Heterogeneous Agents in Macro Models

Creative Destruction and Uncertainty

Petr Sedláček

Lake Como School of Advanced Studies
July 2018

Starting point: Uncertainty rises in recessions

Dominant view in the literature

- exogenous uncertainty increases cause recessions
  - e.g. Bloom (2009), Christiano et al. (2010), Schaal (2015)

This paper: think about uncertainty related to innovation and growth

- 1. why and how is growth related to uncertainty?
- 2. can such “growth-driven” uncertainty be *counter*-cyclical?
- 3. to what extent is uncertainty in the data driven by growth?

This paper: structural model

In all what follows, I focus on *firm-level* uncertainty

- cross-sectional dispersion of firm-level TFP (Bloom et al., 2014)

Tractable general equilibrium model of endogenous firm dynamics

- firms differ in productivity levels
  - can invest in improving technology
  - $\uparrow$ tech. investment $\rightarrow \uparrow$ chances of adopting better technology vintages
- endogenous entry, exit and employment decisions

1. Why/how is technology growth related to firm-level uncertainty?

- innovation is uncertain and faster growth leads to
  - larger productivity gains (losses) if innovation is (not) successful

This paper: structural model

2. Can such growth-driven uncertainty be *counter*-cyclical?
   - faster technology growth spurs a process of creative destruction
     - firms at the frontier expand and shut down less often
     - firms below the frontier become more obsolete, shrink and shut down
   - $\rightarrow$ simultaneous increase in job creation and job destruction
     - in calibrated model destruction dominates $\rightarrow$ Schumpeterian downturn
     - $\rightarrow$ growth-driven uncertainty is counter-cyclical

This paper: empirical evidence

3. To what extent is uncertainty growth-driven in the data?

- estimate series of structural VARs with long-run restrictions
- positive technology shocks lead to
  - an increase in R&D, job creation and job destruction
  - a temporary drop in aggregate employment
  - an increase in firm-level uncertainty
- quantify extent of uncertainty variation driven by technology shocks
  - on average technology shocks explain 27 percent
  - certain periods more important (70% around dot-com bubble recession)
  - certain periods less important (Great Recession unrelated to growth)

Related literature

Uncertainty shocks and their effects

- Bloom (2009), Christiano, Motto, Rostagno (2010), Arellano, Bai, Kehoe (2012), Bloom et al. (2012), Schaal (2012), Bachmann, Born, Elstner, Grimme (2013), Bachmann, Bayer (2014), Caggiano, Castelnuovo, Groshenny (2014), Vavra (2014), Jurado et al. (2015)

Model of creative destruction and technology adoption

- Aghion, Howitt (1994), Caballero, Hammour (1996), Mortensen, Pissarides (1998), Gali (1999), Klette, Kortum (2004), Fisher (2006), Lopez-Salido, Michelacci (2007), Comin, Gertler, Santacreu (2009), Buera, Oberfield (2015), Akcigit, Kerr (2016)

Endogenous fluctuations in uncertainty

- Bachmann, Moscarini (2012), Gourio (2014), Orlik, Veldkamp (2014), Plante et al. (2014), D'Erasmo et al. (2015), Ludvigson et al. (2016)

Nexus of growth, business cycles and uncertainty?

(Structural model)

Household preferences and choices

Utility-maximizing representative household

- chooses consumption (C_t) and labor supply (N_t)

$$\max_{\{C_t, N_t\}_0^\infty} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\ln C_t - \zeta N_t\right)$$

$$C_t = W_t N_t + \Pi_t$$

- W_t is competitive wage rate and Π_t are firm profits
- optimal labor supply implies

$$W_t = \zeta C_t$$

Technology growth and technology investment

Exogenous stochastically growing technological frontier

$$\ln Z_t = \overline{Z} + \ln Z_{t-1} + \epsilon_{Z,t}$$

- $\overline{Z} > 0$: average technology growth
- $\epsilon_{Z,t} \sim N(0, \sigma_Z^2)$: technology shocks

Firms endogenously adopt newer technology

- investing r units of final good results in p probability of innovating

$$p = \left(\frac{r}{\chi}\right)^{1/\eta} \gamma^{1-1/\eta}$$

  - $\gamma = z/Z$: relative "stock of knowledge" (distance from frontier)
  - $1/\eta$: elasticity of tech. adoption "production function"

Firm-level productivity

Given tech. expenditures, incumbent firm with technology vintage of age j

1. retains its previous productivity level if it fails to innovate
2. attains younger vintage of technology if it innovates
   - θ share of innovations are *radical* $\rightarrow$ attain leading technology
   - remaining innovations are *incremental* $\rightarrow$ attain closest younger vintage

$$\ln z_{j,t} \rightarrow \begin{cases} \ln z_{j+1,t+1} & \text{with probability } 1 - p_{j,t}, \\ \ln z_{j,t+1} & \text{with probability } p_{j,t}(1-\theta), \\ \ln Z_{t+1} & \text{with probability } p_{j,t}\theta \end{cases}$$

