The Dynamic Effects of Recyclable Materials on Oligopoly Competition: Evidence from the US Paper Industry

Eddie Watkins

UNC Chapel Hill

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Competition from Recycling Firms over Time

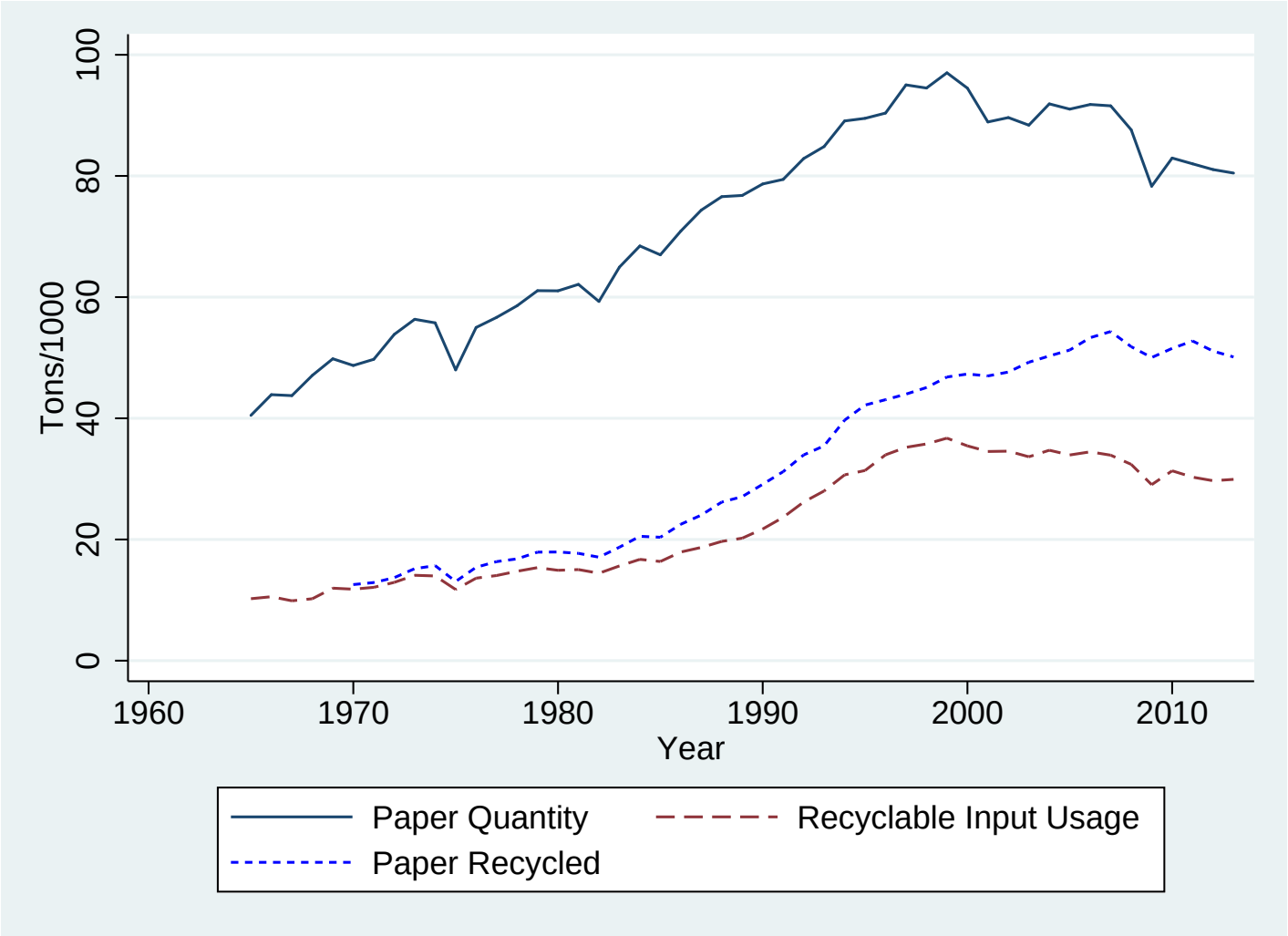

Figure 1: Total Paper Quantity, Amount of Paper Recycled and Use of Recyclable Inputs at Paper Mills over Time

Economic Issues

1. Dynamics: Supply today affects competition tomorrow.
2. Effect of recycling on market power has been a concern since U.S. v. Alcoa (1945).
3. Competition: Cournot in final product and oligopsony in recycled input market.
4. Policy: Subsidy for purchase of paper made from recycled inputs.

