

# A Model of Productivity Growth through Creative Destruction by Employee Spinouts

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# Introduction

- ▶ A **spinout** of a firm is a competing firm founded by a previous employee of the original firm
  - ▶ E.g. Fairchild semiconductor spinouts form basis of SV [detail](#)
  - ▶ NOT a *spinoff*, which refers to a subsidiary of a company which is broken off from the balance sheet
- ▶ **This presentation:** Discuss a candidate model of long-run productivity growth which brings to the fore **creative destruction by employee spinouts**.
  - ▶ Adapt the Grossman-Helpman 1991 quality ladders framework to endogenize mass of potential entrants

# Empirical motivation

- ▶ Technological innovation is major source of long-run growth in labor productivity
- ▶ Entry contributes substantially to tech innovation, e.g.:
  - ▶ Empirical decomposition: net job creation higher for young firms
  - ▶ Productivity growth due to entry: over 10-year horizon, 25% of labor productivity growth accounted by entry in manufacturing (Baily-Bartelsman-Haltiwanger 1996)
  - ▶ Decomposition based on model-based extrapolation from patent citation counts: 25% of aggregate productivity growth due to entrants (Akcigit & Kerr 2017)
- ▶ Employee spinouts comprise an important, influential subset of entrants
  - ▶ e.g. Fairchild semiconductor spawned Silicon Valley; earlier, Detroit automakers
  - ▶ In Brazil, employee spinouts account for between 15-30% of entrants; substantially larger, grow faster, fail less frequently (Muendler et al. 2012)

# Theory: big picture

- ▶ Schumpeter 1942, Arrow 1962, etc.: if knowledge is only partially excludable, it will be underproduced in equilibrium because no private benefit to agent incurring costs of production
- ▶ Intellectual property laws (e.g. patents, copyright, etc.) render knowledge excludable
- ▶ Patent literature: optimal level of excludability? Dynamic efficiency vs. static monopoly distortion tradeoff (Nordhaus 1967, etc.)
- ▶ Employee learning and creative destruction by spinout formation implies similar tradeoff

# Theoretical motivation

- ▶ Models of endogenous technological innovation and productivity growth assume knowledge immediately spills over to potential competing entrants
  - ▶ Grossman & Helpman 1991
  - ▶ Akcigit & Kerr 2017
  - ▶ Acemoglu & Cao 2015
- ▶ Models of spinouts are typically partial equilibrium and not focused on long-run growth or creative destruction
  - ▶ Klepper & Sleeper 2005 - very partial equilibrium
  - ▶ Franco & Filson 2006 - no creative destruction (Pareto efficient)
  - ▶ Franco & Mitchell 2008 -
  - ▶ Rauch 2015 - partial equilibrium, no growth or innovation
  - ▶ Rossi-Hansberg & Chatterjee 2012 - no creative destruction

# Model overview

- ▶ Time  $t$  is continuous
- ▶ Agents:
  - ▶ Households
  - ▶ Intermediate goods firms
  - ▶ Final goods firm

# Model overview

- ▶ Builds on standard quality ladders model (Grossman & Helpman 1991)
- ▶ Endogenous productivity growth through improved quality of intermediate goods
- ▶ Quality improvements result from labor allocated to R&D
- ▶ Creative destruction
- ▶ **New ingredient:** R&D workers learn on the job how to form competing spinouts

## Model: Intermediate goods production

- ▶ Standard quality ladders model, step size  $\lambda > 1$
- ▶ Continuum of intermediate goods, indexed by  $j \in J = [0, 1]$
- ▶ Frontier quality of good  $j$  by  $q_j$
- ▶  $x_j$  is amount produced
- ▶ Each good produced with technology

$$x_j = \bar{q} l_j$$

where  $\bar{q} = \int_0^1 q_j dj$  is the average quality level of the economy

- ▶ Each good  $j$  has monopolist, standard assumptions to guarantee no limit pricing
- ▶ Demand (final goods production) CES across goods  $j$  implies constant markup



