Macroeconomía y Costos de Ajuste
Cátedras 5 y 6
11 de agosto de 2008

Eduardo Engel

Yale University

CEA - DII - U. de Chile
Agosto, 2008.

III. Investment

1. Basics
2. Lumpy investment in partial equilibrium:
    1. The cautionary effect of uncertainty
    2. Increasing hazards and time-varying IRFs
    3. Uncertainty shocks and an application to 9/11
3. Lumpy investment in general equilibrium:

1. Basics

- Accelerator
- Neoclassical model
- q-theory

Accelerator

- Clark (1917), Clark (1944), Koyck (1954).
- Have:

$$I_t = \phi(\Delta Y_t, \Delta Y_{t-1}, \ldots),$$

  increasing in all arguments.
- If output accelerates, investment increases...
- Not a bad fit of the data...
- Poor economics: no prices involved...

Neoclassical Model

- Jorgenson (1963).
- Derives demand for capital for a profit maximizing firm.
- Obtains:

$$I_t = \phi(u_t),$$

decreasing, with

$$u_t = (r + \delta)p_t - \overset{\circ}{p}_t = \text{user cost of capital}.$$

Neoclassical Model

- u is the opportunity cost of investing in capital.
- A good theory for demand of capital...
- If taken literally, this model implies either a zero of an infinite investment rate, depending on whether the determinants of demand for capital change or not.
- To avoid this undesirable property, when taking the theory to the data, lagged values of the user-cost are included too. At this point the model's theoretical appeal is lost. The empirical fit isn't good either: user-cost matters little...

q Theory

Keynes (1936, p. 151):

> *"there is no sense in building up a new enterprise at a cost greater than that at which a similar existing enterprise can be purchased; whilst there is an inducement to spend on a new project what may seem an extravagant sum, if it can be floated off the Stock Exchange at an immediate profit."*

Brainard and Tobin (1968, p. 103-4):

> *"the market valuation of equities, relative to the replacement cost of the physical assets they represent, is the main determinant of new investment."*

Average q

- Brainard and Tobin define:

$$\bar{q}_t \equiv \frac{\text{Value of firm}}{\text{Units of capital}},$$

  known as average q.

- What Keynes meant was:

$$I_t = \phi(\bar{q}_t - p_t),$$

  with ϕ increasing.

- Can calculate $\bar{q}$ from stock market data, easy to implement.
- Not an empirical success: coefficients on $\bar{q}$ pretty small, implies adjustment costs that are too large.
- No microfoundations...

Marginal q

- Abel (1980): Introduces convex adjustment costs and derives the firm's optimal investment schedule, showing that it satisfies:

$$\frac{I_t}{K_t} = \phi(q_t - p_t),$$

where $q_t \equiv \partial V_t / \partial K_t$, known as marginal q and p_t denotes the price of new units of capital.

- Problem: empirical counterpart of q?

Marginal q

- Hayashi (1982): if the revenue function exhibits constant returns to scale, then $\bar{q} = q$.
- Problems:
  - Hayashi's result does not solve poor empirical performance.
  - Theory predicts that q is sufficient for investment, in practice lagged vales of q improve the fit.
  - When you add the firms' cash-flow to the regressors, the goodness of fit improves significantly.

Recent Developments

- Non-convex adjustment costs: to model lumpy investment behavior. Improves fit dramatically. Includes irreversible investment as a particular case. Hard to implement, will cover next.
- Financial market imperfections: to rationalize inclusion of cash flow as explanatory variable. Elegant theory. Controversial empirics. Won't cover in this course.

2. Lumpy investment in partial equilibrium

1. The cautionary effect of uncertainty
2. Increasing hazards and time-varying IRFs
3. Uncertainty shocks and an application to 9/11

2.1. The cautionary effect of uncertainty

- Leahy and Whited (JMCB, 1996)
- Guiso and Parigg i (QJE, 1999)
- Bloom, Bond and Van Reenen (REStud, 2007)

Leahy and Whited (1996): Overview

- Panel estimation of the effects of uncertainty on investment
- Fundamental idea:
  - uncertainty measure: yearly volatility of daily stock returns

$$\sigma_{i,y} \cong \sum_{d} (r_{i,y,d} - r_{i,y,\cdot})^2$$

  - estimate firm's yearly investment as a function of this uncertainty measure
  - use firm and year controls to account for omitted variables
  - use GMM to deal with exogeneity

Results

The Effect of One-Period Uncertainty Forecasts on Investment							
Tobin's q	0.024	–	0.022	–	0.025	–	–0.061
	(0.009)		(0.023)		(0.010)		(0.208)
Variance	–	–0.538	–0.054	–	–	–0.768	–2.51
		(0.276)	(0.536)			(0.388)	(5.80)
Covariance	–	–	–	–0.057	0.153	0.153	0.413
				(0.087)	(0.155)	(0.155)	(0.867)

Notes: The sample consists of six hundred U.S. manufacturing firms from the COMPUSTAT database from 1982 to 1987. The dependent variable is Investment/Capital Stock. Standard errors, calculated using the procedure in Newey (1984), are in parenthesis.

