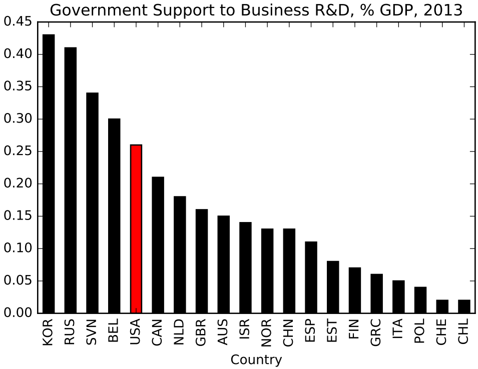
Growth and Welfare Implications of Sector-Specific Innovations

İlhan Güner
University of Virginia

November 6, 2016

U.S. Government Support to R&D

Total US government support to business R&D (tax relief and direct funding) was .26% of GDP (OECD, 2011)



Research Question

- How much should governments subsidize business R&D?

Agenda

- Develop an endogenous growth model with firm dynamics implications.
- Link firm dynamics with externalities.
- Identify magnitudes of externalities using observed US firm dynamics.
- Show sectors (consumption-goods, investment-goods) have different firm dynamics and hence externalities
- Characterize a sector dependent subsidy system that corrects these externalities
- Show short and long-run implications of these subsidies

Model

- Based on Klette and Kortum (2004)
- Time is continuous
- Two sectors: consumption goods producers, and investment goods producers
- Households own firms and capital.

Sectors

Consumption-goods:

$$C = \exp \int_0^1 \ln(q_i c_i) di$$

$$1 = P_c = \exp \int_0^1 \ln \frac{p_i}{q_i} di$$

Investment-sectors

$$X = \exp \int_0^1 \ln(q_j x_j) dj$$

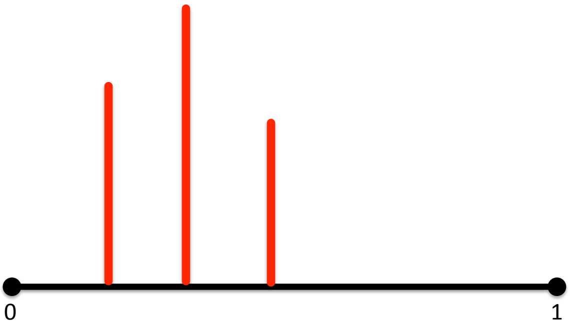
$$P_x = \exp \int_0^1 \ln \frac{p_j}{q_j} dj$$

Households

$$\max \int_0^\infty \exp(-\rho t) \ln C(t) dt \qquad \text{s.t.}$$

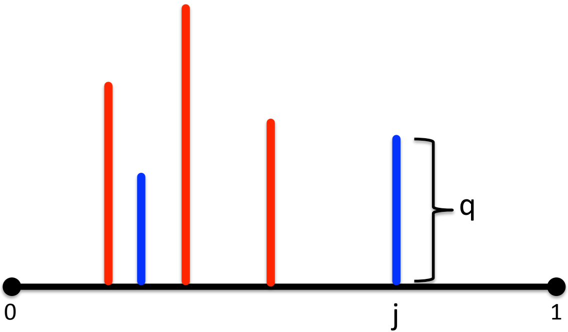
$$\begin{aligned} \dot{K} &= X - \delta K, \\ C + (1 - s_{in}) P_x X + \dot{A} &= RA + wL + rK - T \end{aligned}$$

Firm and Innovation



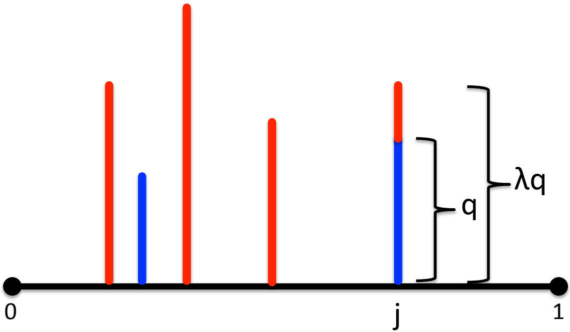
- A firm is defined by the set of goods it produces
- Hiring $\phi(b)$ researchers leads to b Poisson innovation arrival rate per good

Firm and Innovation



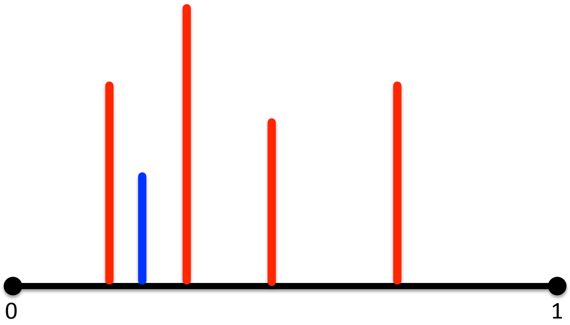
- Innovated good is chosen randomly.

Firm and Innovation



- Increase quality by $\lambda > 1$, innovative step.
- Innovative step is sector dependent.

Firm and Innovation



- Red firm expanded, blue firm shrank.

