Innovation: Selected Topics

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⋆Graduate IO. Parts of notes gratuitously borrowed from Tobias Salz, Ariel Pakes, Allan Collard-Wexler, Jan De Loecker.

OUTLINE

Road Map

- Topics in Innovation
- Intellectual Property (Patents as Options)
- Reallocation and creative destruction (US Steel)

Pakes (1986): Patents as Options
Econometrica

PAKES (1986): PATENTS AS OPTIONS

The patent literature:

- Intellectual property (what is the value of patents?)
- Measuring the causes, effects and distribution of benefits from innovation (often uses patent counts and author linkages)

Main idea

- In many countries, patent holders required to pay renewal fee to keep patents in force.
- Usually more than 90% of patent holders let patents expire before the limit on patent lives.
- Use patent renewal decisions and costs of renewal to infer the distribution of patent values. Patents as options.

Methodological contributions

- Simulation estimator, serially correlated unobserved state variable (relaxes iid, conditional logit assumptions)

Pakes (1986)

TABLE I

CHARACTERISTICS OF THE DATA[a]

Country Characteristic	France	U.K.	Germany
1. f	2	5	3
2. L	20	16	18
3. Application dates of cohorts	1951–79	1950–74	1952–72
4. First/last year in which renewals are observed	1970/81	1955/78	1955/74
5. Patents studied from cohort: all patents	Applied for	Applied for	Granted
6. Estimated average ratio of patents granted to patents applied for[b]	.93	.83	.35
7. $\overline{NPAT} = N/J$	36,865	37,286	21,273

[a] Symbols are defined as follows: f is the first age for which a renewal fee is due; L is the last age at which an agent can keep the patent in force by payment of an annual renewal fee; and $\overline{NPAT}$ is the average number of patents per cohort.

[b] For France and the U.K. these estimates were obtained as follows. Let n_t be the number of patents applied for in year t, and $\tilde{n}_t$ be the number of patents granted. Then the ratio was calculated as $T^{-1}\sum_{t=1}^{T}[(\sum_{\tau=1}^{4} .25\tilde{n}_{t+\tau})/n_t]$. In Germany the ratio of the patents granted to those applied for from a given cohort was directly available, and these ratios were simply averaged over the cohorts studied.

PAKES (1986)

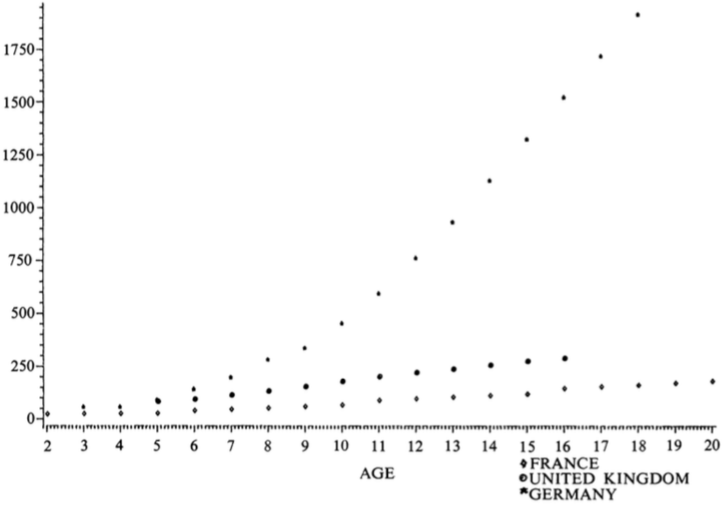


FIGURE 3.—Average of renewal fee schedules.

PAKES (1986): PATENTS AS OPTIONS

Main idea

- This is an optimal stopping problem!
- First year returns from patent protection are r_1. (May be only small part of total returns to the patented idea).
- Returns in future years $r_2, r_3, \ldots$ are random.
- Cost of renewing each year $c_1, c_2, \ldots$
- 2 period intuition:
  - 2nd period: renew if $r_2 > c_2$, so obtain $\max\{r_2 - c_2, 0\}$
  - First period (if renew):

$$r_1 - c_1 + \beta \int \max\{r_2 - c_2, 0\} P(dr_2 | r_1)$$

  - P stochastically increasing in r_1.
  - There is a cutoff $\bar{r}_1 < c_1$ s.t. if $r < \bar{r}_1$, patent is not renewed.
  - Second period cutoff is simply $\bar{r}_2 = c_2$.

