Technology Innovation and Diffusion as Sources of Output and Asset Price Fluctuations

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What we do:

- Develop and estimate a DSGE model where innovations in growth potential are a source of fluctuations.
- Growth potential represented by the technology frontier.
- Key aspect: endogenous adoption of new technologies.
- Analyze implications (of shock and propagation mechanism) for both output and stock price fluctuations.

Why we do it:

- Motivation similar to news shock literature:
  - Observable shocks: few and far between
  - Shifts in beliefs about future growth appealing driving force
    - Innovations to stock prices orthogonal to current TFP growth are correlated to future TFP growth (Beaudry and Portier, 2006).
    - The second half of the 90s: 1994-1995, emergence of VC, # of patents, internet,... companies that become public at the end of the decade. Large productivity growth 1995-2000
- In our framework, beliefs tied to evolution of technology frontier
  - Consider cases of both exogenous/endogenous evolution

Why we do it (cont'd):

- Need to confront similar pitfalls as news shocks literature
  - Anticipated shocks can have perverse effects on labor supply (Cochrane, 1994)
  - Amplitude, co-movement and persistence of Stock market
- Fixes:
  - Beaudry and Portier (2004): Two complementary consumption goods, one durable and one non-durable. Both goods are produced with labor and a fixed production factor. Labor is sector-specific. $\uparrow C \Rightarrow \uparrow I \Rightarrow L$ has to $\uparrow$
  - Rebelo and Jaimovich (2006): Play with utility function. The shock is not such good news since it makes so much harder to work in the future. Crash in the market.
  - Christiano, Motto and Rostagno (2007): Overly accommodating monetary policy.

Our Framework: the wealth effect

- Difference between potential and adopted technologies.
- Prototypes will eventually be used in production (i.e. slow diffusion and lags in development), so their presence constitutes news about future technology
- When they will be used, depends on the intensity of adoption investment.
- The arrival of a large flow of prototypes introduces TODAY a substitution effect since agents can substitute away from consumption to adopt earlier the new technologies.
- This substitution effect can dominate the wealth effect and generate co-movement of C, I, Y and hours.
- Our mechanism is consistent with the fact that the speed of technology diffusion is pro-cyclical (Comin, 2007).

Our Framework: the stock market

- The value of our firms is much more than the value of installed capital.
  - Firms' valuations also incorporate the present discounted value of the future profits from selling current and future intermediate goods at price above marginal cost.
  - Since profits, adoption, arrival and expectations about future arrival of new intermediate goods are pro-cyclical, stock market value can be pro-cyclical despite relative price of new capital is counter-cyclical.
  - Persistence in shocks on the growth rate of future technologies, and Stock market value forward looking:
    - Large and persistent fluctuations in stock market
    - Price dividend ratio is mean reverting
- The efficiency of production of new capital is pro-cyclical → counter-cyclical relative price of capital

Plan of the talk

1. Model with endogenous adoption
2. IR to future technology shock under endogenous and exogenous adoption
3. Estimation of more general model to show:
    - robustness of intuitions
    - amplification of endogenous adoption of other shocks
    - quantitative importance of different shocks
    - evolution of stock market

Model - Framework

- There are two sectors that produce output, Y, and new capital, J.
- In each sector (s),there are two layers of production:
  - Output of N_t^s differentiated final producers is aggregated competitively
    - N_t^s is determined by a free entry condition
  - Each differentiated final producer produces using (directly or indirectly) an endogenous number of adpted intermediate goods (A_t^s).
    - Shocks about future technology are shocks about the potential growth of A_t^s

Model - Production of new capital

$$K_t = (1 - \delta(U_t))K_{t-1} + J_t$$

$$J_t = \left(\int_0^{N_t^K} J_t\left(r\right)^{\frac{1}{\mu^k}} \, dr \right)^{\mu^k}, \text{ with } \mu^k > 1,$$

$$J_t\left(r\right) = \left(J_t^s(r)\right)^{\gamma}\left(J_t^e(r)\right)^{1-\gamma}, \text{with } \gamma \in (0,1)$$

where

$$J_t^s(r) = \frac{I_{st}^r}{P_{st}^k},$$

$$p_{st}^k = p_{st-1}^k + \varepsilon_{st}$$

$$J_t^e(r) = \left(\int_0^{A_t^k} I_t^r(s)^{\frac{1}{\theta}} ds \right)^{\theta}, \text{ with } \theta > 1.$$