Tech. investment conducted also by potential entrants

- assume that only those with radical innovations successfully start up

Firm dynamics: entry, growth and exit

- firm entry
  - free entry of radically innovating startups
- employment choices conditional on firm-level productivity
  - incumbent production function $y_{i,t} = A_t z_{i,t} n_{i,t}^{\alpha}$
- firm life-cycle growth
  - efficiency gains from learning-by-doing ψ_a
- firm exit
  - payment of stochastic idiosyncratic operational costs ϕ

$$\mathbb{V}_a(z_{i,t}, \mathcal{F}_t) = \max_{n_{i,a,t}, p_{i,a,t}, \widetilde{\phi}_{i,a,t}} \int^{\widetilde{\phi}_{i,a,t}} \left[\begin{array}{c} y_{i,a,t} + \psi_{a,t} n_{i,a,t} - W_t n_{i,a,t} \\ -R(p_{i,a,t}, \gamma_{i,t}) - \phi \\ +\mathbb{E}_t \beta \frac{C_t}{C_{t+1}} \mathbb{V}_{a+1}(z_{i,t+1}, \mathcal{F}_{t+1}) \end{array} \right] dH_t(\phi)$$

Firm productivity (size) distribution and its evolution

- $\omega_{j,a,t}$: mass of firms of age a and technology vintage j years old
- $\overline{E}$: fixed mass of potential startups

$$\omega_{0,0,t} = \overline{E} p_{e,t} \theta$$

$$\omega_{0,a+1,t+1} = \begin{matrix} \sum_j \sum_a \int^{\widetilde{\phi}_{j,a,t}} p_{j,a,t} \theta \omega_{j,a,t} dH(\phi) \\ \int^{\widetilde{\phi}_{0,a,t}} p_{0,a,t}(1-\theta)\omega_{0,a,t} dH(\phi) \end{matrix} \qquad \begin{matrix} j = 0,1,2,..., \\ a = 0,1,2,..., \\ j \leq a, \end{matrix}$$

$$\omega_{j+1,a+1,t+1} = \sum_j \sum_a \left[\begin{matrix} \int^{\widetilde{\phi}_{j,a,t}} (1-p_{j,a,t})\omega_{j,a,t} dH(\phi) + \\ \int^{\widetilde{\phi}_{j+1,a,t}} p_{j+1,a,t}(1-\theta)\omega_{j+1,a,t} dH(\phi) \end{matrix} \right] \qquad \begin{matrix} j = 0,1,2,..., \\ a = 0,1,2,..., \\ j \leq a, \end{matrix}$$

Firm-level uncertainty: measurement

Follow Bloom et al. (2014): dispersion of establishment-level TFP shocks

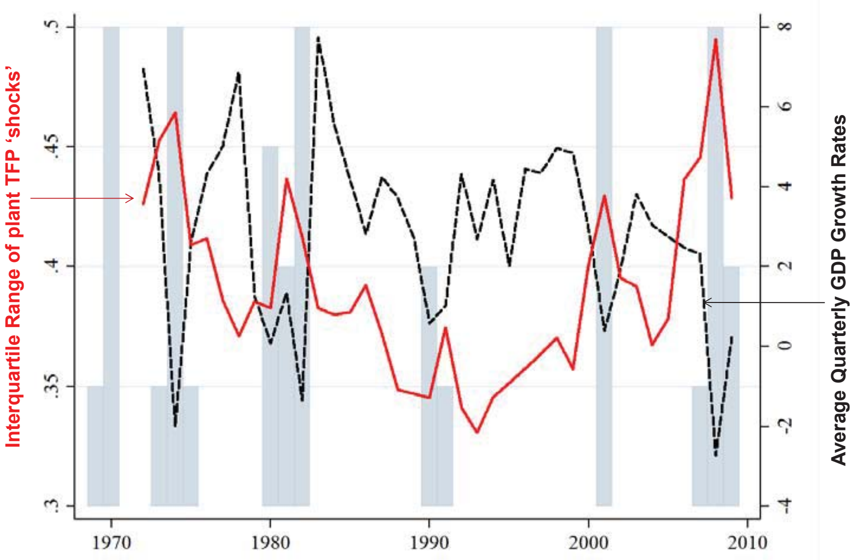
- define productivity *shocks* from

$$\ln \widehat{z}_{i,t} = \rho \ln \widehat{z}_{i,t-1} + \mu_i + \lambda_t + \upsilon_{i,t}$$

  - μ_i: establishment fixed-effects
  - λ_t: time fixed-effects
  - $\upsilon_{i,t}$: establishment-level TFP shocks with time-varying variance σ_t^2

- uncertainty (σ_t) measured as cross-sectional dispersion of TFP shocks

Firm-level uncertainty: measurement



Source: Bloom et al. (2012).