Product Line Profit

- Bertrand competition $\Rightarrow$
  (Price) $=$ (Innovative Step) $\times$ (Marginal Cost) $\Rightarrow$
  Same price across goods
- Symmetric equilibrium $\Rightarrow$ Same demand
- Same profit across goods in a sector

Incumbents

b_j: innovation intensity a firm chooses
τ_j: equilibrium innovation rate in the market
s_j^i: rate of subsidy to incumbents

$$
\begin{aligned}
\underbrace{RV(n, E_j)}_{\text{Return on the firm}} = \max_{b_j \geq 0} \Big\{ & \underbrace{n\pi(E_j)}_{\text{Profit}} - \underbrace{(1 - s_j^i) n \phi_j(b_j) w}_{\text{R\&D cost}} \\
& + \underbrace{n b_j [V(n+1, E_j) - V(n, E_j)]}_{\Delta V \text{ by successful innovation}} \\
& + \underbrace{n \tau_j [V(n-1, E_j) - V(n, E_j)]}_{\Delta V \text{ by innovation by others}} \\
& + \underbrace{\frac{\partial V(n, E_j)}{\partial E_j} \dot{E}_j}_{\Delta V \text{ by economic growth}} \Big\},
\end{aligned}
$$

where $\phi_j(b_j) = \chi_j b_j^\gamma$ is the research labor, $i = c, x$, $E_j = C, P_x X$.

Entrants

$$\underbrace{RV_E}_{\text{Return on entry}} = \max_{z_j \geq 0}\{-\underbrace{(1-s_j^e)wz_jf_j(\tilde{z}_j)}_{\text{Cost of Entry}} + \underbrace{z_j[V(1,E_j)-V_E]}_{\Delta V \text{ by entry}}\},$$

where $f_j(\tilde{z}_j) = \psi_j \chi_j \tilde{z}_j^{\gamma-1}$.

Free entry $\Rightarrow V_E = 0$

Parametrization

A length one unit of time corresponds to a year.

α, δ, ρ, γ, s_c^i and s_x^i are calibrated to match

- .33 elasticity of output w.r.t. capital (α)
- .05 annual depreciation rate [KLEMS, US] (δ),
- .97 annual discount factor (ρ),
- .675 elasticity of R&D with respect to user cost [Bloom et al. (2002)] (γ),
- 20% R&D subsidy rate [Bloom et al. (2002)] (s_c^i, s_x^i).

Targets

Model	Variable	Data
Entrant innovation rates	z_c and z_x	Job creation rate by entering establishments
Incumbent innovation rates	b_c and b_x	Job creation rate by expanding establishments
Consumption growth rate	g_C	Average annual consumption growth rate
Growth rate of investment good price	g_{P_x}	Average annual growth rate of relative investment good prices

Calibration

	Parameter	Value
Quality ladder step size, investment	λ_x	1.23
Quality ladder step size, consumption	λ_c	1.04
R&D cost function parameter, investment	χ_x	10.93
R&D cost function parameter, consumption	χ_c	5.73
Entry cost function parameter, investment	ψ_x	6.75
Entry cost function parameter, consumption	ψ_c	4.30

Calibration

	Variable	Data	Model
Entrant innovation rate, consumption	z_c	.06	.06
Entrant innovation rate, investment	z_x	.04	.04
Incumbent innovation rate, consumption	b_c	.10	.10
Incumbent innovation rate, investment	b_x	.09	.09
Consumption growth rate	g_C	.02	.02
Investment good price growth rate	g_{P_x}	-.02	-.02

Identification

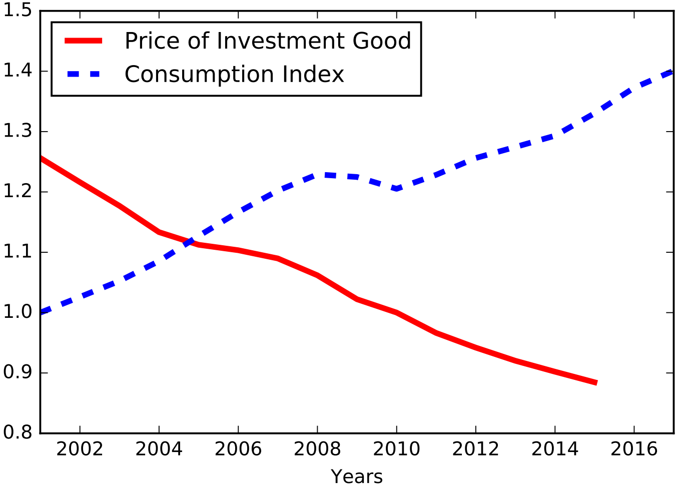
- Innovative steps, λ_c and λ_x, are identified by

$$\begin{aligned} g_C &= \tau_c \ln \lambda_c + \frac{\alpha}{1-\alpha} \tau_x \ln \lambda_x, \text{ and} \\ g_{P_x} &= \tau_c \ln \lambda_c - \tau_x \ln \lambda_x, \end{aligned}$$

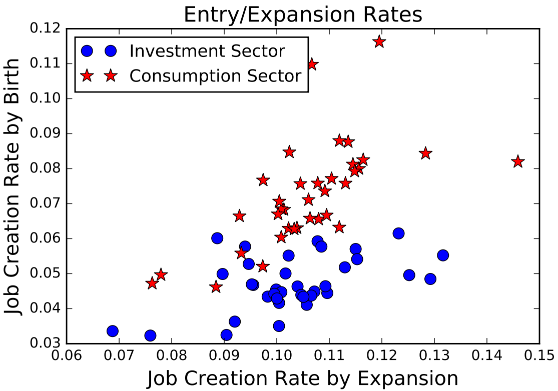
  where τ_c, τ_x are innovation rates in consumption-goods and investment-goods sectors.