Model - Production of output

$$Y_t = \left(\int_0^{N_t^y} Y_t(j)^{\frac{1}{\mu}} dj \right)^{\mu}, \text{ with } \mu > 1,$$

$$Y_t(j) = \left(\int_0^{A_t^y} Y_t^j(s)^{\frac{1}{\vartheta}} ds \right)^{\vartheta}$$

$$Y_t(s) \equiv \int_0^{N_t^y} Y_t^j(s) dj = X_t \left(U_t(s) K_t(s) \right)^{\alpha} \left(L_t(s) \right)^{1-\alpha}$$

Model - Technology

$$Z_{t+1}^s = (\bar{\chi}_s e^{\xi_s \chi_t} + \phi) Z_t^s, \text{ for } s = \{k, y\}$$

$$\chi_t = \rho \chi_{t-1} + \varepsilon_t$$

$$A_t^s = \lambda_{t-1}^s [Z_{t-1}^s - A_{t-1}^s] + \phi A_{t-1}^s$$

$$\lambda_t^s = \lambda(\Gamma_t^s h_t^s)$$

with $\lambda' > 0$, $\lambda'' < 0$,

$$\Gamma_t^s = A_t^s / (\bar{P}_t^k K_t)$$

Model - Value of innovation and optimal adoption

$$v_t^s = \pi_t^s + \phi E_t \left[\beta \Lambda_{t,t+1} v_{t+1}^s \right].$$

$$j_t^s = \max_{h_t^s} -h_t^s + E_t \{ \beta \Lambda_{t,t+1} \phi [\lambda_t^s v_{t+1}^s + (1 - \lambda_t^s) j_{t+1}^s] \}$$

$$1 = E_t \left[\beta \Lambda_{t,t+1} \phi \Gamma_t \lambda^{s\prime} \left(\Gamma_t^s h_t^s \right) \left(v_{t+1}^s - j_{t+1}^s \right) \right]$$

Model - Households

$$Max \ E_t \sum_{i=0}^{\infty} \beta^{t+i} e^{\mu^b_{t+i}} \left[\ln C_t - e^{\mu^w_t} \frac{(L_t)^{\zeta+1}}{\zeta+1} \right]$$

s.t.

$$C_t = W_t L_t + \Pi_t + [D_t + P^k_t] K_t - P^k_t K_{t+1} + R_t B_t - B_{t+1} - T_t$$

Relative price of capital

$$P_t^K = \mu_k (N_t^k)^{-(\mu_k - 1)} \left(P_{st}^K\right)^{\gamma} \left(P_{et}^K\right)^{1-\gamma}$$

$$P_{et}^K = \theta \left(A_t^k\right)^{-(\theta-1)}$$

$$\overline{P}_t^K = \theta^{(1-\gamma)} \left(A_t^k\right)^{-(1-\gamma)(\theta-1)} \left(P_{st}^K\right)^{\gamma}$$

Standard Parameters	Value
β	0.98
δ	0.015
G/Y	0.2
α	0.35
α_s	0.17/0.35
ζ	1
θ	0.7
$\bar{\theta}$	0.8
U	0.8
$(\delta''/\delta')U$	0.15
μ	1.1
μ_w	1.2
μ_k	1.15
Non-standard Parameters	**Value**
$\bar{\chi}_y$	so that growth rate of y=0.024/4
$\bar{\chi}_k$	so that growth rate of p_{et}^K=-0.035/4
ϕ	0.99
$\bar{\lambda}^y$	so that λ^y=0.2/4
$\bar{\lambda}^k$	so that λ^k=0.2/4
ρ_λ	0.9
ξ_y	0.6

Table 1: Calibrated parameters

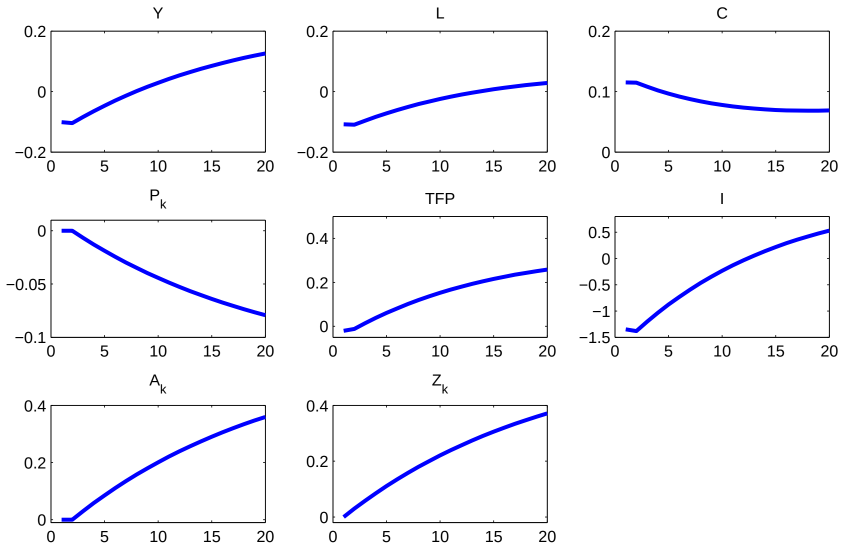

Figure 1: Impulse responses to an innovation shock in conventional model (immediate diffusion)