Pakes (1986): Patents as Options:

Model Details

Primitives, parameterized by θ

Ω_a : history of returns up to age, $\{r_1, ..., r_a\}$. The expectation is over $r_{a+1}|\Omega_a$. The sequence of conditional distributions $F(a_{t+1|\Omega_a}), a = 1, 2, ...$ is an important component of the model. Pakes' assumption:

$$r_{a+1} = \begin{cases} 0 & \text{with prob. } \exp(-\theta r_a) \\ \max(\delta r_a, z) & \text{with prob. } 1 - \exp(-\theta r_a) \end{cases}$$

where density of z is $q_a = \frac{1}{\sigma_a} \exp[-(\gamma + z)/\sigma_a]$ and $\sigma_a = \phi^{a-1}\sigma, a = 1, \ldots, L-1$.

Sequence of renewal fees $\{c_a\}$, increasing in age. Gives rise to value function:

$$V(r, a) = \begin{cases} \max\{0, r - c_a + \beta E[V(r', a+1)|r, a]\} & \text{if } a < A \\ \max\{0, r - c_A\} & \text{if } a = A \end{cases}$$

Pakes (1986): Patents as Options:

Model Details

A note on the nature of this problem: Since the maximal age is finite this is a finite horizon (non-stationary) dynamic optimization problem. Most dynamic problems fall into two camps (i) infinite horizon stationary problems and finite horizon, non-stationary problems. Stationarity just means that the value functions and optimal decision rules are *time-invariant* functions of the state variables.

Solution is a cut-off strategy:

- Note that agent renews if $r + \beta E[V(r', a+1)|r, a] > c_a$.
  - Since this is strictly increasing in r at each a, there exists a unique cutoff $\bar{r}_a < c_a$ s.t. patent is renewed iff $r > \bar{r}_a$.
- $\bar{r}_a < \bar{r}_{a+1} < ... < \bar{r}_A = c_A$ (The fact that renewal fees are increasing in age, while the option value is decreasing, implies that cutoffs are increasing in age.).
  - Solved for starting in the last period.

PAKES (1986): PATENTS AS OPTIONS: ESTIMATION

OVERVIEW

Outer loop: is concerned with evaluating likelihood that arises from a complicated integral:

- Maximize log-likelihood: $\log \mathcal{L}(\theta) = n^{-1} \sum_a s(a) \log \pi_a(\theta)$.
  - n is # of patents in cohort
  - s_a is the fraction of the original sample dropping out at age a (or surviving until terminal year if $a = A$.
  - $\pi_a(\theta)$ is probability of dropping out at age a.
- If $F(r, a; \theta)$ be the distribution of patent values at age a we have $\pi_a(\theta) = F(\bar{r}_a, a; \theta) - F(\bar{r}_{a-1}, a-1; \theta)$
- Issue: family $\{F(\cdot, \cdot; \theta)\}$ is complicated (not analytic).

Inner loop: solve the agent's problem.

PAKES (1986): PATENTS AS OPTIONS: ESTIMATION

Outer loop procedure: simulation estimator.

- Start with a draw $r_1 \sim f(r, 1; \theta)$.
- Let $\bar{r}_t$ be cut-off from value functions.
- At iteration $t < A$:
  - If $r_t \geq \bar{r}_t(\theta)$, take a draw from $r_{t+1} \sim P(\cdot|t, r_t; \theta)$.
    - i.e., stayed in at t
  - if $r_t < \bar{r}_t(\theta)$, up counter for $\hat{\pi}_t(\theta)$ by one.
    - i.e., dropped out
- Use $\hat{\pi}_t(\theta)/(NSIM)$ as estimate of probability of dropping out at age a (conditional on making it to that point) to compute likelihood.

Inner loop procedure: backwards induction.

- At L there is no more continuation value, return is r_L.
- At $L - 1$ solve for the continuation value via transitions of returns (expectations over returns depend on parameter guess).
- ...
- This procedure gives the cut-offs needed for the outer loop.