## Model: R&D race

At time  $t$  with average quality  $\bar{q}_t$ , incumbent in the R&D race for good  $j$  of quality  $q_j$  begins with monopoly on good  $j$  R&D



Hires R&D labor; at rate  $\nu(q_j/\bar{q}_t)^{-1}$  per unit of R&D labor hired, employees learn, adding to mass of potential entrants (**scaling factor**  $(q_j/\bar{q}_t)^{-1}$  **for BGP**))



At some point, either an incumbent or an entrant firm wins the race, and obtains a monopoly on production and R&D on good  $j$  of quality  $\lambda q_j$

# Model: R&D technology

- ▶ Consider an intermediate  $j$  with relative quality  $\tilde{q} = q/\bar{q}$
- ▶ **Scaling assumption for BGP:** flow cost of  $\tilde{q}z$  units of labor yields  $z$  units of effective labor
- ▶  $z, \hat{z}$  units of R&D effort by incumbent and entrant respectively yields victory in the R&D race at Poisson rate

$$R(z) = \chi z \phi(z)$$

$$\hat{R}(\hat{z}; \bar{z}) = \hat{\chi} \hat{z} \eta(\bar{z})$$

where  $\bar{z} = \int_0^m \hat{z}(m') dm'$  is total good- $j$  R&D effort by entrants.

- ▶ Entrant  $m'$  can perform  $\hat{z} \leq \xi$  units of R&D effort (equilibrium does not pin down; look for equilibria where  $\hat{z}(m') \in \{0, \xi\}$ )
- ▶ Aggregate rate of innovations:

$$\tau = \chi z \phi(z) + \hat{\chi} \bar{z} \eta(\bar{z})$$

## Model: R&D technology - congestion

- ▶ The reduced-form functions  $\phi(z), \eta(z)$  capture diminishing returns and congestion in the R&D race, respectively
- ▶ As such, assume  $\phi(z), \eta(z)$  decreasing,  $z\phi(z), z\eta(z)$  increasing
- ▶ For the incumbent,  $\phi(z)$  captures *individual* decreasing returns in the R&D technology
- ▶ For the entrants,  $\eta(z)$  captures *aggregate* decreasing returns due to the possibility that different entrants use the same approach
- ▶ Cross-congestion:
  - ▶ Incumbent and entrants do not congest each other (as in other models of innovation by entrants and incumbents, c.f. Acemoglu & Cao 2015, Akcigit & Kerr 2017)
  - ▶ Adds tractability and reflects empirical fact that spinouts often attempt different approaches
  - ▶ Can be relaxed

# Intermediate goods firms optimization: incumbent static optimization

- ▶ Static optimization in product market: CES final goods production implies constant markup
- ▶ In equilibrium, flow profits  $\pi(q) = \pi q$ , with

$$\begin{aligned}\pi &= L(1 - \beta)\tilde{\beta} \\ \tilde{\beta} &= \beta^\beta(1 - \beta)^{1-2\beta}\end{aligned}$$

# Intermediate goods firms optimization: incumbent R&D decision

- HJB equation for incumbent:

$$\begin{aligned}
 (\rho + \overbrace{\hat{\chi} \bar{z}(q, m, t) \eta(\bar{z}(q, m, t))}^{\text{Entrant innovation rate}}) V(q, m, t) = & \overbrace{\pi q}^{\text{Flow profits}} + \overbrace{V_t(q, m, t)}^{\text{Changing aggregate state}} \\
 & + \overbrace{\nu \bar{z}(q, m, t) V_m(q, m, t)}^{\text{Knowledge spillovers from entrant R\&D}} \\
 & + \max_z \left\{ \underbrace{\chi z \phi(z)}_{\text{Arrival rate of R\&D victory}} \overbrace{\left( V(\lambda q, 0, t) - V(q, m, t) \right)}^{\text{NPV of successful innovation}} \right. \\
 & \left. - \underbrace{z(q/\bar{q}_t)}_{\text{R\&D labor}} \left( \underbrace{w(q, m, t)}_{\text{R\&D wage}} - \overbrace{\nu(q/\bar{q}_t)^{-1} V_m(q, m, t)}^{\text{Knowledge spillovers from own R\&D}} \right) \right\}
 \end{aligned}$$