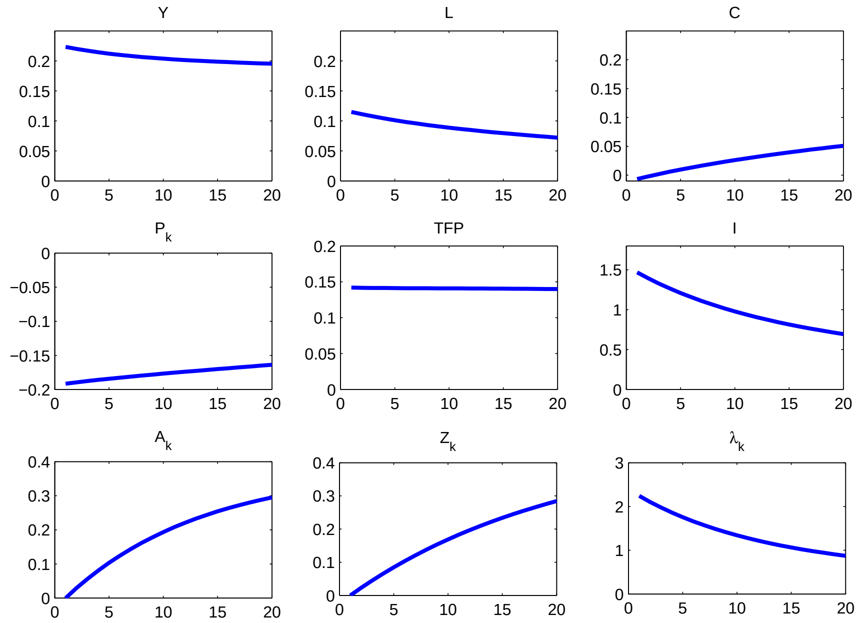

Figure 2: Impulse responses to an innovation shock in baseline model (slow diffusion, endogenous adoption)

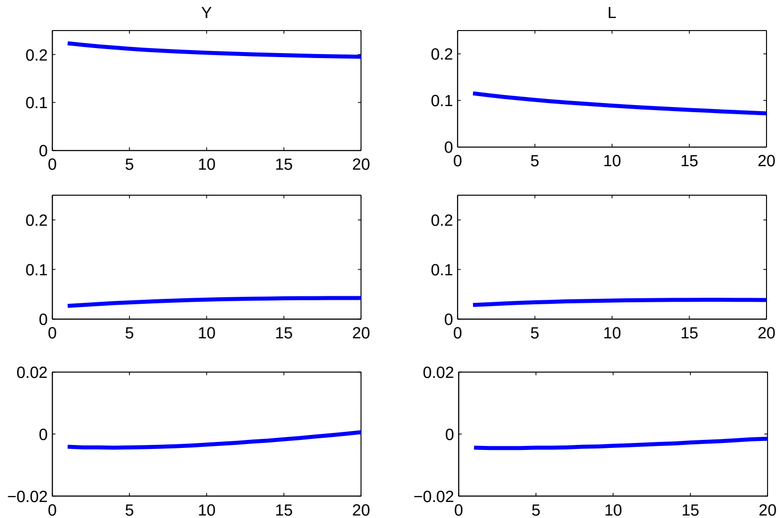

Figure 3: Robustness: Impulse responses to innovation shock. Top row: baseline model (slow diffusion, endogenous adoption). Middle row: baseline model without entry. Bottom row: baseline model without endogenous adoption.

Bayesian estimation

- Bayesian estimation is a bridge between calibration, through the specification of priors, and maximum likelihood, confronting model with data.
- Advantages of Bayesian estimation:
  - fits the complete DSGE model to a vector of time series rather than particular equilibrium relationships
  - Based on the likelihood function generated by the DSGE system rather than discrepancy between DSGE and VAR IRs
  - Allow for the use of priors that act as weights in the estimation process.
  - Addresses model misspecification by adding shocks interpreted as observation errors in the structural equations

Dynare

- We use Dynare (Juillard 1996) to estimate the model.
- Dynare estimates in the following way:
  - it estimates the likelihood of the DSGE solution system using the Kalman filter.
  - it uses the priors and the estimated likelihood function to obtain the posterior distribution (posterior kernel).
  - The posterior kernel obtained before is nonlinear in the parameters. Dynare uses a Metropolis-Hastings algorithm to simulate the posterior distribution of the parameters.