PAKES (1986)

TABLE V

PERCENTILES (pl) AND LORENZ CURVE COEFFICIENTS (lc) FROM THE DISTRIBUTION OF REALIZED PATENT VALUES[a]

	Country					
	France		U.K.		Germany	
Per cent p	pl ($)	lc per cent	pl ($)	lc per cent	pl ($)	lc per cent
.25	75.23	.544	355.55	.554	1,999.60	2.249
.50	533.96	1.833	1,516.84	3.247	6,252.93	7.341
.75	3,731.35	8.087	7,947.55	16.369	19,576.26	25.288
.85	10,292.06	19.575	15,357.09	31.721	32,428.14	41.001
.90	17,423.11	31.261	22,206.21	44.257	44,241.87	52.672
.95	31,609.59	52.461	34,740.07	62.960	65,753.61	69.223
.97	42,905.78	65.514	43,889.95	73.640	78,299.01	78.348
.98	51,215.84	73.729	51,277.22	80.072	94,842.63	83.800
.99	66,515.40	84.011	65,075.08	87.858	118,354.78	90.330
maximum	259,829.27	—	374,028.70	—	419,217.55	—
mean	5,631.03	—	7,357.05	—	16,169.48	—
NPAT	36,865		37,826		21,273	

[a] The realized value for patent i is $\sum_{\tau=1}^{\tau_i^*} \beta^{(\tau-1)}(r_{i,\tau} - c_\tau)$, where τ_i^* is the last age at which patent i was kept in force. See also the note to Table III.

[16] Of course some of these patents had negative (though small in absolute value) realized values, as they were patents on which early renewals were paid for options which did not materialize. If, for example, we had defined the realized values as the discounted sum of net returns from age two, rather than from age one (as in the table), the Lorenz curve coefficient corresponding to $p = .25$ would have been negative, though close to zero.

PAKES (1986)

PATENTS AS OPTIONS 769

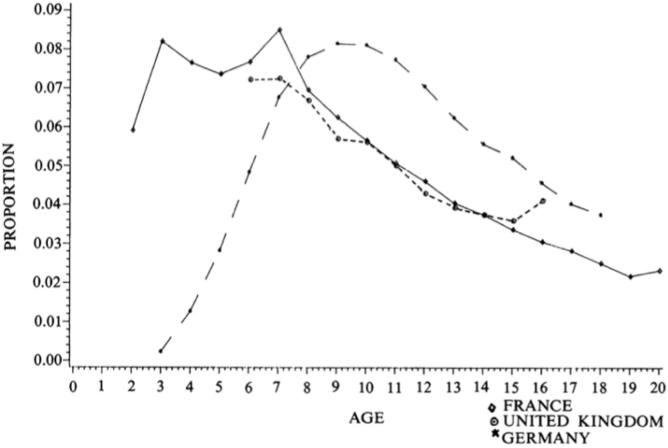
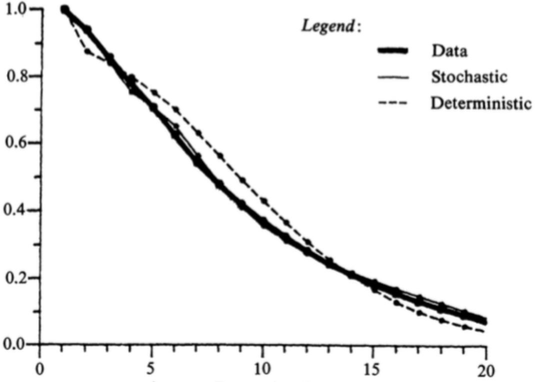


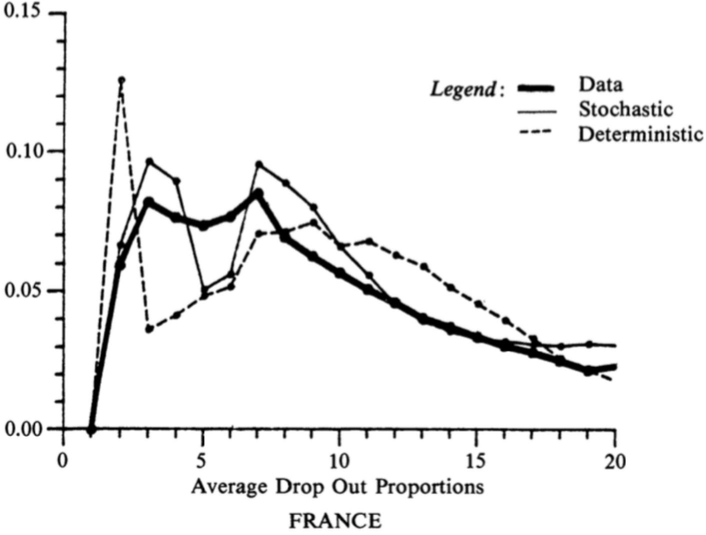
FIGURE 2.—Average drop out proportions.[a]