# Intermediate goods firms optimization: entrant R&D decision

- HJB equation for entrant:

$$\begin{aligned}
 & \overbrace{(\rho + \hat{\chi} \bar{z}(q, m, t) \eta(\bar{z}(q, m, t)))}^{\text{Entrant innovation rate}} W(q, m, t) = \overbrace{W_t(q, m, t)}^{\text{Changing aggregate state}} \\
 & + \overbrace{\nu \bar{z}(q, m, t) W_m(q, m, t)}^{\text{Knowledge spillovers from entrant R\&D}} \\
 & + \max_z \left\{ \overbrace{\hat{\chi} z \eta(\bar{z}(q, m, t))}^{\text{Arrival rate of R\&D victory}} \overbrace{(V(\lambda q, 0, t) - W(q, m, t))}^{\text{NPV of successful innovation}} \right. \\
 & \quad \left. - \underbrace{z(q/\bar{q}_t)}_{\text{R\&D labor}} \underbrace{w(q, m, t)}_{\text{R\&D wage}} \right\}
 \end{aligned}$$

## Model: Households

- ▶ Unit mass continuum of risk-neutral households indexed by  $i \in I = [0, 1]$ , each with objective

$$U = \int_0^{\infty} \exp(-\rho t) c(t) dt$$

where  $c(t)$  is final goods consumption at  $t$ .

- ▶ Instantaneous borrowing and lending at interest rate  $r$ ;  $r = \rho$  in equilibrium
- ▶ Individual  $i$  supplies labor to final goods production  $\ell_i^F(t)$ , intermediate good production  $\ell_i^I(t)$  and R&D  $\ell_i^{RD}(t)$  such that

$$\ell_i^F(t) + \ell_i^I(t) + \ell_i^{RD}(t) = 1$$

- ▶ Aggregate labor market satisfies (where  $L^k(t) = \int_I \ell_i^k(t) di$  for  $k \in \{F, I, RD\}$ )

$$L^F(t) + L^I(t) + L^{RD}(t) = 1$$

# Household optimization timeline

Worker  $i$  allocates labor to R&D, intermediate and final goods production



While performing R&D for some good  $j$  of relative quality  $\tilde{q}_j$ , receives learning shock with Poisson intensity  $\nu \tilde{q}_j^{-1}$  per flow unit of R&D labor supplied to



Provided it is still profitable, he opens entrant R&D lab performing R&D effort  $\xi$  and competing in developing the next step of good  $j$



# Household optimization

- ▶ Workers indifferent between occupations (Final goods production, intermediate goods production, R&D)
- ▶ In equilibrium, closed form for final goods wage  $\bar{w}_t = \tilde{\beta} \bar{q}_t$  where  $\bar{w}$  is a function of parameters
- ▶ Indifference condition intermediate goods wage  $w_t^I = \bar{w}_t$
- ▶ R&D wage at product  $j$  depends on state of the product, which is  $(q, m)$
- ▶ For now, no employment / entrepreneurship choice; hope to include eventually
- ▶ Household block of the model boils down to equilibrium condition

$$w(q, m, t) + \nu W^{NC}(q, m, t) = \bar{w}_t$$

where  $W_t^{NC}(q, m)$  is the value of the knowledge to open an entrant in a good  $j$  in state  $(q, m)$  at time  $t$

