} \quad \text{where we normalize} \quad p_t^c = 1$$

Return

Calibration

	Economic Interpretation	Value	Reference
β	Discount factor of households	$0.97^{\frac{1}{4}}$	Match 3M-T-bill return
δ^c	Depreciation of hard capital	0.0206	BEA
δ^i	Depreciation of ICT capital	0.0398	BEA
a	Hard capital share	0.3	Standard value
b	ICT capital share	0.031	Oulton (2012)
Γ^c	Steady state growth rate of hard capital	1.0034	See below
Γ^i	Steady state growth rate of ICT capital	1.0160	See below
χ	Frisch elasticity	1	Standard value

Get (Γ^c, Γ^i) by solving the following model-implied steady state system

$$\begin{cases} \frac{p_t}{p_{t-1}} = \frac{\Gamma^c}{\Gamma^i} \\ \frac{c_t}{c_{t-1}} = (\Gamma^c)^{\frac{1-b-\gamma}{1-a-b-\gamma}} (\Gamma^i)^{\frac{b+\gamma}{1-a-b-\gamma}} \end{cases} \tag{6}$$

Return