PAKES (1986)



FRANCE

PAKES (1986)


0.15
0.10
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Legend: Data
Stochastic
Deterministic
Average Drop Out Proportions
FRANCE

Collard Wexler and De Loecker (2015): Reallocation and Technology: Evidence from the US Steel Industry
American Economic Review

Collard Wexler and De Loecker (2015): Abstract

We measure the impact of a drastic new technology for producing steel - the minimill - on industry-wide productivity in the US steel industry, using unique plant-level data between 1963 and 2002. The sharp increase in the industry's productivity is linked to this new technology through two distinct mechanisms: (i) the mere displacement of the older technology (vertically integrated producers) was responsible for a third of the increase in the industry's productivity, and (ii) increased competition, due the minimill expansion, drove a productivity resurgence at the surviving vertical integrated producers and, consequently, the productivity of the industry as a whole.

Collard Wexler and De Loecker (2015): Research Question

How much does technological innovation and adoption contribute to productivity growth? What impacts does it have distributionally?

Collard Wexler and De Loecker (2015): Steel vs typical industry 1972-2002

Table 1—Relative Performance of the Steel Sector (*Percent*)

	Steel sector	Mean sector	Median sector
Δ TFP	28	7	3
Δ shipments	−35	60	61
Δ labor	−80	−5	−1
Δ materials	−41	45	39
Δ value added	−43	34	38
Δ price†	−23	−2	−3
Δ material price†	−10	−11	−9

Notes: Only sectors over ten billion dollars are included. Changes computed between 1972–2002.

†Material and output prices indexes are deflated by the GDP deflator.

Source: NBER-CES Dataset for SIC Code 3312.

Collard Wexler and De Loecker (2015): Context

- Vertically Integrated plans (legacy)
- Minimills (New technology)

Collard Wexler and De Loecker (2015): Data

- Production Data from the Census Bureau's Research Data Program on US Steel Mills (NAICS 331111).
- 40 years of data: 1963-2002, complete census every 5 years, plants representing 90% of output other years.
- Detailed Input and Output Use Data:
  "Steel Wire" or
  "Consumption of Coal for Coke"
- Additional Information from Special Surveys 1992-2002: presence of different furnaces and processing operations at the plant.
  - Vertically Integrated: blast furnace used to combine iron-ore, limestone and coal.
  - Minimills: electric arc furnace used to melt scrap steel.
  - Rolling Mills: shaping and rolling of steel shapes.
- Product and Material price deflators from BLS.

COLLARD WEXLER AND DE LOECKER (2015)

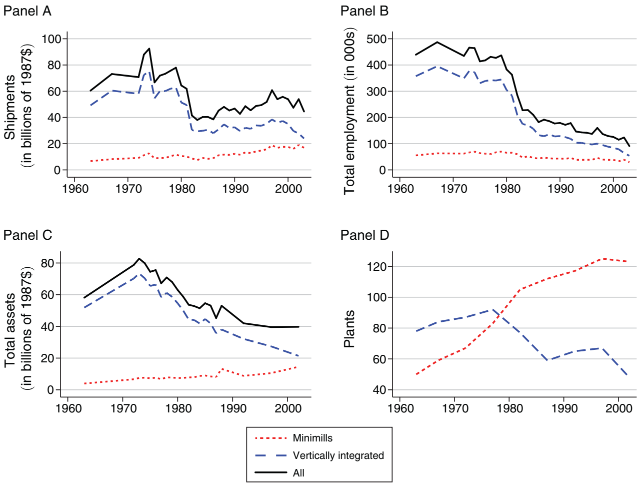
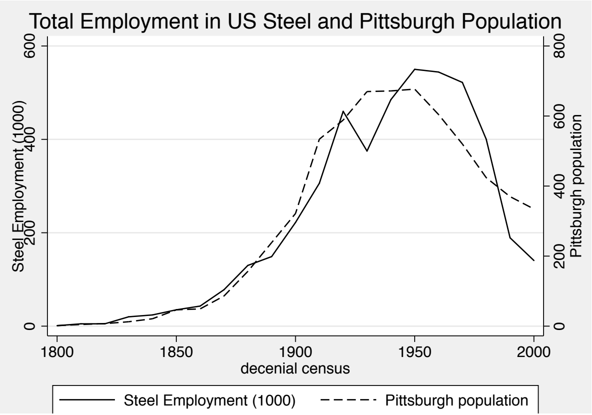