## Model: Final good production

- ▶ Final good is produced using labor and a continuum of intermediate goods  $j \in [0, 1]$  with production technology

$$\begin{aligned} X(t) &= L(t)^\beta \left( \left( \int_0^1 q_j(t)^\beta x_j(t)^{1-\beta} dj \right)^{1/(1-\beta)} \right)^{1-\beta} \\ &= L(t)^\beta \int_0^1 q_j(t)^\beta x_j(t)^{1-\beta} dj \end{aligned}$$

where  $q_j$  is quality,  $x_j$  is quantity

- ▶ Restricts labor share to be related to markup  $\mu = 1/(1 - \beta)$
- ▶ Can relax this using Grossman et. al 2016
- ▶ CRS implies zero profits so no need to consider ownership

# Aggregation: Kolmogorov Forward Equation

- Define  $d\mu(q, m, t)$  as the distribution of intermediate goods  $j$  across states  $(q, m)$  at time  $t$
- Kolmogorov Forward Equation (somewhat heuristic)

$$\begin{aligned}
 \mu_t(q, m, t) = & \overbrace{-\frac{d}{dq}(a^q(q, m, t)\mu(q, m, t))}^{\text{Drift in } q} - \overbrace{\frac{d}{dm}(a^m(q, m, t)\mu(q, m, t))}^{\text{Drift in } m} \\
 & - \underbrace{\tau(q, m, t)\mu(q, m, t)}_{\text{Innovation arrival: jump } (q, m) \rightarrow (\lambda q, 0)} \\
 & + \underbrace{\mathbb{1}_{\{m=0\}} \lambda^{-1} \int \tau(\lambda^{-1}q, m', t) d\mu(\lambda^{-1}q, m', t)}_{\text{Innovation arrival: jump } (\lambda^{-1}q, m') \rightarrow (q, 0)}
 \end{aligned}$$

- $a^q(q, m, t), a^m(q, m, t)$  are drift in  $q, m$  direction, respectively, computed from  $z(q, m, t)$  and  $\bar{z}(q, m, t)$
- Last term for  $m = 0$  arises because receiving inflows from  $(\lambda^{-1}q, m')$  for all  $m'$
- Factor  $\lambda^{-1}$  due to  $d(\lambda q) = \lambda dq$

# Recursive BGP Equilibrium

- ▶ For notation, below I sometimes omit dependence of functions on  $(q, m, t)$
- ▶ Growth rate  $g$  of average quality  $\bar{q}_t$ , value functions  $V, W$ , individual R&D policies  $z$  and  $\hat{z}$ , aggregate R&D intensity  $\tau$ , entrant R&D intensity  $\bar{z}$ , prices of intermediate goods, final and intermediate goods wage  $\bar{w}$ , and a distribution  $d\mu$  such that:
  - ▶ Intermediate goods firms and final goods firms statically optimize production decisions
  - ▶ Value functions  $V, W$  solve HJB eqs, individual policy functions optimal given value functions
  - ▶ Distribution  $\mu(q, m, t)$  satisfies KF equation (time dependent, haven't shown)
  - ▶ Final and intermediate goods wage satisfy  $\bar{w} = \Gamma(\beta)$
  - ▶ R&D wages satisfy indifference condition
$$w(q, m, t) + \nu(q/\bar{q}_t)^{-1} W(q, m, t) = \bar{w}$$
  - ▶ Labor resource constraint:  $L^F + L^I + L^{RD} = 1$
  - ▶ Growth is constant at  $g$ , and consistent with R&D policy functions and distribution  $\mu(q, m, t)$ :
$$g = (\lambda - 1) \int \tau(q, m, t)(q/\bar{q}_t) d\mu(q, m, t)$$