A more general model to estimate

- Investment adjustment costs

$$K_t = (1 - \delta(U_t))K_{t-1} + I_t \left(1 - \gamma \left(\frac{I_t}{(1+g_K)I_{t-1}} - 1\right)^2\right)$$

- Habit

$$\tilde{C}_t = C_t - hC_{t-1}$$

- Price setting a la Calvo with partial indexation
- Taylor rule for the determination of nominal interest rate

Data

- Sample: 1984:I to 2008:II
- Output growth: Real GDP per capita
- Consumption growth: Real consumption (personal consumption expenditures of non-durables and services)
- Hours growth
- Equipment investment growth
- Structures investment growth: personal consumption of durables and gross private domestic investment that are not equipment
- GDP deflator
- Real interest rate: federal funds rates deflated by GDP deflator

Exogenous shocks

- Shock to the discount factor
- TFP shock: stationary TFP with deterministic trend
- Shock to the arrival of new technologies
- Shock to the price of structures investment
- Labor supply shock
- Government spending
- Monetary policy shock

Table2: Prior and Posterior Estimates of Structural Coefficients

Parameter	Prior Distribution	Posterior max	Posterior mean	5%	95%
υ	Beta (0.50,0.10)	0.502	0.565	0.104	0.952
ρ_r	Beta (0.65,0.10)	0.642	0.623	0.518	0.800
ξ	Beta (0.5,0.10)	0.565	0.557	0.366	0.758
ι_p	Beta (0.5,0.10)	0.488	0.487	0.280	0.694
ψ	Normal (1.00,0.50)	1.305	1.185	0.818	1.510
ϕ_p	Gamma (1.70,0.30)	1.707	1.944	1.226	2.746
ϕ_y	Gamma(0.125,0.10)	0.079	0.082	0.062	0.106
ζ	Gamma (1.20,0.10)	1.193	1.344	1.150	1.516
$\frac{\delta'' U}{\delta'}$	Gamma (0.10,0.10)	0.025	0.022	0.003	0.043

Table 3: Prior and Posterior Estimates of Shock Processes

Coefficient	Prior Distribution	Posterior max	Posterior mean	5%	95%
ρ_b	Beta (0.25 0.05)	0.235	0.230	0.185	0.284
ρ_m	Beta (0.25,0.05)	0.248	0.247	0.186	0.301
ρ_w	Beta (0.35,0.10)	0.346	0.349	0.331	0.364
ρ_{rd}	Beta (0.95,0.15)	1.000	0.999	0.999	0.999
ρ_g	Beta (0.6,0.15)	0.349	0.894	0.893	0.894
ρ_s	Beta (0.95,0.15)	1.000	0.999	0.999	0.999
σ_{rd}	IGamma(0.25, ∞)	0.285	0.292	0.255	0.337
σ_w	IGamma (0.25, ∞)	0.254	0.263	0.254	0.272
σ_g	IGamma (0.25, ∞)	0.252	0.267	0.248	0.287
σ_b	IGamma (0.25, ∞)	0.252	0.261	0.227	0.296
σ_m	IGamma (0.25 ∞)	0.251	0.268	0.191	0.352
σ_x	IGamma (0.25, ∞)	0.253	0.277	0.269	0.287
σ_s	IGamma (0.25, ∞)	0.306	0.206	0.164	0.245

Observable	Data	Endogenous	Exogenous	Benchmark
ΔY_t	0.50	0.63	0.78	1.18
ΔI_t^e	2.92	2.91	2.24	1.40
ΔI_t^s	2.80	2.77	2.18	2.00
ΔC_t	0.33	0.43	0.31	0.40
ΔL_t	0.66	0.60	0.30	0.66

Table 4: Standard deviations in data and alternative models

Specification	Log Marginal
Benchmark	1906
Exogenous Adoption	2092
Endogenous Adoption	2337

Table 5: Log-Marginal Density Comparison

Observ.	Gov.	Lab.Sup.	Int.Pref.	Innov.	Neutr.Tech.	Inves.	Mon.Pol.
ΔY_t	3.45	0.38	9.94	27.15	42.57	10.62	5.89
ΔI_t^e	0.07	0.08	0.74	49.36	35.15	13.67	0.93
ΔI_t^s	0.08	0.09	0.83	33.53	42.05	22.13	1.29
ΔC_t	0.16	1.70	19.38	18.05	40.03	9.43	11.25
ΔL_t	1.61	32.34	0.99	13.69	49.04	1.64	0.69
ΔQ_t	0.27	0.59	0.01	14.83	84.14	0.16	0.00