1. Why is growth linked to uncertainty in the model?

Consider simplified version of innovation process

- assume $p_{i,t} = p$ and $\theta = 1$

In a large enough cross-section of firms

- fraction p of firms adopt the leading technology Z_t
- fraction $1 - p$ retain their previous productivity levels

Individual firm productivity can then, on average, be described by

$$\ln z_{i,t} = (1 - p) \ln z_{i,t-1} + p \ln Z_t + \upsilon_{i,t}$$

- with $\mathbb{E}[\upsilon_{i,t}] = 0$

1. Why is growth linked to uncertainty in the model?

Consider simplified version of innovation process

- assume $p_{i,t} = p$ and $\theta = 1$

In a large enough cross-section of firms

- fraction p of firms adopt the leading technology Z_t
- fraction $1 - p$ retain their previous productivity levels

Individual firm productivity can then, on average, be described by

$$\ln z_{i,t} = \rho \ln z_{i,t-1} + \lambda_t + \upsilon_{i,t}$$

- with $\mathbb{E}[\upsilon_{i,t}] = 0$, $\rho = (1 - p)$ and $\lambda_t = p \ln Z_t$

1. Why is growth linked to uncertainty in the model?

Firm-level uncertainty measured as cross-sectional variance of TFP shocks

$$\upsilon_{i,t} = \quad \omega_{i,t}(p-1)(\ln \gamma_{i,t-1} - \overline{Z}) + (1-\omega_{i,t})p(\ln \gamma_{i,t-1} + \overline{Z})$$

- $\omega_{i,t}$: is an indicator function
  - $\omega_{i,t} = 1$ with probability p and 0 otherwise

$$\sigma_t^2 = \text{var}[\upsilon_{i,t}] = p[(1+p)\sigma_\gamma^2 + (1-p)\mu_\gamma] + p(1-p)\overline{Z}^2$$

- where uncertainty depends on
  - uncertainty depends on innovation speed (p)
  - productivity distribution ($\mathbb{E}[\ln \gamma_{i,t}] = \mu_\gamma$ and $\text{var}[\ln \gamma_{i,t}] = \sigma_\gamma^2$)
  - speed of technology growth $\overline{Z}$

1. Why is growth linked to uncertainty in the model?

Firm-level uncertainty measured as cross-sectional variance of TFP shocks

$$\upsilon_{i,t} = \quad \omega_{i,t}(p-1)(\ln\gamma_{i,t-1} - \overline{Z}) + (1-\omega_{i,t})p(\ln\gamma_{i,t-1} + \overline{Z})$$

- $\omega_{i,t}$: is an indicator function
  - $\omega_{i,t} = 1$ with probability p and 0 otherwise

$$\sigma_t^2 = \text{var}[\upsilon_{i,t}] = p[(1+p)\sigma_\gamma^2 + (1-p)\mu_\gamma] + p(1-p)\overline{Z}_t^2$$

- where uncertainty depends on
  - uncertainty depends on innovation speed (p)
  - productivity distribution ($\mathbb{E}[\ln\gamma_{i,t}] = \mu_\gamma$ and $\text{var}[\ln\gamma_{i,t}] = \sigma_\gamma^2$)
  - speed of technology growth $\overline{Z} \rightarrow \sigma_t^2$ rises with $\overline{Z}_t$

Parametrization, model performance and results

Calibration: main model features and related targets

- operational costs distribution: average exit
- learning-by-doing efficiency gains: average size by age
- tech. adoption parameters: estimates from Akcigit, Kerr (2015)
- aggregate shocks: cyclical patterns of output and R&D data

Model matches reallocation and R&D patterns in data

Firm shares and size distributions

- many young firms are small (BDS)

Reallocation process

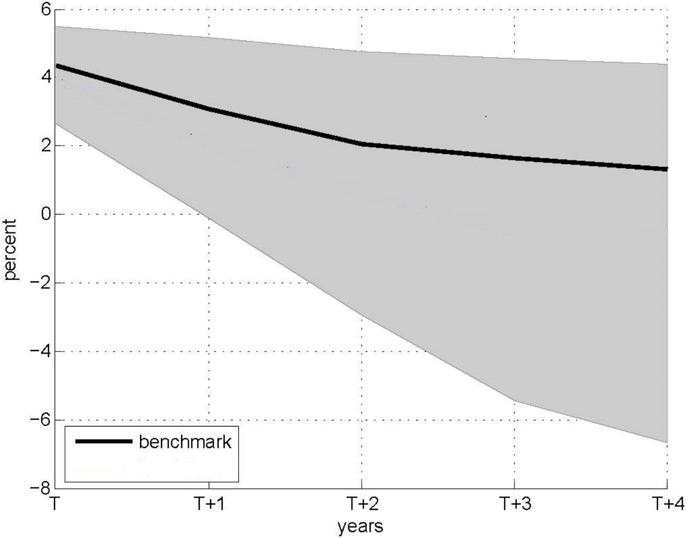
- lots of churn, largely driven by entry and exit (BDS)