  $\tau_c \ln \lambda_c$: growth rate of average quality of consumption goods.
  $\tau_x \ln \lambda_x$: growth rate of average quality of investment goods.

Identification



Entry/Expansion Rates



- Relative costs of entry, ψ_c and ψ_x, are identified by entry, incumbent innovation ratio.

Industry Classification

Social Planner

Maximizes discounted sum of household utility, by choosing

production, factor demands, and innovation rates of incumbents and entrants in each sector

subject to technology constraints (including innovation functions) and resource constrains.

Socially Optimal Level of Innovation

Competitive equilibrium is not socially optimal because of firms

- cannot appropriate all the consumer surplus they created (appropriability, $-$),

Socially Optimal Level of Innovation

Competitive equilibrium is not socially optimal because of firms

- cannot appropriate all the consumer surplus they created (appropriability, –),
- generate spillovers to successive innovators (inter-temporal spillover, –), related to entry rate

Socially Optimal Level of Innovation

Competitive equilibrium is not socially optimal because of firms

- cannot appropriate all the consumer surplus they created (appropriability, $-$),
- generate spillovers to successive innovators (inter-temporal spillover, $-$), related to entry rate
- do not take into account the profit loss they impose on the previous innovator (business stealing, $+$), related to growth rate of relative price of investment goods

Socially Optimal Level of Innovation

Competitive equilibrium is not socially optimal because of firms

- cannot appropriate all the consumer surplus they created (appropriability, $-$),
- generate spillovers to successive innovators (inter-temporal spillover, $-$), related to entry rate
- do not take into account the profit loss they impose on the previous innovator (business stealing, $+$), related to growth rate of relative price of investment goods
- monopoly distortion of prices ($+$),

Socially Optimal Level of Innovation

Competitive equilibrium is not socially optimal because of firms

- cannot appropriate all the consumer surplus they created (appropriability, $-$),
- generate spillovers to successive innovators (inter-temporal spillover, $-$), related to entry rate
- do not take into account the profit loss they impose on the previous innovator (business stealing, $+$), related to growth rate of relative price of investment goods
- monopoly distortion of prices ($+$),
- monopoly pricing distortion in the capital Euler equation (Under accumulation of capital), related to innovative step of investment sector

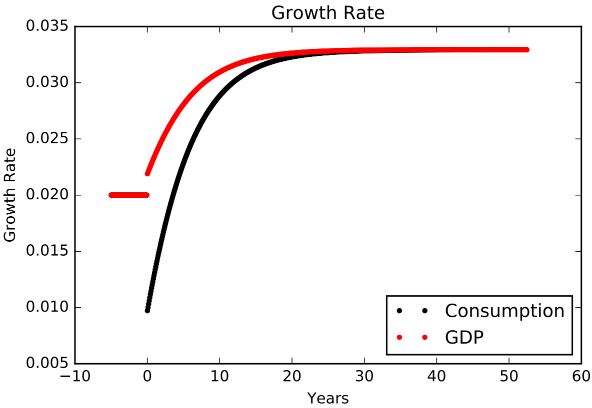
Socially Optimal Level of Innovation

Competitive equilibrium is not socially optimal because of firms

- cannot appropriate all the consumer surplus they created (appropriability, −),
- generate spillovers to successive innovators (inter-temporal spillover, −), related to entry rate
- do not take into account the profit loss they impose on the previous innovator (business stealing, +), related to growth rate of relative price of investment goods
- monopoly distortion of prices (+),
- monopoly pricing distortion in the capital Euler equation (Under accumulation of capital), related to innovative step of investment sector
- externality in entry (Higher than optimal entry).

Details

Social Planner



15% welfare gain in consumption equivalent terms.

Decentralization

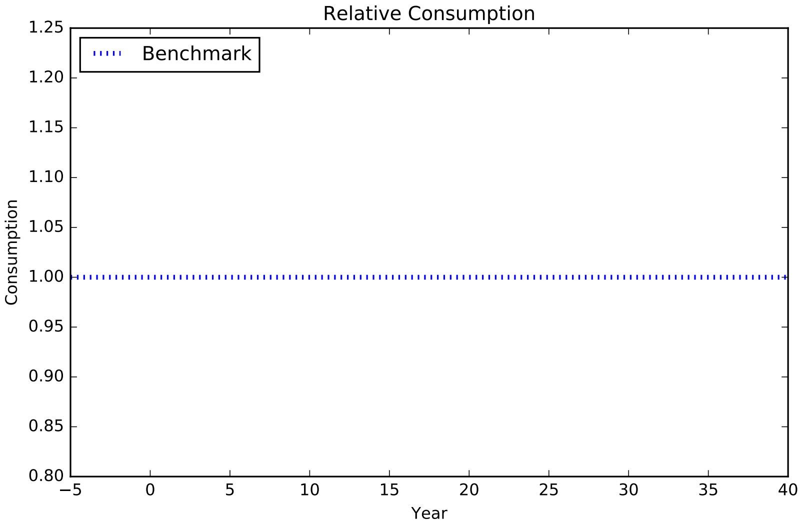
Social planner can be closely approximated by constant subsidies:

- incumbent R&D subsidy to consumption sector $= 82\%$
- incumbent R&D subsidy to investment sector $= 78\%$
- entry subsidy to consumption sector $= 55\%$
- entry subsidy to investment sector $= 45\%$
- capital investment subsidy (or output subsidy) $= 19\%$

15% welfare gain, slightly less than social planner.

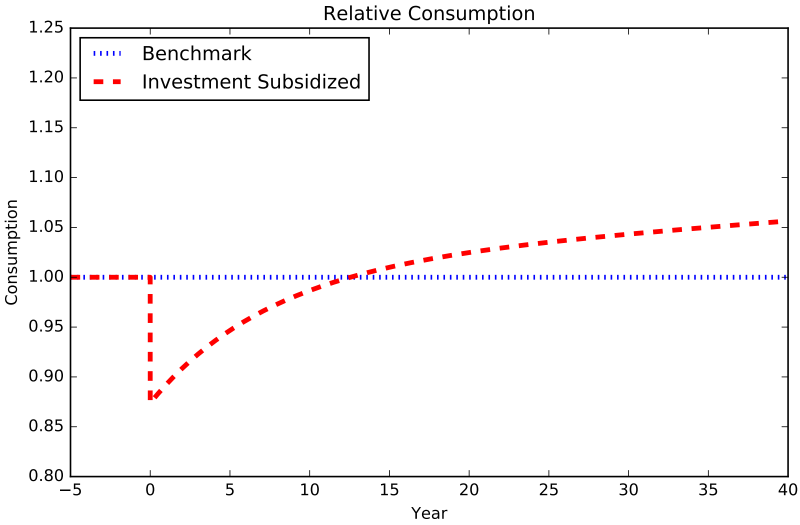
Details

Transition



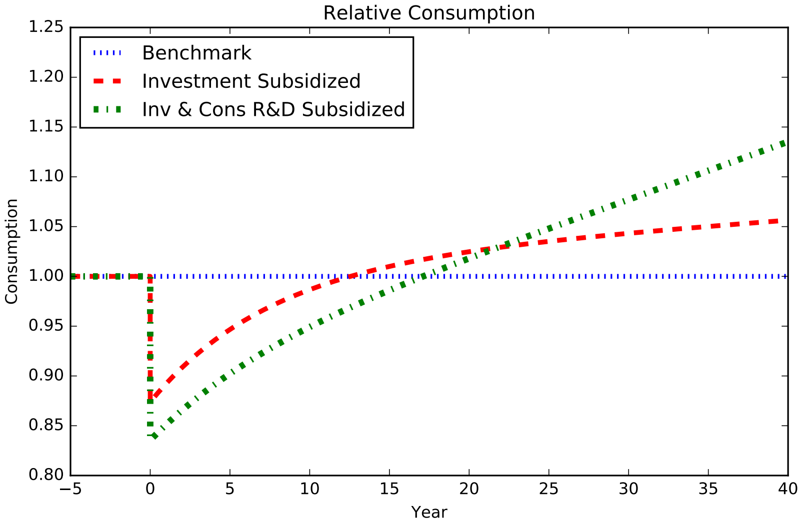
Relative Consumption
Benchmark
Consumption
Year
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
−5
0
5
10
15
20
25
30
35
40

Transition



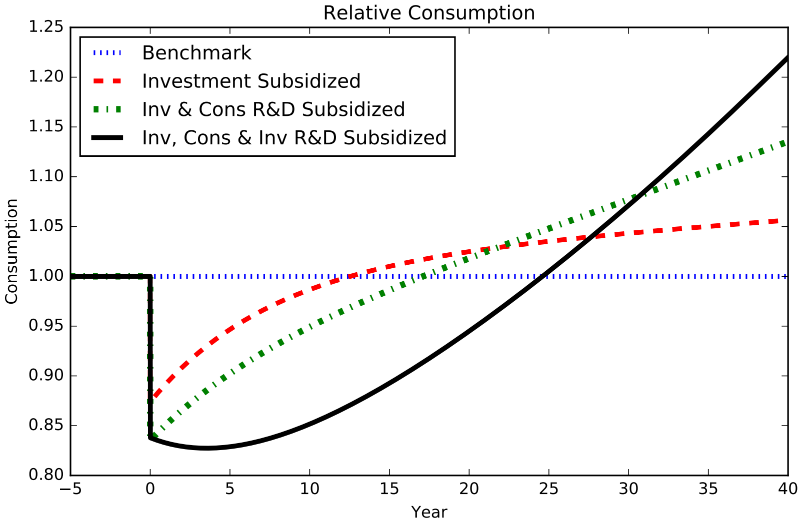
Relative Consumption
Benchmark
Investment Subsidized
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
Consumption
−5
0
5
10
15
20
25
30
35
40
Year