Results

- Uncertainty reduces investment
- Covariance (CAPM-finance theories) has no impact
- Controlling for Tobin's q removes uncertainty effects:
  - authors: uncertainty affects investment through Tobin's q
  - yet Tobin's q is not significant
  - but conditions for Tobin's $q =$ marginal q (e.g., CRS) do not hold

Guiso and Pariggi (QJE, 1999)

- Also estimates the effect of uncertainty on investment
- Main contribution: a new measure of uncertainty, based on a survey of firms' distribution of demand growth expectations
    - used to generate a mean and variance of expected demand
    - hence can estimate effects of the variance correcting for the mean
    - the authors persuaded the Bank of Italy to run this survey

Basic Setup

$$\boxed{\frac{I^p_{0,1}}{K_0} = \alpha_0 + \alpha_1 \frac{\mathcal{Y}_{0,i}}{K_0}(1 - \alpha_2 u_{0,i}) + \alpha_3 \frac{I_0}{K_{-1}} + \alpha_4 Z_i + \varepsilon_1,}$$

- $\frac{I^p_{0,1}}{K_0}$: investment planned at the end of 1993 (year 0) for 1994 (year 1)
- I_0: volume of investment made in year 0
- K_j: stock of capital at the end of year j, $j = 0, -1$
- $\mathcal{Y}_{0,i}$: demand expected at the end of year 0 for year i, $i = 1, 3$
- $u_{0,i}$: measure of the firm's uncertainty of future demand as perceived at the end of 1993 for year i
- Z_i: vector of additional controls
- ε_1: stochastic error term

Irreversible investment models predict $\alpha_2 > 0$

Results

TABLE III
INVESTMENT AND UNCERTAINTY
DEPENDENT VARIABLE: RATIO OF INVESTMENT PLANNED ONE YEAR AHEAD TO THE STOCK OF CAPITAL

	Expectations three years ahead				Expectations one year ahead	
Variable	(1)	(2)	(3)	(4)	(5)	(6)
$\frac{{}_0y_i}{K_0}$	0.0069	0.0072	0.0054	0.0064	0.0085	0.0072
	(0.0011)	(0.0011)	(0.0005)	(0.0011)	(0.0012)	(0.0012)
$\left(\frac{{}_0y_i}{K_0}\right)\left(\frac{{}_0\sigma_i}{K_0}\right)$	−0.0081	−0.0089	—	−0.0079	−0.0084	−0.0069
	(0.0015)	(0.0016)		(0.0015)	(0.0020)	(0.0019)
$\frac{I_0}{K_1}$	0.4249	0.4361	0.4302	0.3956	0.4594	0.4431
	(0.0185)	(0.0186)	(0.0189)	(0.0189)	(0.0177)	(0.0179)
$\frac{({}_0y_i)^2}{K_0}$	—	−1.25E-09	—	—		
		(1.01E-09)				
$\frac{{}_0\sigma_i}{K_0}$	—	0.0281	—	—		
		(0.0212)				
$\left(\frac{{}_0y_i}{K_0}\right){}_0\sigma^2_{di}$	—	—	−0.1974			
			(0.0814)			
$\frac{CF}{K_0}$	—	—	—	0.0078	—	0.0139
				(0.0048)		(0.0053)
RAT	—	—	—	−0.0028	—	−0.0020
				(0.0041)		(0.0038)
Constant	0.0041	0.0026	0.0067	0.0072	0.0030	0.0044
	(0.0122)	(0.0121)	(0.0122)	(0.0121)	(0.0114)	(0.0113)
Number of observations	549	549	549	514	603	568
F-test for all coefficients = 0	26.63	26.10	29.20	20.57	32.02	26.27
	(29, 519)	(34, 514)	(32, 516)	(34, 479)	(32, 570)	(34, 533)

Results

- 500+ Italian manufacturing companies
- Uncertainty measure proxied by $\sigma_{0,i}/K_0$: standard deviation of the level of demand expected at the end of year 0 for year i, $i = 1, 3$, scaled by the stock of capital
- Use robust estimators to account for outliers
- The term that interacts expected demand growth with uncertainty is significantly negative in all specifications
    - Column 1: an increase in the standard deviation of expected demand (scaled by its capital stock) from its sample mean to the 95th percentile reduces investment by 4.7%
    - Column 1: evaluated at the sample mean of uncertainty measures, eliminating uncertainty would increase investment by 2.3%