Technology expenditures at the firm level

- small firms innovate relatively more in data
- R&D positively correlated with productivity level
- less so with productivity growth

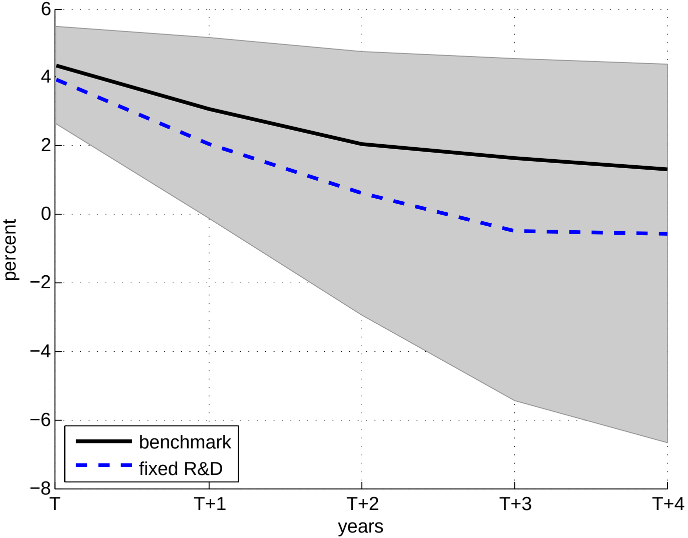
1. How is technology growth linked to uncertainty?

Measuring uncertainty as in Bloom et al. (2014)



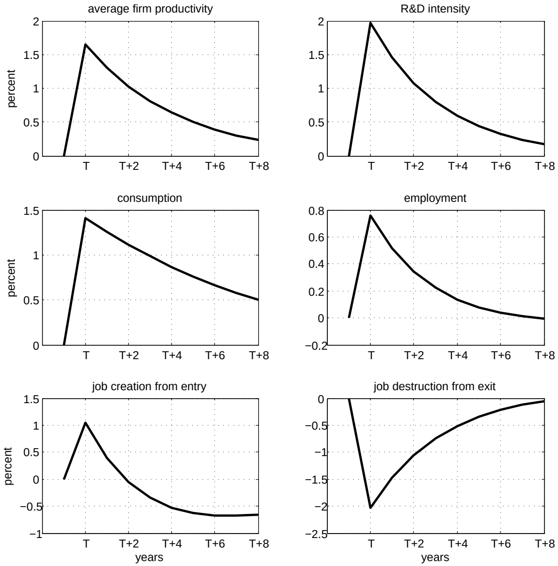
1. How is technology growth linked to uncertainty?

Measuring uncertainty as in Bloom et al. (2014)



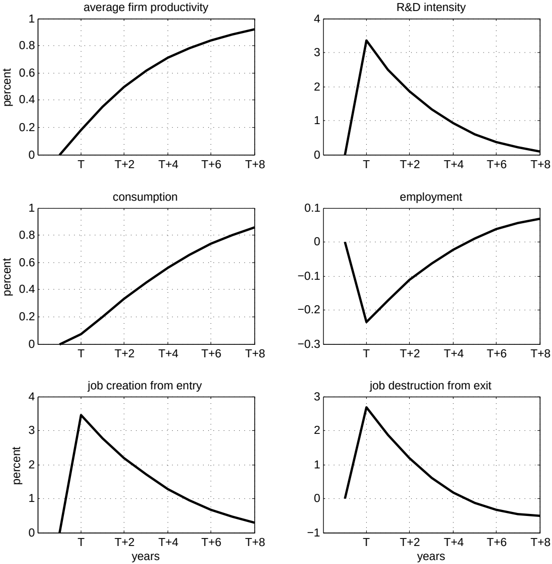
2. Can growth-driven uncertainty be counter-cyclical?

Aggregate dynamics following a positive aggregate TFP shock



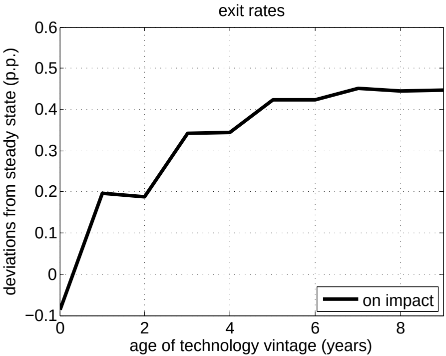
2. Can growth-driven uncertainty be counter-cyclical?