Transition



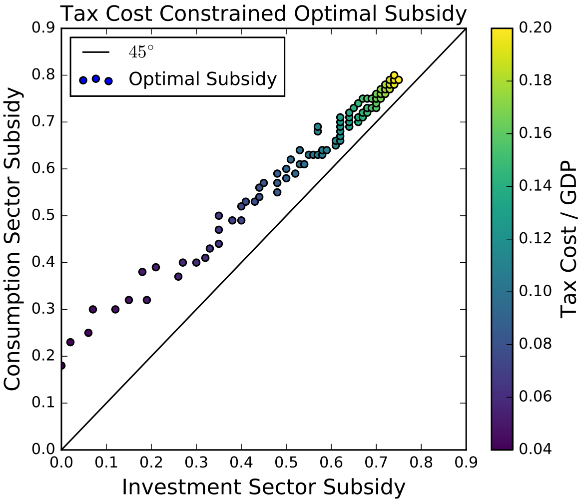
Relative Consumption
Benchmark
Investment Subsidized
Inv & Cons R&D Subsidized
Consumption
Year
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
−5
0
5
10
15
20
25
30
35
40

Transition

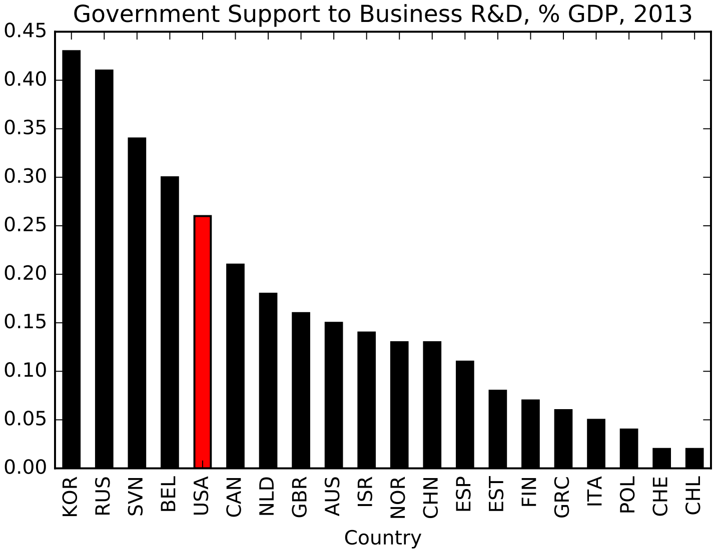


Relative Consumption
Benchmark
Investment Subsidized
Inv & Cons R&D Subsidized
Inv, Cons & Inv R&D Subsidized
Consumption
Year
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
−5
0
5
10
15
20
25
30
35
40

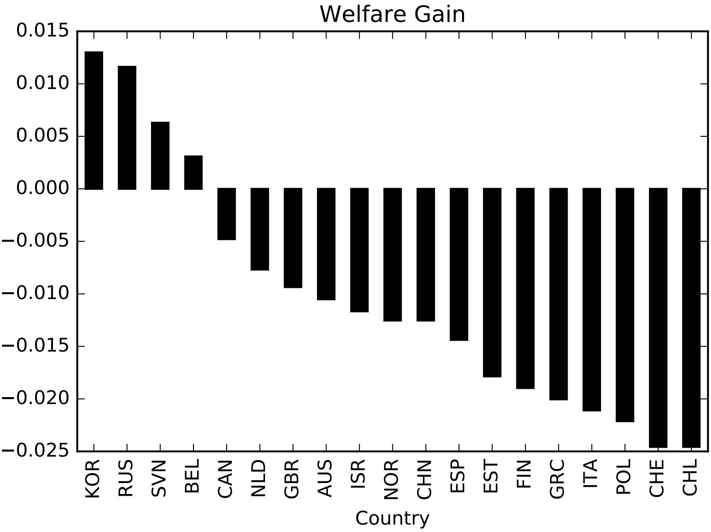
Subsidy Cost



Counterfactuals



Counterfactuals



Conclusion

- Roughly 80 percent subsidy to R&D
- High entry implies high inter-temporal spillover
- Subsidy increases inter-temporal spillover
- Not easily implementable: high tax cost, reduction in consumption in the short and medium run.

Thank You!