Bloom, Bond and Van Reenen (REStud, 2007): Overview

- Also estimates the effect of uncertainty on investment
- Develops a fairly general model with adjustment costs, firms composed of many units and types of capital, and firm-specific uncertainty shocks
- Derives robust predictions from the model and tests with actual firm-level data: a "matched theory-empirics approach"
- Shows that higher uncertainty generates a large and robust "caution effect": 1 SD increase in σ halves the investment response

Basic Setup

- The paper is split between theory and empirics
- Theory is simulation based:
  - solves for time-varying σ
  - shows higher σ induces caution – like an adjustment cost
  - shows this is robust to aggregation – empirically important

Incorporating Heterogeneity

TABLE 1

Episodes of zero investment in different types of data

	Observations with zero investment (%)			
	Buildings	Equipment	Vehicles	Total
Firms	5·9	0·1	n.a.	0·1
Establishments	46·8	3·2	21·2	1·8
Single plants	53·0	4·3	23·6	2·4
Small single plants	57·6	5·6	24·4	3·2

Note: Firm-level data (6019 annual observations) from Extel and Datastream. Establishment-level data (46,089 annual observations) from U.K. Census of Production (see Reduto dos Reis, 1999).

- Motivates a model where firms are composed of a large number of production units with two types of capital that are aggregated over time (decisions made on a monthly basis, aggregated to the annual level)

Theoretical Model: Overview

- Firms assumed to operate a large collection of individual production units (250 units)
- Each unit faces an iso-elastic demand curve for its output, which is produced using labor and two types of capital
- Demand conditions evolve as a geometric random walk, with time-varying uncertainty, and have a unit-specific idiosyncratic component and a common firm level component
- Demand shocks, uncertainty shocks and optimization occur in monthly discrete time (but observed data, both simulated and actual, is aggregated to annual level)
- Labor is costless to adjust while both types of capital are costly to adjust

Theoretical Model: Main Insights

1. The response of company investment to demand shocks is lower at higher levels of uncertainty due to the "cautionary" effect of uncertainty: the option to wait (both to invest and to disinvest) becomes more valuable when uncertainty is high
2. The investment response will be convex in response to positive demand shocks and concave in response to negative demand shocks: in response to a positive demand shock the firm may invest in a greater number of production units or types of capital (the extensive margin) and it may invest more in each unit and type of capital (the intensive margin). Supermodularity in the production technology reinforces this effect

Theoretical Model: Some Details

- Each production unit has a reduced form supermodular revenue function:
$$R(X, K_1, K_2) = X^{\gamma} K_1^{\alpha} K_2^{\beta},$$
based on an underlying Cobb-Douglas production function with two types of capital, after labor, a flexible input, has been optimized out
- X summarizes productivity and demand conditions
- For tractability, we work with a normalized version P of X, defined via:
$$P^{(1-\alpha-\beta)/\gamma} \equiv X,$$
so that
$$\tilde{R}(P, K_1, K_2) \equiv R(X, K_1, K_2)$$
is homogeneous of degree one in (P, K_1, K_2)

Theoretical Model: Some Details

- We assume: $P = P^{\mathrm{U}} \times P^{\mathrm{F}}$
- Unit level component P^{U} evolves according to:

$$\begin{aligned} P_t^{\mathrm{U}} &= P_{t-1}^{\mathrm{U}}(1 + \mu(\sigma_t) + \sigma_t V_t^{\mathrm{U}}), \quad V_t^{\mathrm{U}} \sim N(0,1), \\ \sigma_t &= \sigma_{t-1} + \rho_\sigma(\sigma^* - \sigma_{t-1}) + \sigma_\sigma W_t, \quad W_t \sim N(0,1) \end{aligned}$$

- Firm level demand process:

$$P_t^{\mathrm{F}} = P_{t-1}^{\mathrm{F}}(1 + \mu(\sigma_t) + \sigma_t V_t^{\mathrm{F}}), \quad V_t^{\mathrm{F}} \sim N(0,1).$$

- Baseline value of $\mu(\sigma_t)$ equals 4% (average annual real sales growth)

Theoretical Model: Some Details

- Not clear what assumption is made regarding correlation of shocks across units for a given firm, most likely they are assumed independent
- Costs of adjusting capital: resale price of a unit of capital less than the purchase price:
  - resale loss for K_1: 50%
  - resale loss for K_2: 20%
- Newly invested capital enters production immediately
- Both types of capital depreciate at an annualized rate of 10%
- Firm's annualized discount rate: 10%

