Learning and Forgetting: The Dynamics of Aircraft Production

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Overview

Learning and Forgetting: The Dynamics of Aircraft Production

- **Research Question:** Explore the role of organizational forgetting and incomplete spillover on learning curve.
- Model organizational forgetting and incomplete spillover through learning.
- Estimate the model using 2SLS and GMM.
- **Why is this interesting?:**
    - Macroeconomics: economic scarring
    - Incomplete Spillover: Infant industry and optimal number of product
    - Human Capital and Organizational Structure

Data

Production of L-1011

1. **L-1011 production (1970-1984):** No subcontracted data.

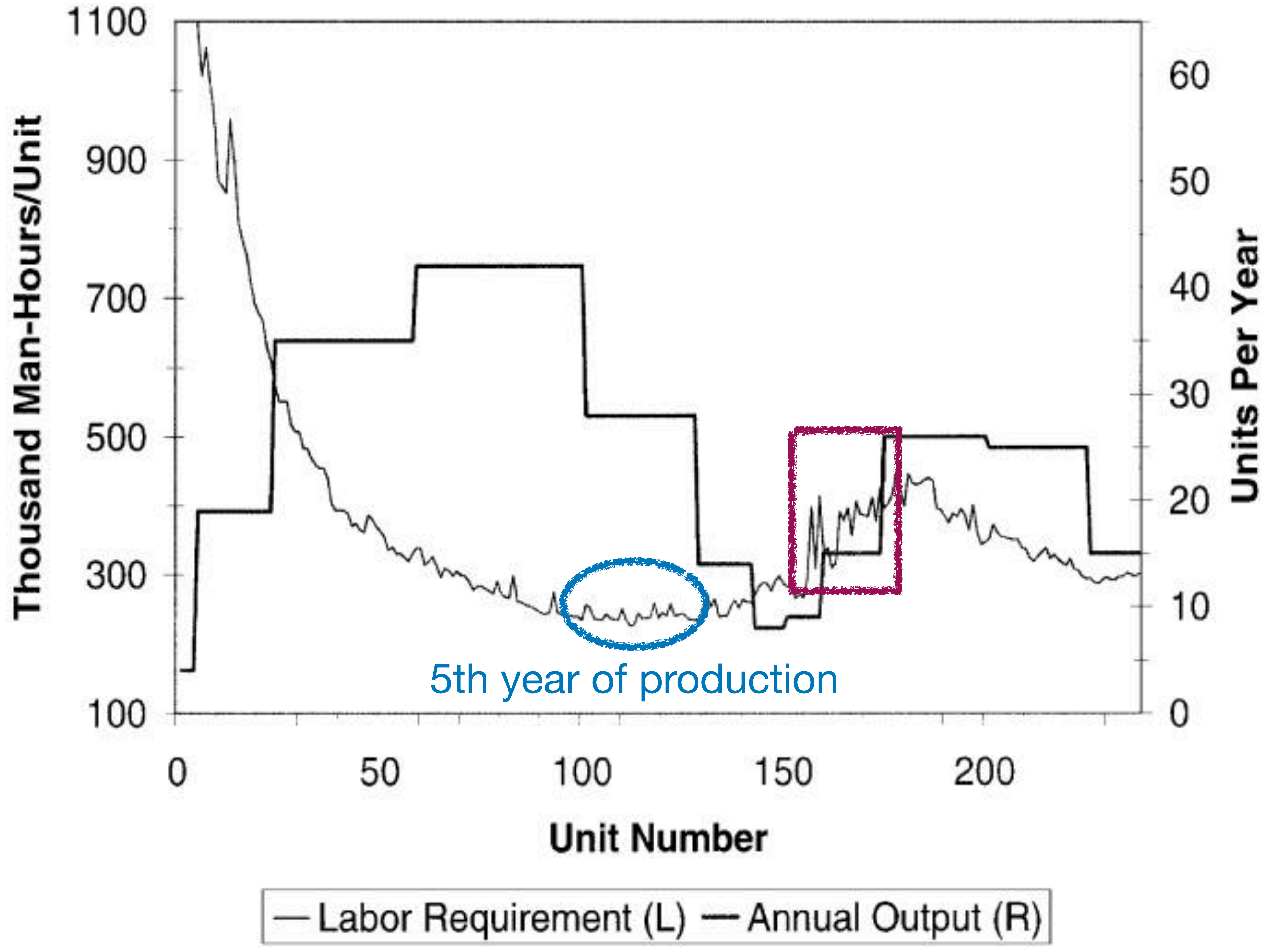
2. **Jet Airline Production List Volume 2:** Model, Serial Number, Ownership history, date of completion

- **Type of Aircraft:** fuselage
    - Type 1 (L1011-1): -1, -100, -200
    - Type 2 (L1011-500): -500 with shorter fuselage

- **Mechanisms:** (1) Learning, (2) Forgetting, (3) Spillover

Aircraft Industry: Data

Unit labor requirement and output



Model of Commercial Aircraft Production

Learning

- Wright (1936): 20% Learning curve

Labor input = f(Experience)

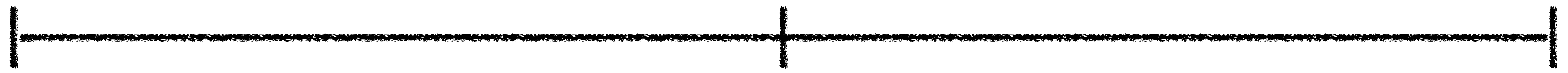
- *Leontief production* function with *fixed capital* ($\bar{K}$)

q = min (G(labor) , H(materials))

- Adjust variable inputs at unit level (L,E,S) - Cobb Douglas efficient frontier

$$\ln L_i = \ln A(\bar{K}) + \theta \ln E_i + \gamma_0 \ln S_i + \varepsilon_i$$

- Production Timeline:



Model of Commercial Aircraft Production

Forgetting and Spillover

Traditional Learning Model:

- $E_i = E_{i-1} + 1$

General Learning Model

- Forgetting: Depreciation of Experience - Job turnover

$$\text{Experience} = \underbrace{\text{Un-depreciated Experience}}_{\text{Forgetting}} + \underbrace{\text{Production Last Period}}_{\text{Learn}}$$

- Spillover: Optimal number of products

$$\text{Experience}_i = \text{Un-depreciated Experience}_{i,t-1} + \text{Production}_{i,t-1} - \boxed{\lambda\text{Production}_{-i,t-1}}$$

Estimation

Instrumental Variable for Experience and Linespeed

- Cobb Douglas Efficient Frontier

$$\ln L_i = \ln A(\bar{K}) + \theta \ln E_i + \gamma_0 \ln S_i + \varepsilon_i$$

- Instrument for Linespeed and Experience
  - Demand shifters: GDP, price of oil and time trend
  - Cost shifters: aluminum price, wage
- Estimate 2SLS for traditional learning model
- Estimate GMM (Hansen, 1982) for general learning model

Result: Traditional Learning Model

TABLE 1—TRADITIONAL LEARNING MODEL REGRESSIONS

	ln A	θ	γ_0	γ_1	Time	Adj.+	Adj.−	SSR	ρ_e	L.R.
Basic regressions										
1. Units 1–112	7.90	−0.51	—	—	—	—	—	1.36	0.73	30%
	(0.06)	(0.01)							(0.04)	
2. Units 1–238	7.16	−0.29	—	—	—	—	—	15.0	0.97	18%
	(0.08)	(0.02)							(0.02)	
Line speed										
3.	6.51	−0.35	0.95	−0.20	—	—	—	11.0	0.92	21%
	(0.21)	(0.02)	(0.17)	0.03					(0.03)	

TABLE 2—TRADITIONAL LEARNING MODEL REGRESSIONS: INPUT PRICES AND DISECONOMIES OF SCOPE

	ln A	θ	γ_0	γ_1	Wage	P_{AL}	P_{oil}	Scope	SSR	ρ_e	L.R.
Diseconomies of scope											
6.	7.35	−0.49	0.49	−0.10	—	—	—	0.55	2.4	0.70	29%
	(0.10)	(0.01)	(0.08)	(0.02)				(0.02)		(0.04)	
Oil price											
7.	5.88	−0.54	1.36	−0.27	—	—	0.27	—	9.3	0.83	32%
	(0.21)	(0.03)	(0.17)	(0.03)			(0.04)			(0.04)	
Input prices											
8.	−15.9	−0.52	0.45	−0.09	8.68	0.50	—	—	10.0	0.81	30%
	(3.37)	(0.03)	(0.18)	(0.03)	(1.32)	(0.09)				(0.04)	
N = 238	TSS = 33.7										

Notes: All regressions are 2SLS. Instruments (Z_t) are present and lagged demand shifters (various world GDP measures, the price of oil, and a time trend; see text) and present and lagged cost shifters (U.S. wage rate, aluminum price). L.R. is the implied learning rate.

Result: General Learning Model

TABLE 3—GENERAL LEARNING MODEL REGRESSIONS

	ln A	θ	γ_0	δ	λ	SSR	GMM(p)	ρ_e	L.R.
OF only									
9. [$S_N^* = 9.3$]	7.63	−0.65	0.14	0.952	—	2.9	0.60	0.51	36%
	(0.01)	(0.02)	(0.12)	(0.003)				(0.05)	
Spillovers									
10. [$S_N^* = 6.9$]	7.73	−0.63	0.11	0.960	0.70	2.3	0.62	0.45	36%
	(0.01)	(0.03)	(0.17)	(0.003)	(0.07)			(0.05)	
N = 238	TSS = 33.7								

TABLE 4—ALTERNATIVE HYPOTHESES

	ln A	θ	γ_0	δ	λ	Wage	P_{AL}	P_{oil}	Scope	SSR	GMM(p)	ρ_e	L.R.
Scope													
11. [$S_N^* = 7.7$]	7.91	−0.71	0.13	0.954	0.73	—	—	—	−0.03	3.1	0.62	0.45	39%
	(0.01)	(0.02)	(0.10)	(0.004)	(0.17)				(1.92)			(0.05)	
Oil price													
12. [$S_N^* = 9.0$]	7.72	−0.72	0.17	0.946	0.79	—	—	−0.003	—	3.3	0.89	0.51	39%
	(0.01)	(0.02)	(0.05)	(0.002)	(0.05)			(1.13)				(0.05)	
Input prices													
13. [$S_N^* = 7.9$]	7.63	−0.70	0.14	0.952	0.77	0.06	0.009	—	—	2.9	0.78	0.46	38%
	(0.13)	(0.01)	(0.08)	(0.003)	(0.04)	(6.36)	(2.96)					(0.05)	
N = 238	TSS = 33.7												

Notes: All regressions in this table use the HAC-IV method described in the text. Instruments (Z_t) are present and lagged demand shifters (various world GDP measures, the price of oil, and a time trend; see text) and present and lagged cost shifters (U.S. wage rate, aluminum price). S_N^* is the optimal bandwidth used in estimating the GMM covariance and optimal weight matrices. L.R. is the implied learning rate.

Conclusion

- **Contribution**
  - Role of organizational forgetting to model learning
- **Implication and Possible Extensions:**
  - Macroeconomic implication of forgetting
    - Experience rate is a choice variable for firms.
  - Stochastic learning
  - Internalization of business stealing effects of product differentiation.