Table 6: Variance Decomposition

Observ.	Gov.	Lab.Sup.	Int.Pref.	Innov.	Neutr.Tech.	Inves.	Mon.Pol.
Y_t	1.45	0.21	3.84	32.29	34.24	24.78	3.19
I_t^e	0.07	0.06	0.62	35.52	38.00	24.03	1.71
I_t^s	0.08	0.07	0.72	36.92	39.93	20.64	1.65
C_t	0.31	3.61	16.91	15.93	25.60	24.31	13.33
L_t	2.09	35.87	0.75	20.06	29.16	11.24	0.84
Q_t	4.10	1.85	0.11	51.83	41.68	0.18	0.26

Table 7: Variance Decomposition (HP Filtered)

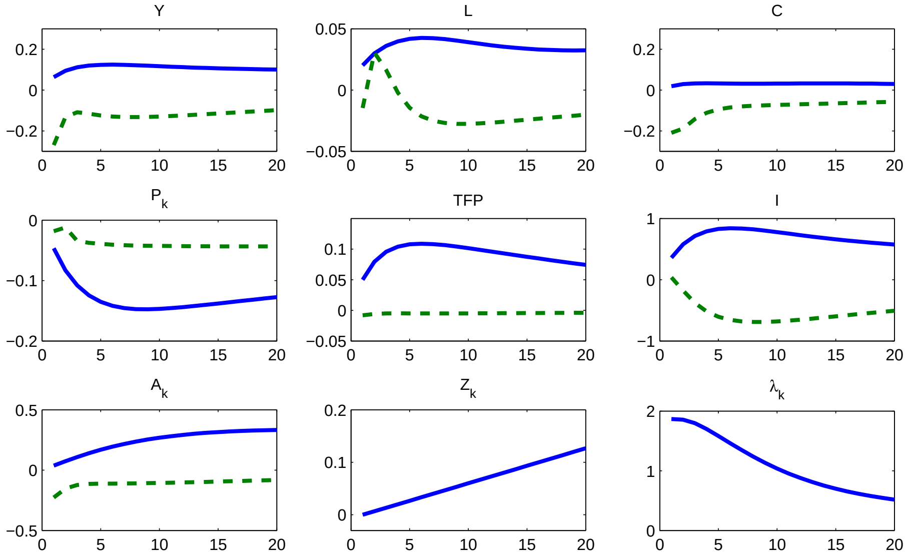

Figure 4: Estimated impulse responses to innovation shock, our model (solid) and model with entry and exogenous adoption (dashed).

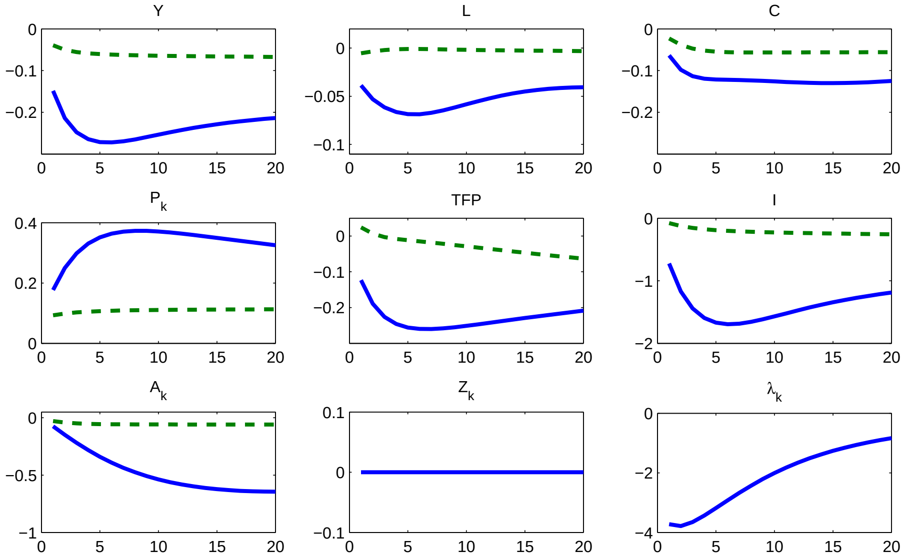

Figure 5: Estimated impulse responses to structures shock, our model (solid) and model with entry and exogenous adoption (dashed).