Aggregate dynamics following a positive technology shock



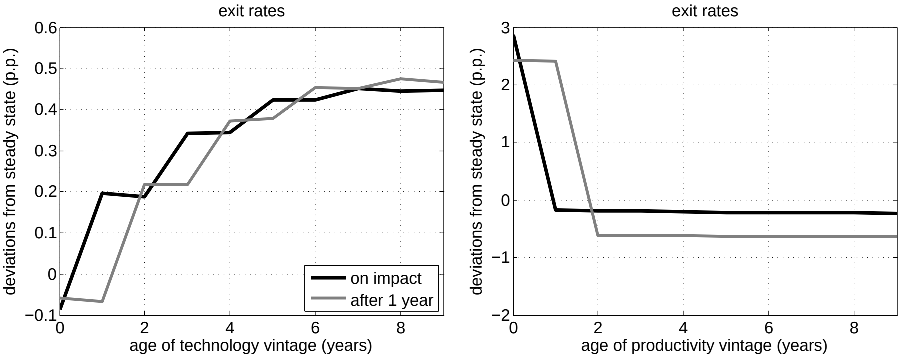
2. Can growth-driven uncertainty be counter-cyclical?

Distributional dynamics following a positive technology shock



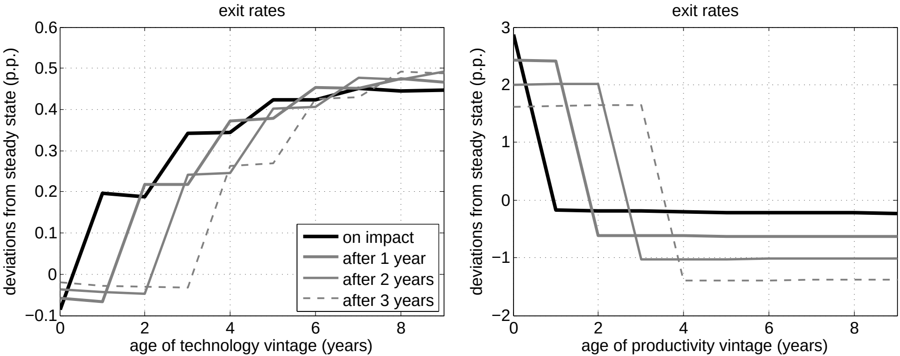
2. Can growth-driven uncertainty be counter-cyclical?

Distributional dynamics following a positive technology shock



2. Can growth-driven uncertainty be counter-cyclical?

Distributional dynamics following a positive technology shock



2. Can growth-driven uncertainty be counter-cyclical?

Unconditional cyclicality of firm-level uncertainty in model

- simulate economy $1,000$ times for $1,040$ periods
- shocks distributed according to calibrated values
- drop first $1,000$ periods

	output	employment	frontier tech.
		model	
corr(σ_t, x_t)	-0.19	-0.13	0.35
	$[-0.37, -0.01]$	$[-0.31, 0.05]$	$[0.17, 0.53]$
		data	
corr(σ_t, x_t)	-0.46	-0.42	0.33

To what extent is uncertainty growth-driven in the data?
(testing the model's predictions)

Technology shocks, firm dynamics and uncertainty

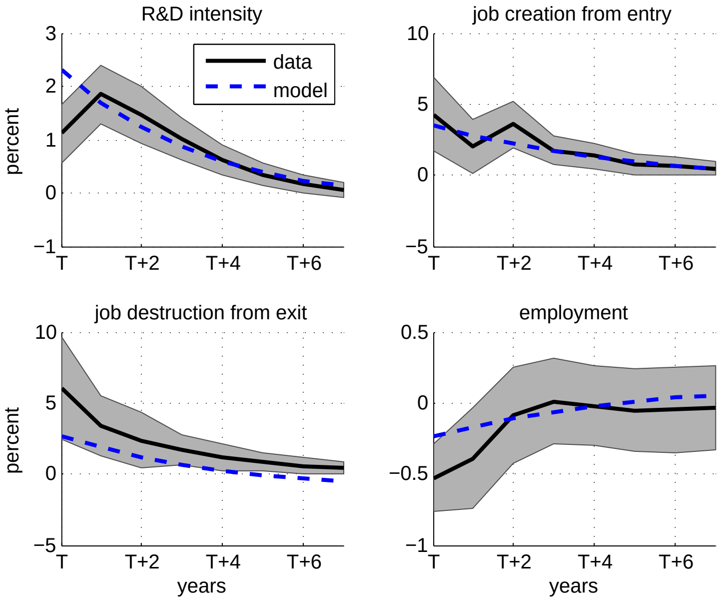
Estimate series of structural VARs with long-run restrictions

- following Blanchard, Quah (1989), Gali (1999)
- only technology shocks affect productivity in long-run
- include firm-dynamics, R&D and uncertainty in data vector