FIGURE 1. EVOLUTION OF THE STEEL INDUSTRY AND VERTICALLY INTEGRATED MILLS AND MINIMILLS

Collard Wexler and De Loecker (2015)



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Collard Wexler and De Loecker (2015)

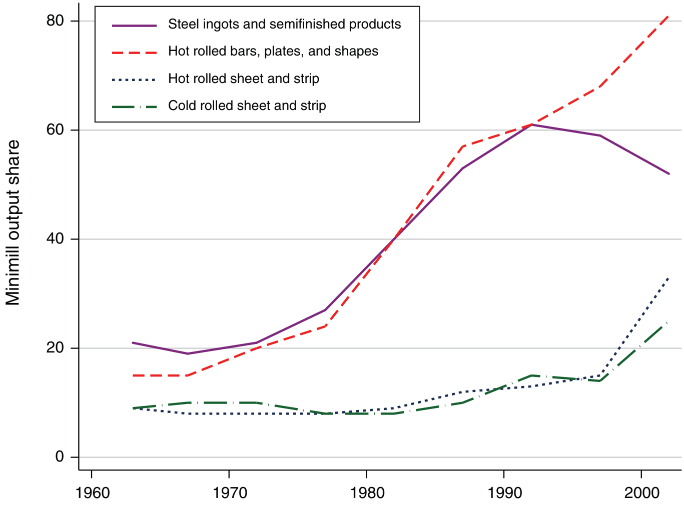

Figure 2. Minimills Market Share by Major Product

Collard Wexler and De Loecker (2015)

Table 2—Entry and Exit in US Steel

	Entrant market share (plants)	Exiter market share (plants)
1963–1972	6 (29)	9 (D∗)
1973–1982	5 (49)	20 (20)
1983–1992	21 (55)	18 (47)
1993–2002	12 (30)	2 (41)
Minimills	Entrants	Exiters
1963–1972	17	D∗
1973–1982	39	0
1983–1992	43	26
1993–2002	D∗	17
Vertically integrated	Entrants	Exiters
1963–1972	12	D∗
1973–1982	10	20
1983–1992	12	21
1993–2002	D∗	24

Notes: D∗ cannot be disclosed due to the small number of observations. Numbers refer to the revenue market share represented by exiters and entrants, while numbers in parentheses refer to the count of plants that enter or exit.

Collard Wexler and De Loecker (2015): Productivity decompositions

Define aggregate productivity as the share weighted average of individual firm productivities. Then,

DEFINITION 1: *Olley-Pakes Decomposition.*

$$\Omega_t = \overline{\omega}_t + \sum_i (\omega_{it} - \overline{\omega}_t)(s_{it} - \bar{s}_t) = \overline{\omega}_t + \Gamma_t^{OP}, \tag{13}$$

DEFINITION 2: *Within-Technology Decomposition.*

$$\begin{aligned} \Omega_t &= \sum_{\psi \in MM, VI} s_t(\psi)\Big(\overline{\omega}_t(\psi) + \sum_{i \in \psi} (\omega_{it} - \overline{\omega}_t(\psi))(s_{it}(\psi) - \bar{s}_t(\psi))\Big) \\ &= \sum_{\psi \in MM, VI} s_t(\psi)(\overline{\omega}_t(\psi) + \Gamma_t^{OP}(\psi)). \end{aligned} \tag{14}$$