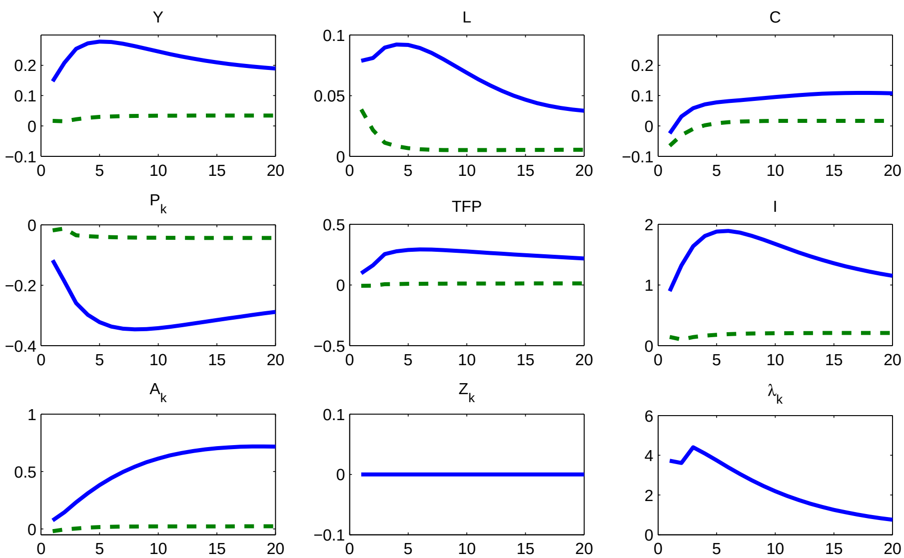

Figure 6: Estimated impulse responses to TFP shock, our model (solid) and model with entry and exogenous adoption (dashed).

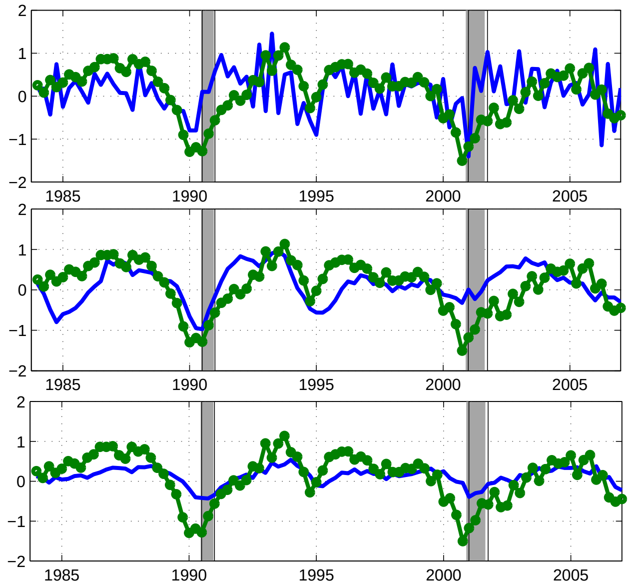

Figure 7: Historical decomposition of output growth. Data in dotted green and counterfactual in solid blue, for innovation shock (first panel), structures shock (second panel), and TFP shock (third panel)).

Stock Market

$$Q_t = \overbrace{P_t^{insk} K_t}^{\text{Replacement value of capital}} + \sum_{s=\{k,y\}} \overbrace{A_t^s (v_t^s - \pi_t^s)}^{\text{Value of adopted technologies}}$$

$$+ \sum_{s=\{k,y\}} \overbrace{(j_t^s + h_t^s)(Z_t^s - A_t^s)}^{\text{Value of existing not adopted technologies}}$$

$$+ E_t \left[\sum_{s=\{k,y\}} \overbrace{\sum_{\tau=t+1}^{\infty} \Lambda_\tau j_\tau^s (Z_\tau^s - \phi Z_{\tau-1}^s)}^{\text{Value of future non-adopted technologies}} \right]$$

$$P_t^k = \mu_K \theta \left(N_t^K \right)^{-(\mu_k - 1)} \left(A_t^k \right)^{-(\theta-1)}$$