Related Literature

- **Endogenous firm dynamics** [Klette and Kortum (2004), Aghion and Howitt (1992), Grossman Helpman (1991), Lentz and Mortensen (2008, 2015), Akcigit and Kerr (2015), Acemoglu et al. (2013), Atkeson and Burstein (2015), Garcia-Marcea et al. (2015)]:
  add capital stock and investment specific innovation
- **Investment specific technological change** [Krusell (1998), Sakellaris and Wilson (2004)]:
  add firm dynamics, link the model to data directly

Contribution to Growth

$$g_C = \tau_c \ln \lambda_c + \frac{\alpha}{1-\alpha} \tau_x \ln \lambda_x$$

$$g_C = (z_c + b_c) \ln \lambda_c + \frac{\alpha}{1-\alpha} (z_x + b_x) \ln \lambda_x$$

$$g_C = \underbrace{z_c \ln \lambda_c}_{\substack{\text{Consumption} \\ \text{Entrants}}} + \underbrace{b_c \ln \lambda_c}_{\substack{\text{Consumption} \\ \text{Incumbents}}} + \underbrace{\frac{\alpha}{1-\alpha} z_x \ln \lambda_x}_{\substack{\text{Investment} \\ \text{Entrants}}} + \underbrace{\frac{\alpha}{1-\alpha} b_x \ln \lambda_x}_{\substack{\text{Investment} \\ \text{Incumbents}}}$$

	Consumption	Investment	Total
Entrant	13%	20%	33%
Incumbent	21%	46%	67%
Total	34%	66%	

Under Investment in Innovation

	Market Economy	Social Planner
g_C	0.020	0.033
τ_c	0.160	0.252
τ_x	0.130	0.219

- Under investment in innovation
- Social planner growth rate is higher than market economy rate

Subsidy System

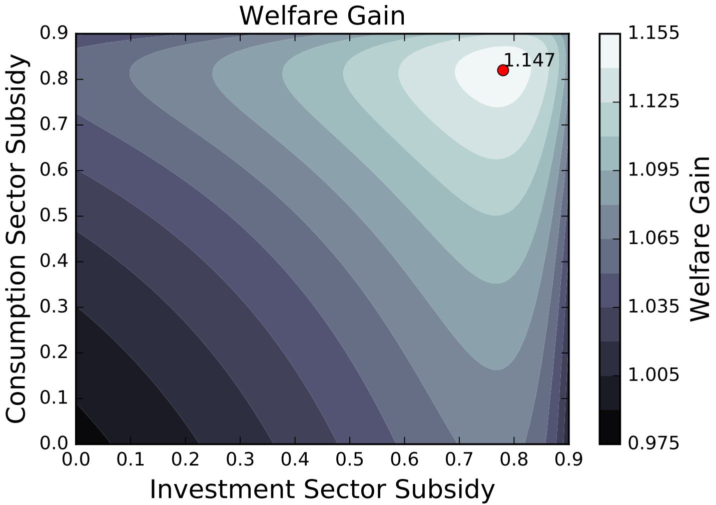
- Capital investment subsidy, $s_{in} = 1 - 1/\lambda_x$:

$$\frac{1}{\lambda_x} \alpha K_x^{\alpha-1} L_x^{1-\alpha} Q_x = (1 - s_{in}) \left(\frac{1}{1-\alpha} \tau_x \ln \lambda_x + \delta + \rho \right)$$

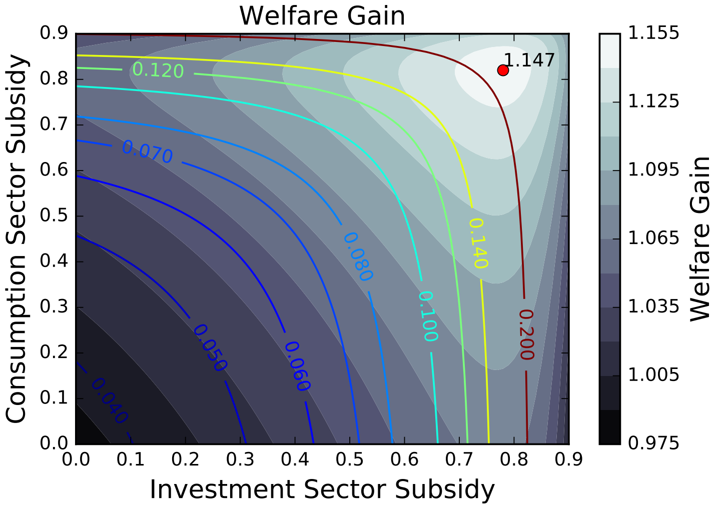
- Entry subsidy/tax, $s_j^e = 1 - \gamma(1 - s_j^i), \quad j = c, x$:

$$(1 - s_j^e) \psi z^{\gamma-1} = (1 - s_j^i) \gamma b^{\gamma-1}$$

R&D Subsidies



R&D Subsidies



Technology Indices

$$
\begin{aligned}
C &= \exp\left(\int_0^1 \ln k_c^{\alpha} l_c^{1-\alpha} q_i d_i\right)\\
C &= k_c^{\alpha} l_c^{1-\alpha} \exp\left(\int_0^1 \ln q_i d_i\right)\\
C &= k_c^{\alpha} l_c^{1-\alpha} Q_c,
\end{aligned}
$$

where Q_c is the average quality in consumption sector.

Technology Indices

$$
\begin{aligned}
C &= \exp\left(\int_0^1 \ln k_c^\alpha l_c^{1-\alpha} q_i d_i\right) \\
C &= k_c^\alpha l_c^{1-\alpha} \exp\left(\int_0^1 \ln q_i d_i\right) \\
C &= k_c^\alpha l_c^{1-\alpha} Q_c,
\end{aligned}
$$

where Q_c is the average quality in consumption sector.

Similarly, $X = k_x^\alpha l_x^{1-\alpha} Q_x$, where Q_x is the average quality in investment sector.