Contributions

1. Theoretical
   1. Develop a dynamic oligopoly model that accounts for dynamic effects of recycled inputs on imperfect competition.
   2. Generate testable hypotheses for firm supply behavior.
2. Empirical
   1. In main specification a 10% increase in the stock of recyclable material reduces supply at mills producing from virgin inputs by 1.8%.
   2. Softening future competition provides further incentive for horizontal mergers between firms using virgin inputs.
   3. Subsidy less effective in shifting supply towards goods produced from recycled inputs in model with dynamic effects.

Model

1. There are M firms that produce from virgin inputs and N firms that produce from recycled inputs.
2. There is a set of price taking wholesalers that turn used good into recycled input.
3. Firms using recycled input have purchasing power for this inputs.

▸ Wholesaler Example

Timing

1. At the start of each period t firms observe the stock of the recyclable material carried over from the previous period, $\bar{Q}_{t-1}$.
2. Firms engage in Cournot competition in the final product market.
3. Consumers use and then recycle a share, ψ_t, of the good.
4. The law of motion for the stock is

$$\bar{Q}_t = f(\psi_t, Q_t, \bar{Q}_{t-1}).$$

Demand and Supply Assumptions

1. Inverse demand, $P(Q_t)$, is continuous, decreasing and not too convex in supply.
2. Total cost for each firm, $C_i(q_i)$, is increasing and convex in own supply.
3. The supply of the recycled input in period t is

$$R\Big(\underbrace{\sum_{n=1}^{N} q_{n,t}}_{Standard\ \ Supply}\ ,\ \underbrace{\bar{Q}_{t-1}}_{Dynamic\ \ Effect}\Big)$$

with $R_1 \geq 0$, $R_2 \leq 0$, and $R_{1,2} \leq 0$.

Payoffs

1. The flow profits for a firm using virgin inputs i and a firm using recycled inputs j are

$$\pi_i(q_{i,t}, q_{-i,t}, \bar{Q}_{t-1}) = P(Q_t)q_{i,t} - C_i(q_{i,t}) \tag{1}$$

$$\pi_j(q_{j,t}, q_{-j,t}, \bar{Q}_{t-1}) = P(Q_t)q_{j,t} - \tilde{C}_j(q_{j,t}) - R(\sum_{n=1}^{N} q_{n,t}, \bar{Q}_{t-1})q_{j,t}. \tag{2}$$

2. Firms have common discount rate δ and each firm of type k solves

$$V_k(\bar{Q}_{t-1}) = \max_{q_{k,t}} \quad \pi_k(q_{k,t}, q_{-k,t}\bar{Q}_{t-1}) + \delta V_k(\bar{Q}_t) \tag{3}$$

$$s.t. \quad \bar{Q}_t = f(\psi_t, Q_t, \bar{Q}_{t-1}).$$

Implications for Behavoir

1. An increase in the stock of recyclable materials decreases supply from firms using virgin inputs and increases supply from firms using recycled inputs.
2. The changes in supply are greater in magnitude in model with dynamic effects.
3. Changes in the recycling rate affect current behavior only by changing future payoffs.

▸ Duopoly Example

Data

1. Mill level information from the Lockwood Post Directory of Paper, Pulp and Allied Product.
2. Data on mill usage of recycled inputs from the Forest Product Laboratory.
3. Information on subsidy law for each state.
4. Data on regional and state level demand shifters, costs, and recycling rates.
5. Construct stock of recyclable material for each product.
6. Each year from 1973 to 1993.

Empirical Evidence of Dynamic Effects

1. Unit of observation is a mill i, manufacturing product j, in state s and year t. I run following regressions separately for primary and secondary mills

$$logQ_{i,j,s,t} = \alpha log\bar{Q}_{j,s,t-1} + \beta Subsidy_{s,t} + \gamma Recycling_{s,t} + \mathbf{X}_{i,j,s,t}\eta + \lambda_i + \lambda_t + \lambda_j + \epsilon_{i,j,s,t}.$$

2. Main hypotheses: $\alpha \leq 0$,$\beta \leq 0$ for primary mills from strategic interaction. $\gamma \leq 0$ for primary mills from dynamic effects.

▸ Exogeneity

Mill Level Response

Within Regressions of Mill Supply on Covariates

	Virgin	Virgin
Subsidy Indicator	-0.28***	-0.26***
Recycling Rate	-0.01**	-0.01***
log(Stock)	-0.18***	-0.16***
# Primary Rivals		-0.08***
# Secondary Rivals		-0.10***
Observations	6,929	6,534
R-squared	0.255	0.259
Number of Mills	325	319

*** p<0.01, ** p<0.05, * p<0.1

Note: All regressions include mill, year, and product fixed effects, and control variables. Coefficients on fixed effects and control variables omitted for brevity.