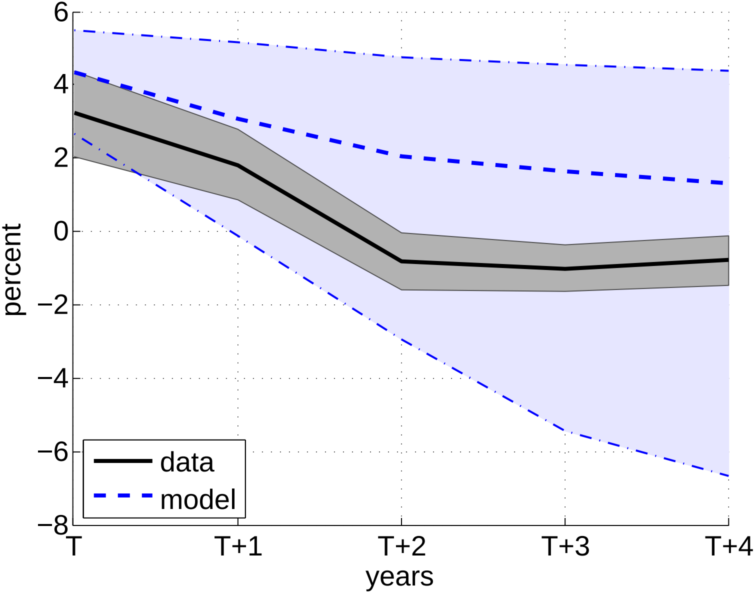
Similar results obtained with alternative estimation strategy

- local projections and Basu et al. (2013) technology shocks

Technology shocks, firm dynamics and uncertainty

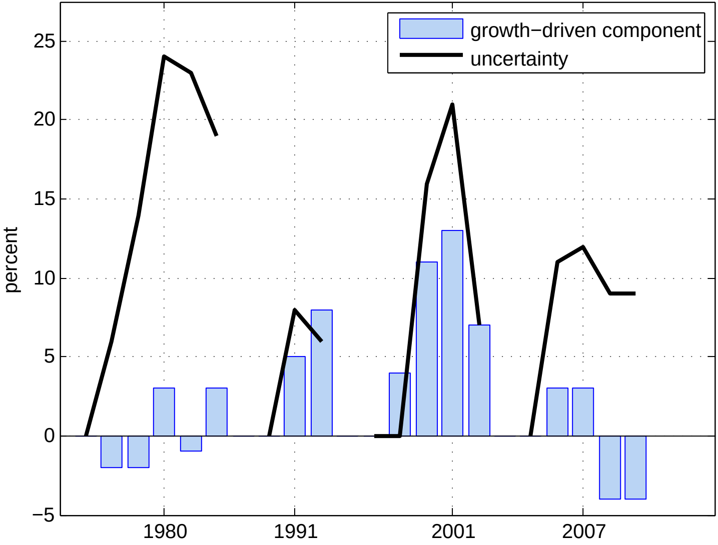


Technology shocks, firm dynamics and uncertainty



3. To what extent is uncertainty growth-driven in data?

On average, technology shocks explain 27% of uncertainty variation



Summary

Structural model linking growth, business cycles and uncertainty

- technology improvements spur creative destruction process
- at the same time, firm-level uncertainty increases
- $\rightarrow$ counter-cyclical uncertainty fluctuations

Model predictions are consistent with the data

- establishment dynamics following technology shocks
- uncertainty increases following positive technology shocks

Role of growth-driven uncertainty in data

- on average accounts for 30% of observed uncertainty variation
- particularly important in the 90's and around the new millennium

Thanks

Model details

Firm maximization problem:

$$\mathbb{V}_a(z_{i,t}, \mathcal{F}_t) = \max_{n_{i,a,t}, p_{i,a,t}, \widetilde{\phi}_{i,a,t}} \int^{\widetilde{\phi}_{i,a,t}} \left[\begin{array}{c} y_{i,a,t} + \psi_{a,t} n_{i,a,t} - W_t n_{i,a,t} \\ -R(p_{i,a,t}, \gamma_{i,t}) - \phi \\ +\mathbb{E}_t \beta \frac{C_t}{C_{t+1}} \mathbb{V}_{a+1}(z_{i,t+1}, \mathcal{F}_{t+1}) \end{array} \right] dH_t(\phi)$$

Household preferences and choices

Utility-maximizing representative household

- chooses consumption (C_t) and labor supply (N_t)

$$\max_{\{C_t,N_t\}_0^\infty} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\ln C_t - \zeta N_t\right)$$

$$C_t = W_t N_t + \Pi_t$$

- W_t is competitive wage rate and Π_t are firm profits
- optimal labor supply implies

$$W_t = \zeta C_t$$

Firm productivity (size) distribution and its evolution

- $\omega_{j,a,t}$: mass of firms of age a and technology vintage j years old
- $\overline{E}$: fixed mass of potential startups