Growth Rate

Poisson innovation arrival rate + Law of large numbers $\Rightarrow$

$$\frac{\dot{Q}_c}{Q_c} = \tau_c \ln \lambda_c$$
$$\frac{\dot{Q}_x}{Q_x} = \tau_x \ln \lambda_x$$

Technological progress is the source of macroeconomic growth.

Industry Classification

- Consumption-type:
  - Retail trade, except of motor vehicles and motorcycles; repair of household goods
  - Hotels and restaurants
  - Finance, insurance, real estate and business services
  - Community social and personal services
- Investment-type:
  - Mining and quarrying
  - Manufacturing
  - Electricity, gas and water supply
  - Construction
  - Wholesale trade and commission trade, except of motor vehicles and motorcycles
  - Transport and storage and communication

Social Planner

- Maximizes sum of discounted utility
- by choosing entrant and incumbent innovation rates over time $\{z_{c,t}, z_{x,t}, b_{c,t}, b_{x,t}\}$
- consumption, investment,capital and labor allocation over time $\{C_t, X_t, K_{c,t}, K_{x,t}, L_{c,t}, L_{x,t}\}$
- subject to resource constraints and technological constraints: $\dot{Q}_j/Q_j = \tau_j \ln \lambda_j$, $j = c, x$
- Notation: $F(K_j, L_j, Q_j) = K_j^{\alpha} L_j^{1-\alpha} Q_j$, $j = c, x$

Optimality

Using the terminology of Aghion and Howitt (1992):

Market Economy **Social Planner**

$$\phi'(b)w = \frac{1(\pi - \phi(b)w)}{\rho + \tau - b}, \quad \phi'(b)F_L(K, L, Q) = \frac{\ln(\lambda)F(K, L, Q)}{\rho}$$

Optimality

Market Economy **Social Planner**

$$\phi'(b)w = \frac{1(\pi - \phi(b)w)}{\rho + \tau - b}, \quad \phi'(b)F_L(K, L, Q) = \frac{\ln(\lambda)F(K, L, Q)}{\rho}$$

- Appropriability
- Business stealing
- Intertemporal spillover
- Monopoly distortion

Optimality

Market Economy **Social Planner**

$$\phi'(b)w = \frac{1(\pi - \phi(b)w)}{\rho + \tau - b}, \quad \phi'(b)F_L(K, L, Q) = \frac{\ln(\lambda)F(K, L, Q)}{\rho}$$

- Appropriability
- Business stealing
- Intertemporal spillover
- Monopoly distortion

Optimality

Market Economy **Social Planner**

$$\phi'(b)w = \frac{1(\pi - \phi(b)w)}{\rho + \tau - b}, \quad \phi'(b)F_L(K, L, Q) = \frac{\ln(\lambda)F(K, L, Q)}{\rho}$$

- Appropriability
- Business stealing
- Intertemporal spillover
- Monopoly distortion

Optimality

Market Economy **Social Planner**

$$\phi'(b)w = \frac{1(\pi - \phi(b)w)}{\rho + \tau - b}, \quad \phi'(b)F_L(K, L, Q) = \frac{\ln(\lambda)F(K, L, Q)}{\rho}$$

- Appropriability
- Business stealing
- Intertemporal spillover
- Monopoly distortion

Optimality (Ctn'd)

Social Planner:

$$\alpha K_x^{\alpha-1} L_x^{1-\alpha} Q_x = \frac{1}{1-\alpha} \tau_x \ln \lambda_x + \delta + \rho$$

Market Economy:

$$\frac{1}{\lambda_x} \alpha K_x^{\alpha-1} L_x^{1-\alpha} Q_x = \frac{1}{1-\alpha} \tau_x \ln \lambda_x + \delta + \rho$$

Optimality (Ctn'd)

Social Planner:

$$\gamma\psi z^{\gamma-1} = \gamma b^{\gamma-1}$$

Market Economy:

$$\psi z^{\gamma-1} = \gamma b^{\gamma-1}$$

Back

Consumption Equivalent Welfare Change

Sum of the discounted utility flows at the balanced growth path:

$$W(C_0, g_C) \equiv \frac{1}{\rho}\left(\ln C_0 + \frac{g_C}{\rho}\right)$$

Consumption path after a permanent change in subsidy system:

$$\{C_t^s\}$$

Consumption equivalent welfare change, ξ:

$$W(\xi C_0, g_C) = \int_0^\infty \exp(-\rho t) \ln(C_t^s) dt.$$

Back

$$
\begin{aligned}
&\frac{\ln \lambda_c}{\rho} = \frac{c'(\tau_c)(1-\alpha)}{L_c} \\
&\frac{\ln \lambda_x}{\rho} = \frac{c'(\tau_x)(1-\alpha)}{L_x} \\
&-\delta + \alpha K_x^{\alpha-1} L_x^{1-\alpha} Q_x = \rho + \frac{1}{1-\alpha}\tau_x \ln \lambda_x \\
&\frac{1-\alpha}{\alpha}\frac{K_x}{L_x} = \frac{1-\alpha}{\alpha}\frac{K_c}{L_c} \\
&1 = L_c + L_x + c(\tau_c) + c(\tau_x) \\
&\frac{K_x^{\alpha} L_x^{1-\alpha} Q_x}{K_c + K_x} - \delta = \frac{1}{1-\alpha}\tau_x \ln \lambda_x
\end{aligned}
$$