# Finding a BGP

- ▶ Recall that in equilibrium,  $w(q, m, t) = \tilde{\beta} \cdot \bar{q}_t - \nu W(q, m, t)$
- ▶ Taking this into account, in equilibrium the following holds:

$$\begin{aligned}
 (\rho + \overbrace{\hat{\chi} \bar{z}(q, m, t) \eta(\bar{z}(q, m, t))}^{\text{Entrant innovation rate}}) V(q, m, t) &= \overbrace{\pi q}^{\text{Flow profits}} + \overbrace{V_t(q, m, t)}^{\text{Changing aggregate state}} \\
 &+ \overbrace{\nu \bar{z}(q, m, t) V_m(q, m, t)}^{\text{Knowledge spillovers from entrant R\&D}} \\
 &+ \max_z \left\{ \underbrace{\chi z \phi(z)}_{\text{Arrival rate of R\&D victory}} \overbrace{\left( V(\lambda q, 0, t) - V(q, m, t) \right)}^{\text{NPV of successful innovation}} \right. \\
 &\quad \left. - \underbrace{z(q/\bar{q}_t)}_{\text{R\&D labor}} \underbrace{\left( \tilde{\beta} \cdot \bar{q}_t - \nu(q/\bar{q}_t)^{-1} W(q, m, t) \right)}_{\text{Equilibrium R\&D wage}} - \overbrace{\nu(q/\bar{q}_t)^{-1} V_m(q, m, t)}^{\text{Knowledge spillovers from own R\&D}} \right\}
 \end{aligned}$$

## Finding a BGP: Guess and verify

- ▶ Guess and verify: abusing notation, value of **incumbent** is  $V(q, m, t) = qV(m)$ , value of **entrant** is  $W(q, m, t) = qW(m)$
- ▶ Given these guesses, makes sense to guess  $\bar{z}(m, q, t) = \bar{z}(m) = \xi \min(m, M)$  for some  $M > 0$
- ▶ Plugging guess into incumbent HJB yields: for  $m < M$ ,

$$\begin{aligned}(\rho + \hat{\chi}\xi m\eta(\xi m))V(m) &= \pi + \nu\xi mV'(m) \\ &\quad + \max_z \left\{ \chi z \phi(z)(\lambda V(0) - V(m)) \right. \\ &\quad \left. - \chi z(\bar{w} - \nu(W(m) + V'(m))) \right\}\end{aligned}$$

where  $\bar{w} = \tilde{\beta}$ .

- ▶ Boundary condition:  $V'(m) = 0$  for  $m \geq M$

## Finding a BGP: Guess and verify (cont.)

- ▶ Similarly, HJB equation for entrant becomes: for  $m < M$ ,

$$\begin{aligned}(\rho + \hat{\chi}\xi m\eta(\xi m))W(m) &= \nu\xi mW'(m) \\ &+ \max_z \left\{ \chi z\eta(\xi m)(\lambda V(0) - W(m)) \right. \\ &\quad \left. - \chi z(\bar{w} - \nu W(m)) \right\}\end{aligned}$$

- ▶ Boundary condition:  $W(M) = 0$
- ▶ Entrant optimality implies that  $M$  is determined by free-entry condition

$$\eta(M)\lambda V(0) = \bar{w}$$

# Finding a BGP: Solving the HJBs numerically

1. Guess  $W(\cdot)$
2. Solve for  $V(\cdot)$ ,  $M$  given  $W(\cdot)$ :
  - 2.1 Guess  $V(0)$
  - 2.2 Free entry condition and  $V(0)$  determine  $M$
  - 2.3 HJB and boundary condition  $V'(M) = 0$  determine  $V(M)$
  - 2.4 Integrate backward starting from  $V(M)$ , using  $w(m) = \bar{w} - \nu W(m)$ , to compute  $\hat{V}(0)$
  - 2.5 If  $\hat{V}(0) \neq V(0)$ , update guess and return to Step 2.1
3. Using  $M$  computed from the previous step, solve for implied  $W(\cdot)$ 
  - 3.1 Integrate entrant HJB backward starting from boundary condition  $W(M) = 0$
  - 3.2 Denote resulting function by  $\hat{W}(m)$
  - 3.3 Check  $d(W, \hat{W})$  using some metric; if not converged, update guess and return to Step 1.