$$\omega_{0,0,t} = \overline{E} p_{e,t} \theta$$

$$\omega_{0,a+1,t+1} = \begin{array}{ll} \sum_j \sum_a \int^{\widetilde{\phi}_{j,a,t}} p_{j,a,t} \theta \omega_{j,a,t} dH(\phi) & j = 0,1,2,..., \\ & a = 0,1,2,..., \\ \int^{\widetilde{\phi}_{0,a,t}} p_{0,a,t}(1-\theta)\omega_{0,a,t} dH(\phi) & j \leq a, \end{array}$$

$$\omega_{j+1,a+1,t+1} = \sum_j \sum_a \left[\begin{array}{l} \int^{\widetilde{\phi}_{j,a,t}} (1 - p_{j,a,t}) \omega_{j,a,t} dH(\phi) + \\ \\ \int^{\widetilde{\phi}_{j+1,a,t}} p_{j+1,a,t}(1-\theta)\omega_{j+1,a,t} dH(\phi) \end{array} \right] \quad \begin{array}{l} j = 0,1,2,..., \\ a = 0,1,2,..., \\ j \leq a, \end{array}$$

back

Model parameters

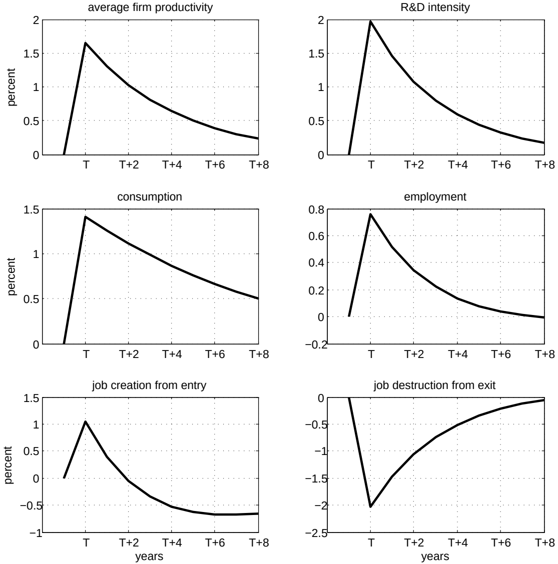
	parameter	value	target/source
β	discount factor	0.97	annual interest rate 3%
υ	disutility of worker labor	3.633	wage normalization, $W_{ss} = 1$
χ	R&D normalizing constant	0.280	firm productivity persistence 0.79, Foster et al. 2008
η	R&D cost curvature	2	patent elasticity w.r.t R&D 0.5, Acemoglu et al. 2013
θ	probability of radical innovation	0.1	Akcigit and Kerr (2016)
α	returns to scale	0.670	labor share 66%
ψ_s	learning-by-doing efficiency gains, startups	-0.545	rel. average size of startups 52%, BDS
ψ_y	learning-by-doing efficiency gains, young establishments	-0.344	rel. average size of young establishments 72%, BDS
ψ_m	learning-by-doing efficiency gains, medium-aged establishments	-0.195	rel. average size of medium-age establishments 90%, BDS
ψ_o	learning-by-doing efficiency gains, old establishments	0	normalization
μ_H	operational cost mean	0.093	0 average paid operational costs, normalization
σ_H	operational cost distribution, scale	0.238	average establishment exit rate of 11%, BDS
$\overline{E}$	mass of potential entrants	8.883	firm mass of 1, normalization
$\overline{Z}$	frontier technology drift	0.016	average patent application growth, USPTO
σ_Z	frontier technology shocks, standard deviation	0.010	corr(R&D,Y)=0.21, BEA
ρ_A	aggregate TFP shock, persistence	0.788	real GDP autocorrelation 0.79, BEA
σ_A	aggregate TFP shock, volatility	0.016	real GDP volatility 0.016, BEA

Firm distributions

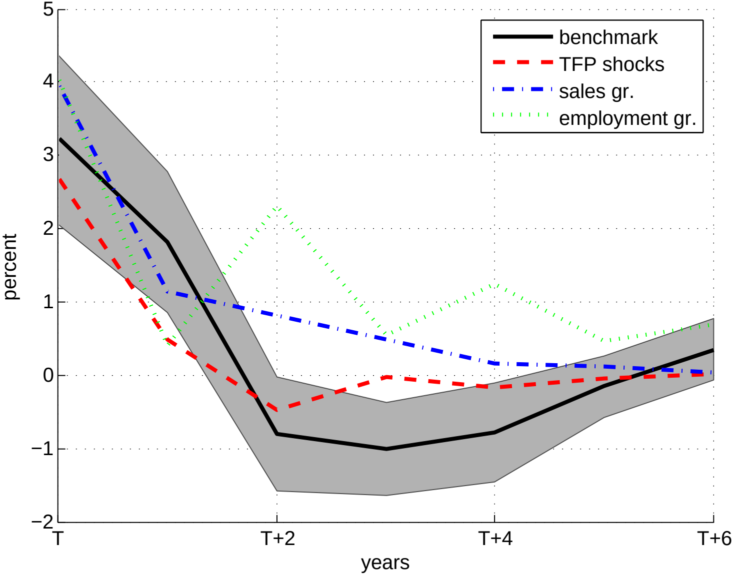
	establishment age			
	0	1-5	6-10	11+
	establishment shares			
data	11	32	19	38
model	12	35	21	32
	employment shares			
data	5	23	17	55
model	6	25	19	50