DEFINITION 3: *Between Technology Decomposition.*

$$\Omega_t = \overline{\Omega}_t + \sum_{\psi \in MM, VI} (s_t(\psi) - 1/2)(\Omega_t(\psi) - \overline{\Omega}_t) = \overline{\Omega}_t + \Gamma_t^B, \tag{15}$$

Collard Wexler and De Loecker (2015)

Table 7—Static Decompositions of Productivity Growth Change 1963–2002 (*Percent*)

Aggregate TFP $\Delta\Omega$	22.1	
Olley-Pakes decomposition:		
Unweighted average: $\Delta\,\overline{\omega}$	15.7 (0.71)	
Covariance: $\Delta\,\Gamma^{OP}$	6.4 (0.29)	
Between decomposition:		
Unweighted average: $\Delta\,\overline{\Omega}$	17.0 (0.77)	
Between covariance: $\Delta\,\Gamma^{B}$	5.1 (0.23)	
Within decomposition:	Minimills	Integrated
Aggregate TFP: $\Delta\,\Omega(\psi)$	9.6	24.3
Unweighted average: $\Delta\,\overline{\omega}(\psi)$	5.4 (0.55)	18.4 (0.83)
Within covariance: $\Delta\,\Gamma^{OP}(\psi)$	4.4 (0.45)	3.7 (0.17)

Note: The share of each component in the total aggregate productivity growth is listed in parentheses.

Collard Wexler and De Loecker (2015)

Table 8—Dynamic Decomposition of Productivity Growth (*Percent*)

Component	All	Minimill	Integrated
Total change	22.1%	9.6 (0.28)	24.3 (0.49)
Plant improvement	9.5%	11.8 (0.34)	9.3 (0.19)
Reallocation	9.3%	−0.3 (−0.03)	11.3 (0.23)
Net entry	3.3%	−2.0 (−0.03)	3.8 (0.07)
Entry-exit premium		0.0	4.4

Notes: The share of each component in the total aggregate productivity growth is listed in parentheses. See equation (17) for definitions of various terms. For example, the share of minimill productivity growth (9.6 percent) in aggregate productivity growth is given by: $9.6/17.7 \times 0.77 = 0.28$—i.e., we compute the share of the minimill productivity growth in the unweighted aggregate productivity growth term, which we know from the top panel is 0.77.

Collard Wexler and De Loecker (2015)

TABLE 10—DETERMINANTS OF EXIT

	Plant exists in 2002				
	Panel A. All plants		*Panel B. Vertically integrated*		
	(1)	(2)	(3)	(4)	(5)
Vertically integrated	–0.36***	–0.39***			
	(0.09)	(0.08)			
Sheet specialization ratio	0.39**	0.36*	0.31*	0.31*	0.22
	(0.14)	(0.14)	(0.13)	(0.13)	(0.14)
log capital (k)		0.02		0.20	0.24
		(0.03)		(0.24)	(0.25)
Productivity (ω)		0.03			0.05
		(0.14)			(0.04)
Observations	128	128	78	78	78
log-likelihood	–73.88	–73.72	–40.36	–40.02	–39.24
χ^2	16.97	17.30	5.89	6.58	8.12
Baseline probability	0.33	0.33	0.23	0.23	0.22

Notes: Marginal effects presented. Dependent variable is whether the plant has not exited by 2002 given its status in 1963. Very similar results are found with 1972 and 1977 as base years.

Collard Wexler and De Loecker (2015)

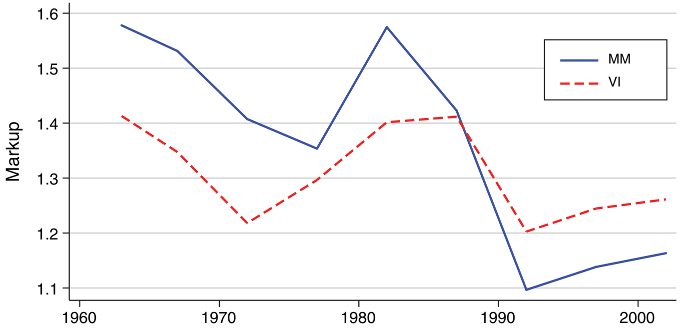

Figure 4. Market Share Weighted Markups

Source: Own calculations using US Census data.