Model Predictions and Empirics

- Shows on simulated data this effect can be estimated (by GMM)

$$\frac{I_{it}}{K_{i,t-1}} = \beta_1 \Delta \log Y_{it} + \beta_2 (\Delta \log Y_{it})^2 + \beta_3 (\mathrm{SD}_{it} \Delta \log Y_{it})$$
$$+\theta \log(Y_{i,t-1}/K_{i,t-1}) + \gamma_1 \mathrm{SD}_{it} + \gamma_2 \Delta \mathrm{SD}_{it} + A_i + \delta_i + B_t + v_{it}$$

  - $\Delta \log Y_{it}$: current sales growth
  - SD_{it}: σ_{it} from the model
  - SD_{it} and $\Delta\mathrm{SD}_{it}$: included to allow for effects of uncertainty on the level of capital in either the short or the long-run
  - A_i, B_t: unobserved firm-specific and time-specific effects
  - v_{it}: approximately serially uncorrelated error term
  - δ_i: firm's depreciation rate
- Finds similar results with actual data:
  - uncertainty measure: stock returns based measure, similar to Leahy-Whited

Model Predictions

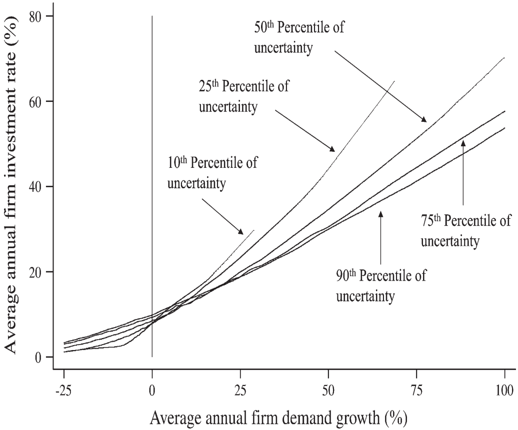


FIGURE 1

Model Predictions

TABLE 3

Econometric estimation on the simulated data

Dependent variable: $I_{it}/K_{i,t-1}$	(1)	(2)	(3)	(4)
Estimation method	OLS	GMM	OLS	OLS
Type of data for P and σ	True	Empirical	True	True
Hartman–Abel effects	No	No	Positive	Negative
Demand growth, Δp_{it}	0·395	0·539	0·387	0·416
	(0·041)	(0·083)	(0·040)	(0·040)
Demand growth squared, Δp_{it}^2	0·028	0·864	0·028	0·028
	(0·005)	(0·212)	(0·004)	(0·005)
Change in uncertainty, $\Delta\sigma_{it}$	−0·095	−0·042	−0·020	−0·755
	(0·046)	(0·019)	(0·160)	(0·161)
Uncertainty, σ_{it}	0·005	−0·080	0·373	−0·402
	(0·021)	(0·097)	(0·080)	(0·066)
Uncertainty × demand growth, $\sigma_{it} * \Delta p_{it}$	−0·441	−0·440	−1·500	−1·733
	(0·108)	(0·166)	(0·368)	(0·373)
Demand ECM, $(p-k)_{i,t-1}$	0·190	0·439	0·189	0·187
	(0·008)	(0·105)	(0·008)	(0·008)
Second-order serial correlation (p-value)		0·185		
Sargan–Hansen test (p-value)		0·856		

Findings

TABLE 5

Econometric estimates using U.K. company data

Dependent variable: $(I_{it}/K_{i,t-1})$	(1)	(2)	(3)	(4)	(5)
Sales growth (Δy_{it})	0·259	0·151	0·382	0·400	0·413
	(0·072)	(0·059)	(0·136)	(0·139)	(0·139)
Cash flow $(C_{it}/K_{i,t-1})$	0·206	0·263	0·260	0·255	0·272
	(0·135)	(0·132)	(0·124)	(0·126)	(0·125)
Lagged cash flow $(C_{i,t-1}/K_{i,t-2})$	0·303	0·269	0·272	0·288	0·273
	(0·086)	(0·082)	(0·075)	(0·075)	(0·076)
Error correction term $(y-k)_{i,t-1}$	0·062	0·056	0·054	0·054	0·053
	(0·030)	(0·030)	(0·026)	(0·026)	(0·026)
Sales growth squared $(\Delta y_{it})^2$		0·481	0·513	0·494	0·500
		(0·175)	(0·152)	(0·150)	(0·151)
Change in uncertainty $(\Delta \mathrm{SD}_{it})$			−0·023	−0·012	
			(0·012)	(0·008)	
Lagged uncertainty $(\mathrm{SD}_{i,t-1})$			−0·015		
			(0·011)		
Uncertainty × sales growth			−0·162	−0·165	−0·167
$(\mathrm{SD}_{it} * \Delta y_{it})$			(0·067)	(0·068)	(0·068)
Goodness of fit—$\mathrm{Corr}(I/K, \widehat{I/K})^2$	0·259	0·287	0·285	0·285	0·307
Serial correlation (p-value)	0·047	0·102	0·069	0·078	0·091
Sargan–Hansen (p-value)	0·510	0·709	0·699	0·629	0·560