2. Can growth-driven uncertainty be counter-cyclical?

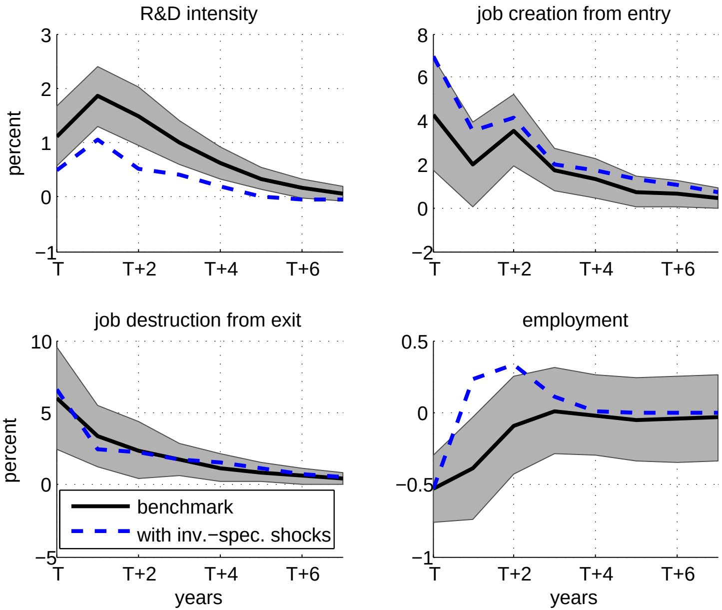
Aggregate dynamics following a positive aggregate TFP shock



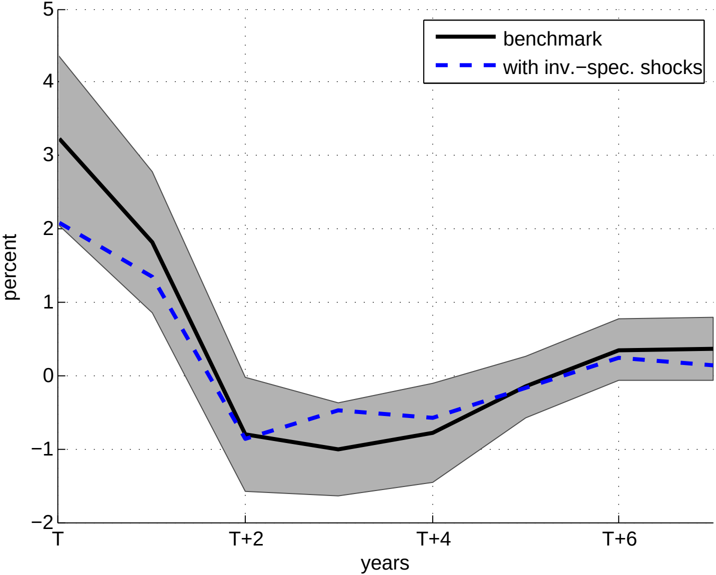
Alternative uncertainty measures



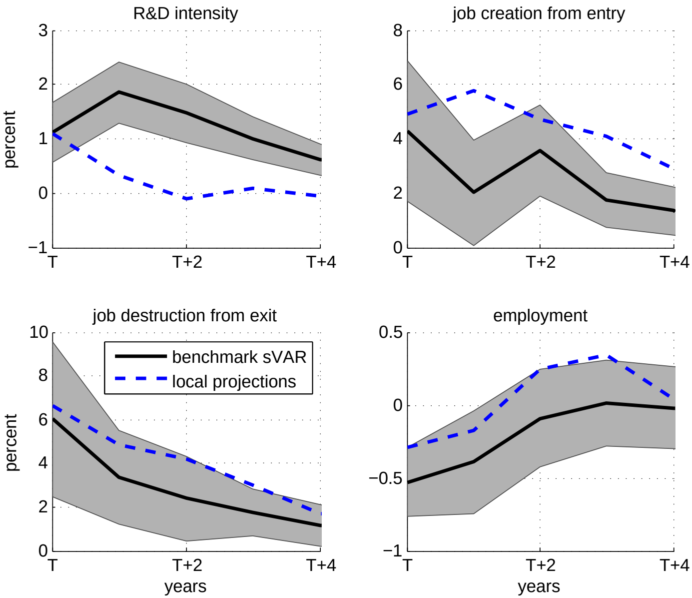
Accounting for investment-specific shocks



Accounting for investment-specific shocks



Alternative estimation strategy



Alternative estimation strategy