# Finding a BGP: Stationary distribution $\mu(m)$

- ▶ No need to keep track of aggregate distribution across  $q$
- ▶ Conjecture that a BGP exhibits a stationary distribution  $d\mu(m, t) = d\mu(m)$
- ▶ For  $m > 0$ , the distribution  $d\mu(m)$  will have no mass points, therefore its density  $\mu(m)$  is well defined and satisfies the Kolmogorov Forward Equation:

$$0 = -\frac{d}{dm}(a(m)\mu(m)) - \tau(m)\mu(m)$$

- ▶ For  $m > M$ , have  $a(m)$  and  $\tau(m)$  constant, so the above becomes

$$\mu'(m) = -\frac{\tau(M)}{a(M)}\mu(m)$$

- ▶ Solution given by  $\mu(m) = \mu(M)e^{-(\tau(M)/a(M))(m-M)}$  for  $m \geq M$
- ▶ Probably solve the rest numerically

# Finding a BGP: Algorithm

- ▶ The numerical algorithm I propose for computing a BGP is as follows:
  1. Guess  $L^F$ , the labor supply to final goods production
  2. This guess pins down equilibrium profit flow  $\pi$  and final goods / intermediate goods wage  $\bar{w}$
  3. Given these, solve HJBs numerically using iterative procedure described above
  4. Next, solve KF equation to compute stationary distribution  $\mu(m)$
  5. Using  $\mu(m)$  and policy functions from previous step, integrate to compute aggregate labor demand
  6. Check that aggregate labor demand is equal to the unit labor supply. If not, adjust guess for  $L^F$  and return to Step 1.
  7. Finally, integrate innovation arrival rates to compute  $g = (\lambda - 1) \int \tau(m) d\mu(m)$

# Efficiency

- ▶ Worker indifference condition implies firm compensated (in expectation) for profits of future spinouts
- ▶ Franco-Filson 2006 logic suggests this may imply Pareto efficiency
- ▶ However, this ignores creative destruction
- ▶ Spinouts may reduce value of incumbent-worker pair by destroying monopoly power
- ▶ Equilibrium wage discount does not fully compensate R&D firm for knowledge produced
- ▶ So model exhibits standard Schumpeterian inefficiency from R&D firms not fully appropriating the returns to their investments
- ▶ Also standard: potential for inefficiently high creative destruction due to entrants not internalizing their “business stealing” effect

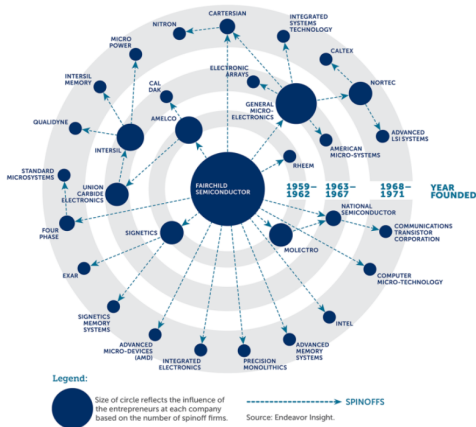
## Next steps

- ▶ Existence and uniqueness of BGP; maybe closed forms for certain functional forms?
- ▶ Implement proposed algorithm for solving model numerically
- ▶ Calibrate, test the model
  - ▶ Microeconomic facts about employee spinouts from e.g., Starr et. al "Screening spinouts"
  - ▶ Klepper-Sleeper 2005
- ▶ Potential extensions
  - ▶ Learning and entrepreneurship decisions
  - ▶ Different step sizes for incumbents and entrants
  - ▶ Cross-congestion
  - ▶ Labor contracts: non-competes

# Spinouts of Fairchild Semiconductor

back

## THE CREATION OF SILICON VALLEY: GROWTH OF THE LOCAL COMPUTER CHIP INDUSTRY



Source: Endeavor Insights