Findings

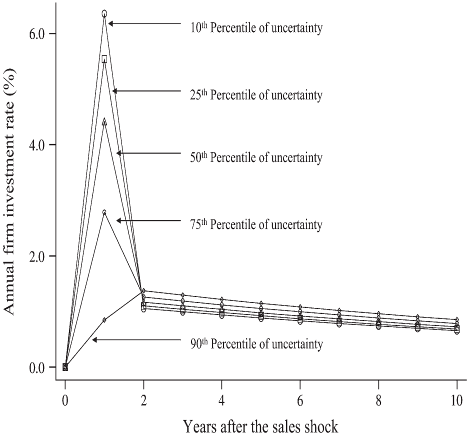


FIGURE 2

Investment response to a sales shock at different levels of uncertainty, U.K. firm-level data

2.2. Increasing Hazards and Time-Varying IRFs

- Goal: build a model of aggregate investment with realistic micro foundations, that can be estimated from aggregate data

Types of Adjustment

1. Ongoing: maintenance
2. Gradual: refinements, training
3. Major and infrequent

Neoclassical and q-theory: only 1 and 2

Stylized Facts

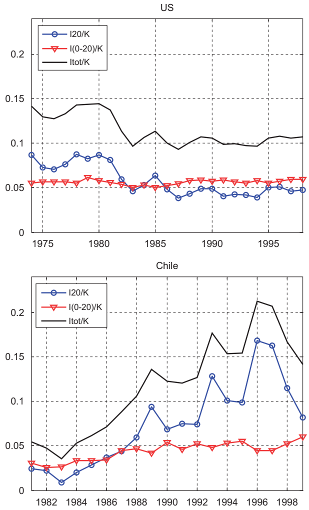
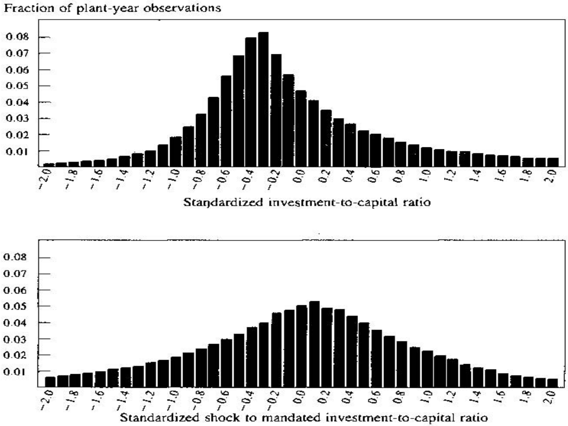


Fig. 1. Decomposition of aggregate investment for U.S. and Chilean manufacturing plant into investment spikes and remaining investment. *Note:* See Table 1 for definitions of the series.

A Non-Linear Relationship

- First panel, next page: histogram I/K, US manufacturing, establishments
- Second panel, next page: corresponding shocks (user cost of capital)
- Linear transformation of normal variables is normal
- Implies that function leading from shocks to investment is non-linear
- Figure from Caballero, Engel and Haltiwanger (1995)

Histograms and Non-Linear Relationship



Outline

- A. Using Micro Data
  - Based on Caballero, Engel and Haltiwanger (1995, BPEA)
- B. Using Only Aggregate Data
  - Based on Caballero and Engel (1999, Econometrica)

A. Using Micro Data

- Accounting
- Implementation

Accounting

- Mandated (by neoclassical theory) investment (to capital ratio):

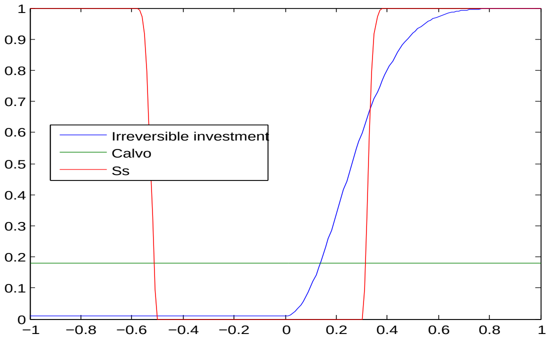
$$x_{it} \equiv \frac{K_{it}^* - K_{i,t-1}}{K_{i,t-1}} \cong k_{it}^* - k_{i,t-1}.$$

- Note: Change in sign for gap variable x
- Adjustment hazard:

$$\Lambda(x) \equiv \frac{\mathrm{E}[I/K|x]}{x}.$$

- $\Lambda(x)$: fraction of mandated investment undertaken on average by firms with gap x
- $f(x,t)$: Cross-section of x_{it}'s