Differentials

$$\dot{C} = C\left(R - \rho - \tau_N \log \lambda_N - \frac{\alpha}{1-\alpha}\tau_D \log \lambda_D\right)$$

$$\dot{K} = D - K\left(\delta + \frac{1}{1-\alpha}\tau_D \log \lambda_D\right)$$

$$\dot{A} = w + rK + RA - P_D D - C - T - A\left(\tau_N \log \lambda_N + \frac{\alpha}{1-\alpha}\tau_D \log \lambda_D\right)$$

$$\begin{aligned}\dot{V}_N = {} & \left(R - \tau_N \log \lambda_N - \frac{\alpha}{1-\alpha}\tau_D \log \lambda_D + z_N\right) V_N \\ & - wL_N \left(\frac{\lambda_N - 1}{1-\alpha}\right) + w(1 - s_N^i)\chi_N b_N^{1/1-\gamma}\end{aligned}$$

$$\begin{aligned}\dot{V}_D = {} & \left(R - \tau_N \log \lambda_N - \frac{\alpha}{1-\alpha}\tau_D \log \lambda_D + z_D\right) V_D \\ & - wL_D \left(\frac{\lambda_D - 1}{1-\alpha}\right) + w(1 - s_N^i)\chi_D b_D^{1/1-\gamma}\end{aligned}$$

Controls

$$C = \frac{wL_N}{1-\alpha}$$

$$D = \frac{wL_D}{1-\alpha}$$

$$1 = \frac{\lambda_N r^\alpha w^{1-\alpha}}{\alpha}$$

$$\frac{r}{1-s_x} = \left(R + \delta - (z_N + b_N)\log\lambda_N + \frac{1-\alpha}{1-\alpha}(z_D + b_D)\log\lambda_D\right)\frac{\lambda_D}{\lambda_N}$$

$$rK = w\frac{\alpha}{1-\alpha}\left(L_N + L_D\right)$$

$$L_N + L_D + \chi_D b_D^{1/1-\gamma} + \chi_N b_N^{1/1-\gamma} + \chi_D\psi_D z_D^{1/1-\gamma} + \chi_N\psi_N z_N^{1/1-\gamma} = 1$$

Controls

$$
\begin{aligned}
&(1-s^e_N)\psi_N z_N^{\gamma/1-\gamma} = (1-s^i_N)\frac{1}{1-\gamma} b_N^{\gamma/1-\gamma}\\
&(1-s^e_D)\psi_D z_D^{\gamma/1-\gamma} = (1-s^i_D)\frac{1}{1-\gamma} b_D^{\gamma/1-\gamma}\\
&V_N = w(1-s^e_N)\psi_N \chi_N z_N^{\gamma/1-\gamma}\\
&V_D = w(1-s^e_D)\psi_D \chi_D z_D^{\gamma/1-\gamma}\\
&T = w\left(s^i_N \frac{1}{1-\gamma}\chi_N b_N^{\gamma/1-\gamma} + s^i_D \frac{1}{1-\gamma}\chi_D b_D^{\gamma/1-\gamma}\right)\\
&\qquad\qquad + w\left(s^e_N \psi_N \chi_N Z_N^{\gamma/1-\gamma} + s^e_D \psi_D \chi_D Z_D^{\gamma/1-\gamma}\right)
\end{aligned}
$$

Social Planner

$$\min_{z,b} \psi\chi z^{1/1-\gamma} + \chi b^{1/1-\gamma}$$

subject to

$$z + b = \tau$$

Resulting cost function is

$$\begin{aligned}
\tilde{c}(\tau) &= \frac{\psi\chi\tau^{1/1-\gamma}}{\left(1+\psi^{1-\gamma/\gamma}\right)^{\gamma/1-\gamma}} \\
c(\tau_c,\tau_x) &= \frac{\psi_c\chi_c\tau_c^{1/1-\gamma}}{\left(1+\psi_c^{1-\gamma/\gamma}\right)^{\gamma/1-\gamma}} + \frac{\psi_x\chi_x\tau_x^{1/1-\gamma}}{\left(1+\psi_x^{1-\gamma/\gamma}\right)^{\gamma/1-\gamma}}
\end{aligned}$$

Social Planner (Ctn'd)

$$\max \int_0^\infty e^{-\rho t} K_{c,t}^\alpha L_{c,t}^{1-\alpha} Q_{c,t} dt$$

subject to

$$\dot{K}_t = K_{x,t}^\alpha L_{x,t}^{1-\alpha} Q_{x,t} - \delta K$$

$$L_{c,t} + L_{x,t} + c(\tau_{c,t}, \tau_{x,t}) \leq 1$$

$$\frac{\dot{Q}_{c,t}}{Q_{c,t}} = \tau_{c,t} \log \lambda_c$$

$$\frac{\dot{Q}_{x,t}}{Q_{x,t}} = \tau_{x,t} \log \lambda_x$$

R&D Subsidies (Incumbents Only)