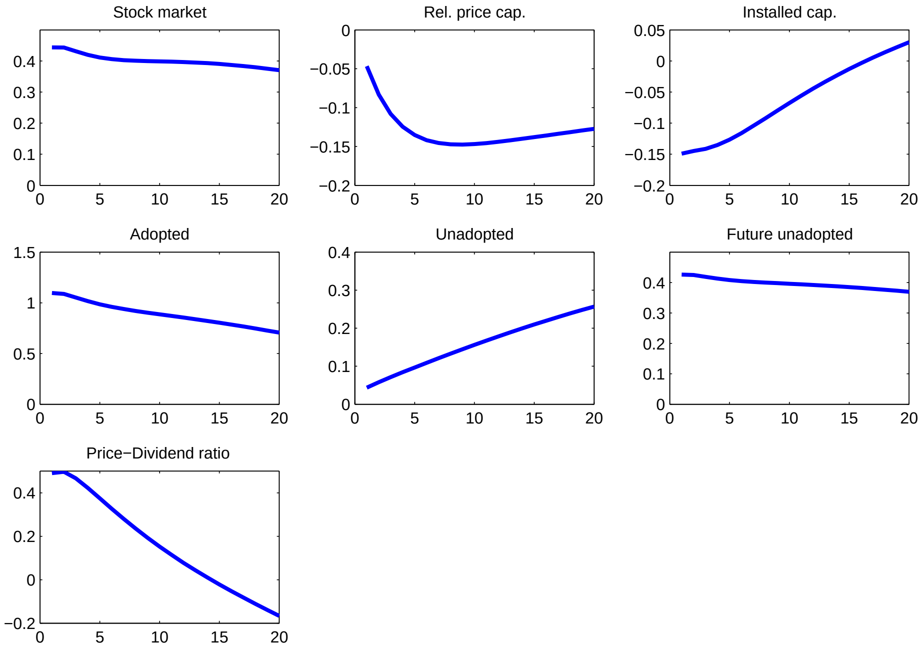

Figure 8: Impulse responses to innovation shock for stock market value and its components: installed capital (first row, third column), adopted technologies (second row, first column), unadopted technologies (second row, second column), and future unadopted technologies (second row, third column).

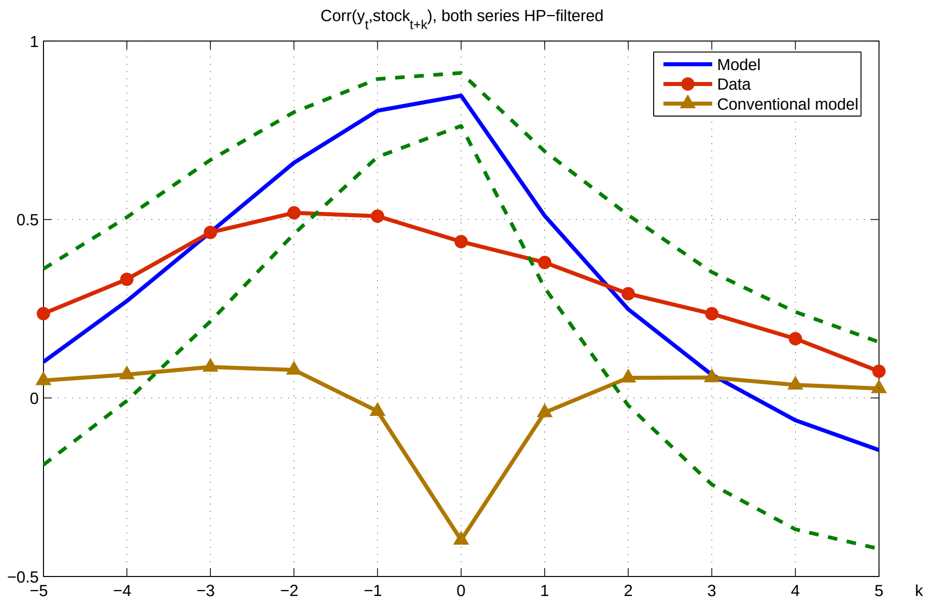

Figure 10: $Corr(y_t, stock_{t+k})$ in the data (first panel), our model (second panel), and conventional model (third panel).

