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

   $\rightarrow$ 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.

   $\rightarrow$ ICT literature: ICT is a general-purpose technology (GPT).

   $\Rightarrow$ 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 & Sichel (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

2. Structural Model

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.

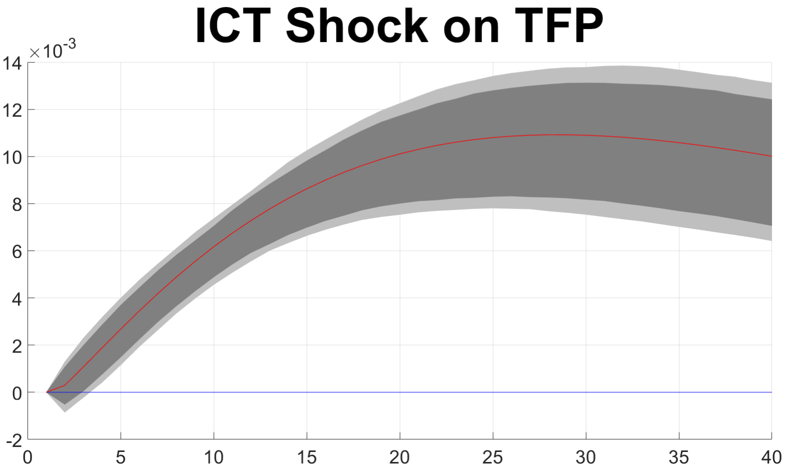
Why this identification?

- ICT shocks fluctuations are small (recovered shocks in VAR and model are small)

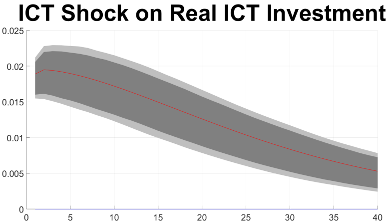
- ICT value added is less than 5% of GDP (BEA, April 2018).
  $\rightarrow$ ICT-I increases shouldn't affect TFP on impact.

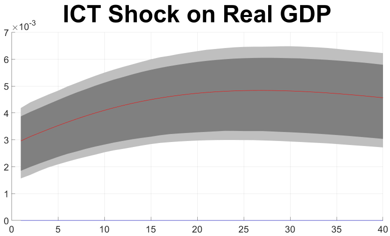
- Prediction of multisector models (GHK): sectoral productivity increase leads to sectoral output becoming cheaper.
  $\rightarrow$ ICT-I should rise after ICT productivity shock.