Examples



1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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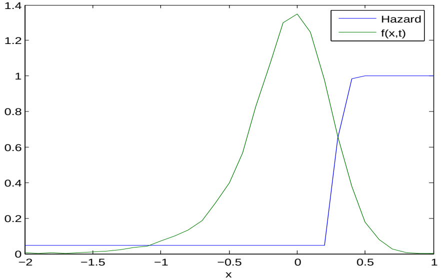
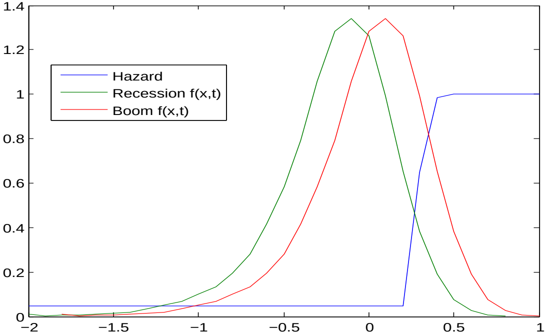
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
Irreversible investment
Calvo
Ss

Aggregate Equation

$$\boxed{\frac{I_t}{K_t} \cong \int x\Lambda(x)f(x,t)dx.} \qquad (1)$$



Recessions and Booms



Accounting

- Aggregate shock:

$$v_t = \text{Avge.}(\Delta k^*_{it}).$$

- Idiosyncratic shock:

$$v_{it} = \Delta k^*_{it} - v_t.$$

Responsiveness Index: General

- Marginal Response:

$$\boxed{\frac{\partial (I/K)_t}{\partial v_t}.}$$

- Corresponds to first element of IRF
- Partial adjustment:

$$\frac{I_t}{K_t} = (1-\lambda)\frac{I_{t-1}}{K_{t-1}} + \lambda v_t. \Rightarrow \frac{\partial (I/K)_t}{\partial v_t} = \lambda.$$

- In general, for process that is linear in the v_t (AR, ARMA, VAR), the responsiveness index does not vary over time.

Responsiveness Index: Increasing Hazard

- Denoting by $\tilde{f}(x,t)$ the pre-aggregate-shock x-section, we have:

$$\frac{I_t}{K_t}(v) = \int x\Lambda(x)\tilde{f}(x-v,t)dx = \int (x+v)\Lambda(x+v)\tilde{f}(x,t)dx$$

- Hence:

$$\begin{aligned}
\frac{\partial(I/K)_t}{\partial v_t} &= \int [\Lambda(x+v) + (x+v)\Lambda'(x+v)]\tilde{f}(x,t)dx \\
&= \int [\Lambda(x) + x\Lambda'(x)]f(x,t)dx.
\end{aligned}$$

where $f(x,t)$ denotes the (usual) post-aggregate-shock, pre-adjustment x-section.

Intensive and Extensive Margin

- Aggregate shocks shift the x-section of mandated investment to the right, one-for-one (assuming aggregate shocks are i.i.d.)
- Thus, if the fraction of units adjusting is unaffected by the marginal shock, the IRF will be equal to the fraction of units adjusting, as is the case with the Calvo model
- It follows that the first term on the r.h.s. of the expression we derived for the responsiveness index captures the effect due to the intensive margin
- Therefore the second term must capture the effect of the extensive margin

$$\frac{\partial(I/K)_t}{\partial v_t} = \underbrace{\int \Lambda(x) f(x,t)dx}_{\text{Intensive margin}} + \underbrace{\int x\Lambda'(x)] f(x,t)dx}_{\text{Extensive margin}}$$

Responsiveness Index: Increasing Hazard

- It follows that the Responsiveness Index (more generally, the IRF):
  - Depends on the x-section
  - Varies endogenously over time
- Adjustment hazard models as a parsimonious approach to incorporating time-varying IRFs

Economic Stimulus and Investment

- Economic stimulus (e.g., interest rate reduction, investment subsidy): shifts the x-section of x_{it}s to the right
- The responsiveness index is small when this x-section is concentrated to the left (recessions)
- Thus: will provide a stimulus that is too small if use the average responsiveness index to gauge size of the stimulus

Accounting: Summary

- Period t begins: x_{it}^B.
- Aggregate shock: v_t

$$x_{it} = x_{it}^B + v_t.$$

- Adjustments take place: Δk_{it}

$$x_{it}^A = x_{it} - \Delta k_{it}.$$

- Idiosyncratic shocks: v_{it}

$$x_{it}^I = x_{it}^A + v_{it}.$$

- "Accounting", if we only knew k_{it}^*.