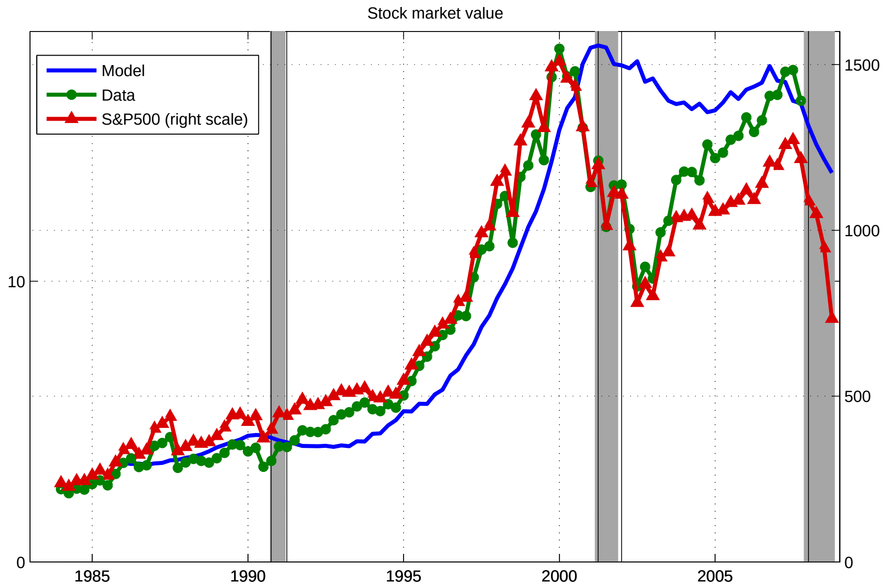

Figure 11: Stock market value in model (solid blue), data (dotted green) and S&P500 (triangled red, right axis).

	Volatility			Autocorrelation		
	Data[a]	Our Model	Conven. Model	Data	Our Model	Conven. Model
Growth rate stock market value	0.077			-0.04		
		0.052	0.021	(-0.25, 0.17)	0	-0.18
		(0.045, 0.059)	(0.018, 0.024)		(-0.2, 0.19)	(-0.35, -0.01)
Growth rate S&P500	0.077			-0.03		
				(-0.24, 0.17)		
HP-filtered stock market value	0.103			0.71		
		0.063	0.02	(0.53, 0.88)	0.67	0.45
		(0.049, 0.079)	(0.016,0.023)		(0.49,0.8)	(0.27, 0.6)
HP-filtered S&P500	0.107			0.76		
				(0.61, 0.91)		
Dividend growth (COMPUSTAT), s.a[b]	0.087			-0.56		
		0.0127	0.014	(-0.83, -0.29)	-0.36	-0.25
		(0.0107, 0.014)	(0.012, 0.016)		(-0.51, -0.2)	(-0.43, -0.06)
Profit growth (NIPA)	0.022			-0.24		
				(-0.67, 0.18)		
HP-filtered dividends (COMPUSTAT), s.a	0.072			0.29		
		0.0106	0.0134	(0.06, 0.52)	0.3	0.46
		(0.009, 0.0127)	(0.011, 0.016)		(0.04, 0.49)	(0.25, 0.64)
HP-filtered profits (NIPA)	0.022			0.53		
				(0.28, 0.82)		
Medium term[c] dividend growth (COMPUSTAT), s.a	0.011			0.99		
				(0.97,1)		
		0.0015	0.001		0.99	0.99
		(0.0006, 0.0027)	(0.0005,0.002)		(0.99,1)	(0.99,1)
Medium term profit growth (NIPA), s.a	0.0031			0.99		
				(0.97,1)		
(Log) capital share	0.025	0.041	0.03	0.83	0.93	0.39
		(0.019, 0.082)	(0.027,0.037)	(0.7,0.96)	(0.81,0.99)	(0.18,0.58)
Medium term (log) capital share	0.0186	0.03	0.01	0.99	0.99	0.99
		(0.0096, 0.063)	(0.027,0.037)	(0.97,1)	(0.99,1)	(0.99,1)

Table 8: Volatility of Stock Market variables

[a]In the stock market data, the period is 1984:I to 2008:II

[b]Seasonally Adjusted

[c]Medium term variables are computed by applying Band Pass filter that isolates fluctuations with periods between 8 and 50 years

Horizon (in quarters)	Data[a]	Model Historical series	Model simulated series
4	0.001	-0.0025	-0.0028
	(-0.0087, 0.0107)	(-0.008, 0.0029)	(-0.0288, 0.0154)
12	0.0034	-0.0037	-0.0484
	(-0.0174, 0.024)	(-0.015, 0.007)	(-0.1352, 0.0352)
20	0.0031	-0.004	-0.0985
	(-0.0194, 0.025)	(-0.02, 0.012)	(-0.2094, 0.0351)

[a]Coefficient reported is β from the following regression: $\sum_{\tau=1}^{T} \Delta c_{t+\tau} = \alpha + \beta x_t + \varepsilon_t$, where x_t is the price-dividend ratio and T is the horizon.

Table 9: Long-run predictability of consumption growth

Conclusions

- Importance of endogenous technology (adoption) to understand business cycle dynamics:
  - generates right co-movement
  - amplifies effect of shocks
  - provides appealing theory for relative price of capital and stock market
    - relative price of capital and the stock market move in opposite directions
    - price-dividend ratio is mean reverting
    - stock market leads output
    - and moves one order of magnitude more
    - model propagates identified shocks to generate a series for stock market that follows closely actual evolution of stocks
- News about future technologies can be a significant source of fluctuations once we recognize that technologies diffuse slowly and its speed of diffusion is endogenous.