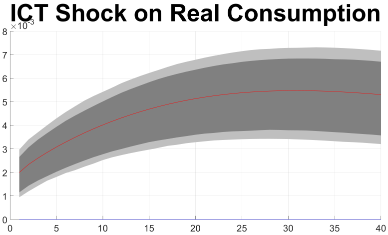
Results

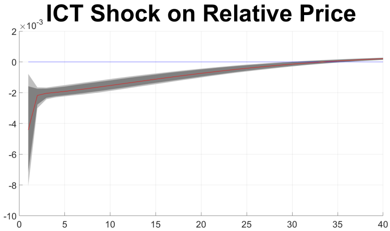


Results II









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

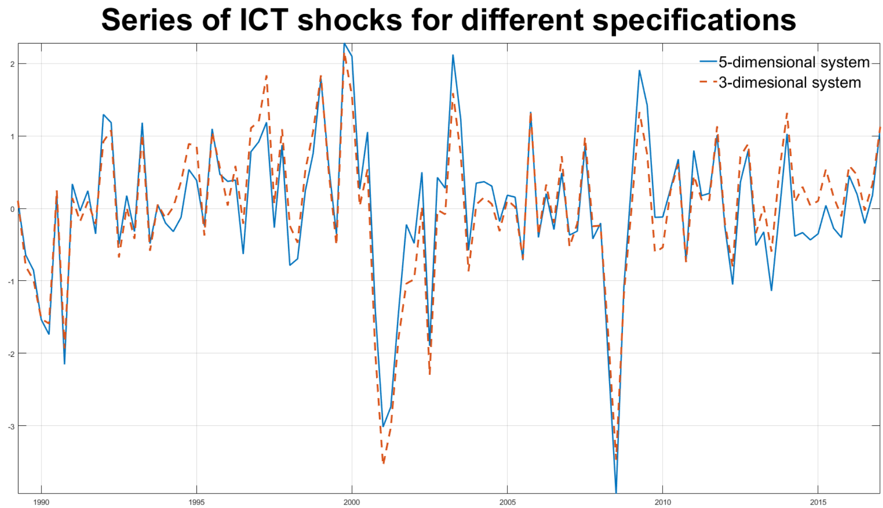
Robustness checks

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

$\rightarrow$ 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

1. SVAR Analysis
2. Structural Model

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

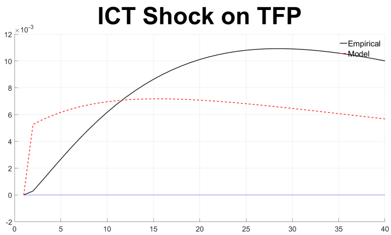
$$\min_{\Omega} \left[\hat{\Psi} - \Psi(\Omega)\right]' \Lambda \left[\hat{\Psi} - \Psi(\Omega)\right] \tag{4}$$

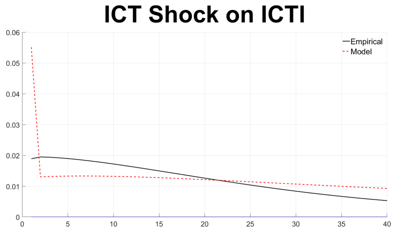
- $\Psi(\Omega)$ = mapping from Ω to the theoretical impulse responses
- $\hat{\Psi}$ = the empirical impulse responses of an ICT shock to TFP, ICTI, C and RP

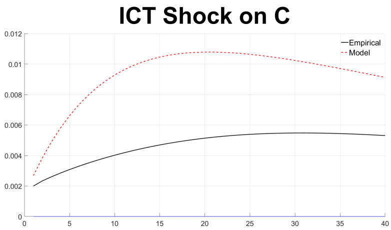
IR-matching results I

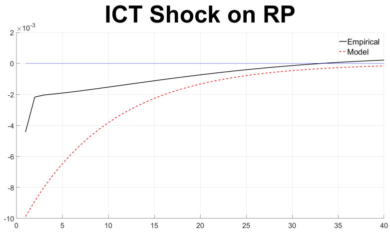
Symbol	Economic Interpretation	Estimated Value
σ_ι^2	Variance of ICT technological shock	0.01
ρ_ι	Persistence of ICT technological shock	0.9
γ	Size of spillover of ICT capital on TFP	0.5881

IR-matching results II









Conclusion

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

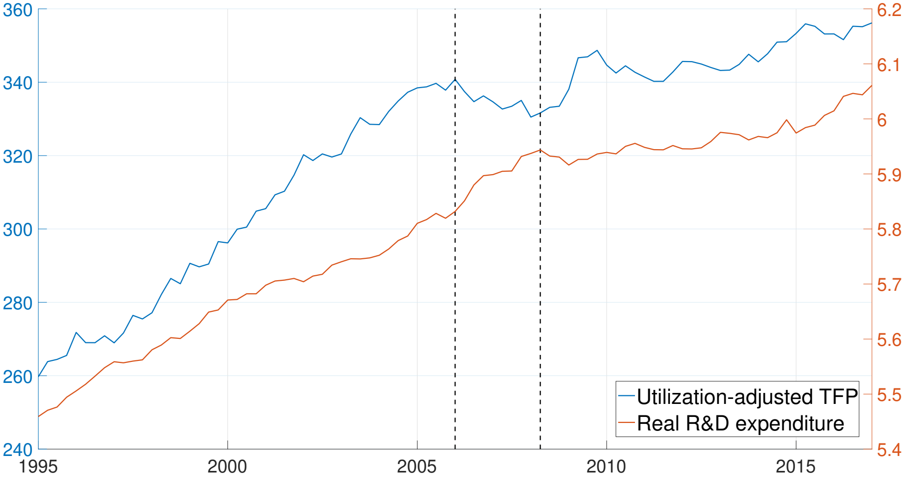
  $\rightarrow$ An ICT shock leads to delayed but persistent TFP increases.