Implementation

- Caballero, Engel and Haltiwanger (1995):
  - 7,000 US manufacturing plants, 1972-88
  - Continuous, large
  - Equipment investment and retirements

Estimating k^*

- From Neoclassical Model:

$$k^* - y = -\gamma u$$

with:

  - u: user-cost-of-capital
  - γ: elasticity of substitution K-L

- It is reasonable to assume that k and k^* are non-stationary, and that their difference, is stationary:

$$\varepsilon \equiv k - k^* \text{stationary}$$

Estimating k^*

- From both assumptions above we have that k and $y - \gamma u$ are cointegrated, so that we can estimate γ running OLS with:

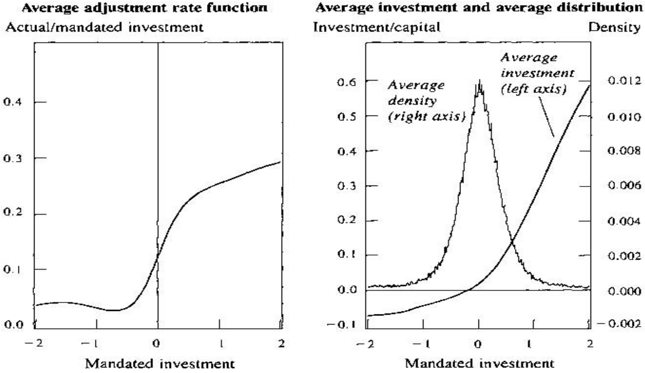
$$k - y = -\gamma u + \varepsilon.$$

- Use above cointegration argument with
  - sub-sector specific γ
  - small-sample correction (important, since $\mathrm{Var}(k - y) << \mathrm{Var}(k^* - y)$
- Find $\mathrm{Avge}(\gamma) \cong 1$, as predicted by Neoclassical Model

Estimated Hazard and Avge. Cross-section

22 *Brookings Papers on Economic Activity, 2:1995*

Figure 8. Relationship between Investment and Mandated Investment



B. Using Only Aggregate Data

- Micro model
- Aggregation
- Estimation
- Why so much better?

Microeconomic Model

- Discrete time
- Firm's profit:

$$\Pi(K,\theta) = K^{\beta}\theta - (r+\delta)K;$$

- With:
    - $0 < \beta < 1$
    - θ: demand/productivity/wage shocks

Microeconomic Model

- Assume: θ follows a Geometric Random Walk
- Define:

$$K^* = \text{argmax}\Pi(K, \theta) = \left(\frac{\beta\theta}{r+\delta}\right)^{1/(1-\beta)}.$$

- It follows that:

$$\Delta \log K^* \equiv \Delta k^* \text{is i.i.d.}$$

Adjustment Costs

- Assume:

$$\text{Adjustment cost} = \omega[\text{Foregone Profits}].$$

with ω i.i.d. with c.d.f. $G(\omega)$ observed before deciding whether to adjust

- Assuming stochastic fixed adjustment costs combines two literatures:
  - Ss: fixed cost leads to infrequent and lumpy adjustment
  - Search: a distribution of adjustment costs means that it may be attractive to wait for a better draw.

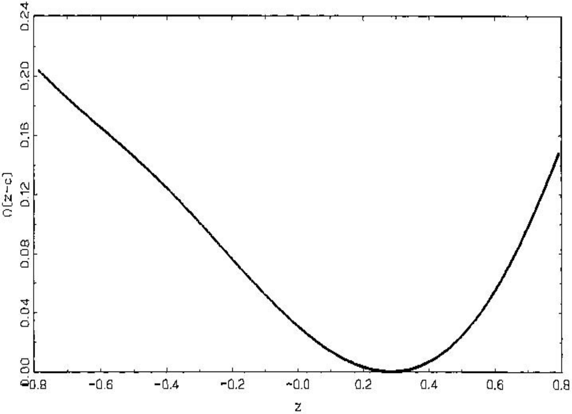
Solving the Dynamic Programming Problem

- See Caballero and Engel (1999) for details
- State variable:

$$z = \log(K^*/K) = k^* - k.$$

  corresponds to mandated investment, mandated by the neoclassical model
- Adjustment: 0/1
- Figure on next page depicts adjustment and non-adjustment regions, $x \equiv z - c$, where c is the return point

Optimal Microeconomic Policy



Optimal Microeconomic Policy

- Conditional on current draw ω:
  - Two-sided *Ss* policy (LCU policy)
  - Inaction range larger for larger values of ω
- Conditional on current gap x:
  - Probability of adjusting:

$$\Lambda(x) \equiv G(\Omega(z-c)) = G(\Omega(x)).$$

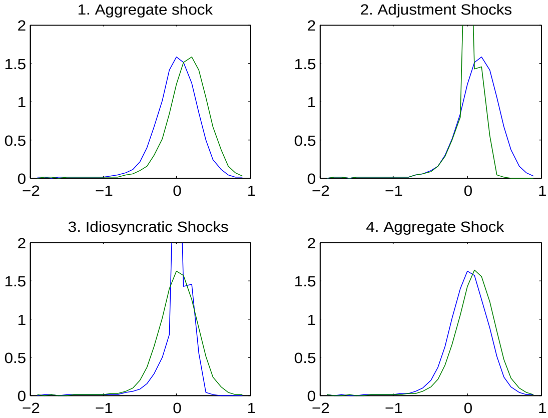
Particular Cases

- Calvo: $G(\omega)$ with mass λ at 0 mass $1 - \lambda$ at ω_M, with $\omega_M \to \infty$.
- Quadratic adjustment: equivalent to Calvo
- Ss: $G(\omega)$ mass one at K. In this case $\Lambda(x) = 0$ or 1.

Estimation Using Aggregate Data

- We need: $f(x, t); \;\; t \geq 0$
- Replace data by assumptions:
  - v_t: i.i.d. normal
  - v_{it}: i.i.d. normal
  - Adjustment: either full (x) or not at all
- Data:
  - US Manufacturing, 1947-1992
  - Two digit, constrained panel
  - Equipment and structures separately

Evolution of the Cross-Section



Given $\Lambda(x)$ and $f(x, 0)$, can find a unique sequence of aggregate shocks that matches observed I/K

Econometrics

- Non-linear filter
- v_t i.i.d. avoids having to proxy for K^*
- Maximum likelihood estimation
- Semi-structural:

$$\Lambda(x) = 1 - e^{-\lambda_0 - \lambda_2 x^2}.$$

- Structural:

$$G(\omega) \rightsquigarrow \text{Gamma distribution.}$$

Econometrics: Details in One Dimensional Case

- Given a set of parameters Θ:
  - $G(\omega)$ or $\Lambda(x)$
  - μ_A, σ_A, σ_I,...
- Based on x-sectional dynamics:

$$y_t = y_t(v_1, ..., v_t; \Theta);$$

with $y \equiv I/K$.

Econometrics: Details in One Dimensional Case

- For estimation need:

$$v_t = v_t(y_t, v_1, \ldots, v_{t-1}; \Theta) = v_t(y_t, f(\cdot, t-1); \Theta).$$

- To find v_t consistent with given Θ solve:

$$y_t = \int x\Lambda(x) f(x - \delta - v_t, t-1) dx.$$

- From $f(x, t-1)$ to $f(x, t)$: apply aggregate shock v_t followed by adjustment shock determined by $\Lambda(x)$ followed by idiosyncratic shock determined by σ_I

Econometrics: Details in One Dimensional Case

- Doing the above for $t = 1, 2, \ldots, T$ you determine:

$$\begin{array}{ccc} v_1, & \ldots, & v_T \\ \dfrac{\partial y_1}{\partial v_1}, & \ldots & \dfrac{\partial y_T}{\partial v_T}. \end{array}$$

- Initial density, $f(x, 0)$: individual plants' invariant density

A Simple Example

- MLE:

$$-\text{lik}(\Theta|y_1, ..., y_T, f(x,0)) =$$

$$= \text{const} + \sum_t \log \left| \frac{\partial y_t}{\partial v_t} \right| + \frac{T}{2} \log \left(\sum_t (v_t - \mu_A)^2 \right).$$

- Note: since $\Lambda(x)$ varies with x, we have that $\partial y_t / \partial v_t$ varies with t

Numerical Issues

- Two options

  1. Stochastic Markov chain with dynamic grid
  2. Choose $\Lambda(x)$ and $g(x)$ (density idio. shocks) within families s.t. $f(x,t)$ is easy to track:

     - $\Lambda(x)$: inverted normal
     - $g(x)$: normal
     - Then: $f(x,t)$ is a convex combination of normals

Results: Semi-Structural

- $\lambda_2 >> 0$
- Implied adjustment hazard:

	x:	0	$\longrightarrow$	40%
$\Lambda(x)$:	Equip.:	14	$\longrightarrow$	45%
	Structures:	0	$\longrightarrow$	32%

Results: Structural

	Equipment	Structure
Average ω:	16.7%	22.8%
Average cost paid:	11.1%	21.4%

Comparison

- Compare with unconstrained AR(2)
- Within sample criteria:
  - increasing hazard has much better likelihood
  - not surprising, given non-linear relationship
- Out-of-sample criteria:
  - Increasing hazard has much smaller RMSE for one-step-ahead forecasts
  - Equipment: 6.6% smaller
  - Structures: 31.3% smaller

Why so much better

- Ability to capture non-linearities:
  - Normal shocks
  - I/K: positive skewness (at plant and sectoral levels)
  - Direct evidence of non-linearity shortly
- Endogenous variation:
  - Number of firms adjusting changes over time
  - Marginal response changes over time

Estimated Responsiveness Index