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

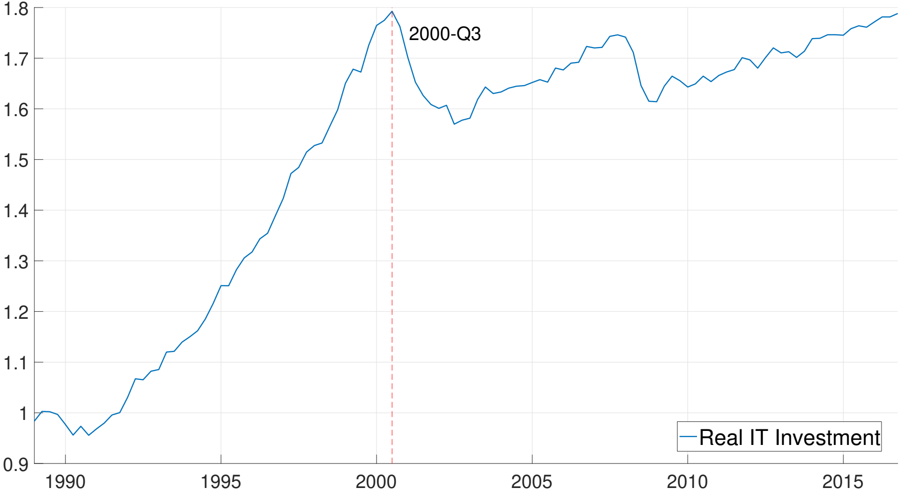
  $\rightarrow$ Estimation of the model suggests that data supports the GPT-interpretation of ICT.

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

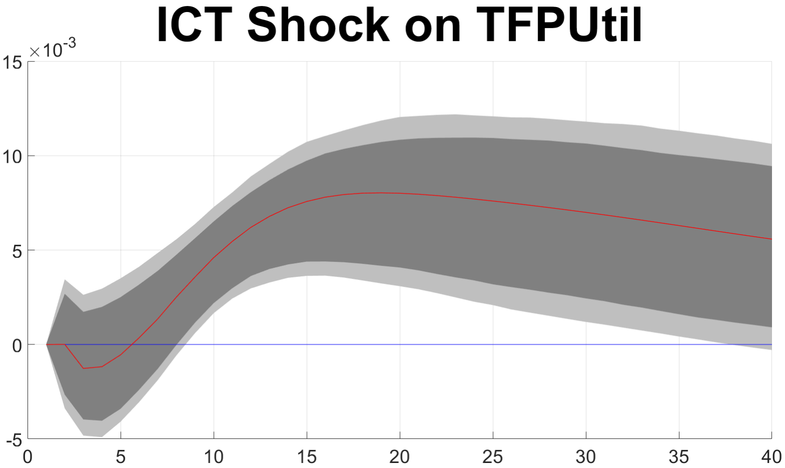
$$\Pi_{i,j}(0) = e_i' \tilde{A}_0 D e_j$$

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.

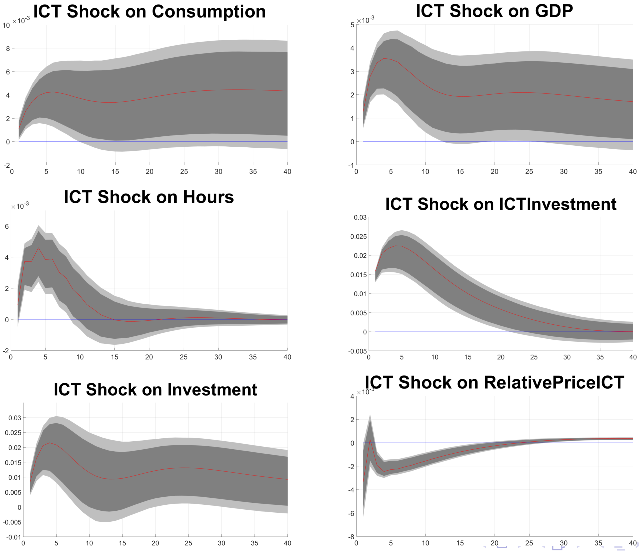
Return

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:

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

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

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

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

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

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

Return