Counterfactual Exercises

1. Solve for equilibrium in a parameterized two-period version of the game.
2. First set of exercises motivated by wave of horizontal mergers in paper industry.
3. Second set of exercises motivated by government policies to increase secondary production.

Merger Exercises

Merger Exercises: Markups and Payoffs

%Δ Dyn over Non-Dyn Model		
Market Structure	Virgin Firm Lerner	HHI
3 V 3 R	2.07	-1.44
1 V 3 R	1.75	-7.30
1 V 10 R	1.61	-11.91

Note: Results of antitrust exercises with linear demand, recycled input supply function of Swan (1980), and constant marginal costs. Mergers combine the firms using virgin inputs. V denotes virgin firms and R denotes recycled firms.

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%Δ Pre-Merger over Post-Merger		
Pre-Merge Market Structure	Insiders Profit $t = 1$	Insiders Profit $t = 2$
2 V 1 R Dyn	-3.97	9.91
2 V 1 R No Dyn	2.41	8.51

Note: Results of antitrust exercises with linear demand, recycled input supply function of Swan (1980), and constant marginal costs. Mergers combine the firms using virgin inputs. V denotes virgin firms and R denotes recycled firms.

Policy Analysis

Policy Exercises: Outcomes and Recycled Supply Share

%Δ Policy vs Baseline

Policy	Q_v t=1	Q_v t=2	Share Rec t=1	Share Rec t=2
Observed Subsidy Dyn	-0.72	-0.36	1.19	0.15
Observed Subsidy No Dyn	-0.46	-0.39	1.09	0.31
Inc. Initial Stock Dyn	-3.17	-0.68	21.95	2.80

Note: Results of policy exercises with linear demand, recycled input supply function of Swan (1980), and constant marginal costs. These results are for 1 virgin and 1 recycled firm.

Implication for Policy Design

1. Change in behavior caused by subsidy less in model with dynamic effects.
2. Issue is strategic actions affect future competition.
3. Future work on accounting for competition and dynamics in policy design.

Thanks

Thank you!

Eddie Watkins
wewatkin@live.unc.edu

Wholsaler Behavior and Recycled Supply

1. Following Swam (1980) specify the wholesaler's problem as

$$\pi_w = \max_z \ (P_R r(z) - z)\bar{Q}.$$

2. Using $r(z) = 1 - e^{-kz}$, the optimal wholesaler recovery rate is

$$r(z^*) = 1 - \frac{1}{kP_R}.$$

3. Plug into wholesalers' supply and rearrange to get

$$P_R(Q_R) = \frac{\bar{Q}}{k(\bar{Q} - Q_R)}$$

which satisfies conditions of theoretical setup.

▸ Return

Duopoly Example

1. Apply the Implicit Function Theorem to first order conditions for virgin firm, 1, and recycled firm, 2.
2. The result is given by

$$sign(\frac{dq_1}{d\bar{Q}}) = sign(-\pi^1_{1,3}\pi^2_{2,2} + \pi^2_{2,3}\pi^1_{1,2}) \ , \ sign(\frac{dq_2}{d\bar{Q}}) = sign(-\pi^1_{1,1}\pi^2_{2,3} + \pi^2_{2,1}\pi^1_{1,3}).$$

   where the partial derivatives are with respect to q_1, q_2 and $\bar{Q}$ respectively.
3. Under assumptions of theoretical model: $\pi^1_{1,3} = 0$, $\pi^2_{2,3} \geq 0$, and $\pi^1_{1,1} \leq 0$. Thus, the claim holds if $\pi^i_{i,-i} \leq 0$, i.e. if goods are strategic substitutes.
4. Profit result follows from signing the change in profit

$$(\Delta\bar{Q})\frac{d\pi^i}{d\bar{Q}} = (\Delta\bar{Q})[\pi^i_i\frac{dq_i}{d\bar{Q}} + \pi^i_{-i}\frac{dq_{-i}}{d\bar{Q}} + \pi^i_3].$$

▸ Return

Exogeneity of Subsidies

Table: Subsidy Law Regressions

VARIABLES	(1)	(2)	(3)	(4)
LCV House Ave	0.014***	0.049	0.014**	0.013**
# Recycled Mills	-0.00041	-0.029		
# Laws in Effect				0.062***
Observations	896	796	775	796
Subsidy Absorbs		Yes	Yes	Yes
Number of States			42	

*** p<0.01, ** p<0.05, * p<0.1

Note: League of Conservation Voters (LCV) scores averaged over all Representatives for the state based on votes on environmental issues. Regressions in which subsidy is an absorbing states drops observations after subsidy.

▸ Return

Variation in Subsidies for Paper made from Recycled Inputs over Time

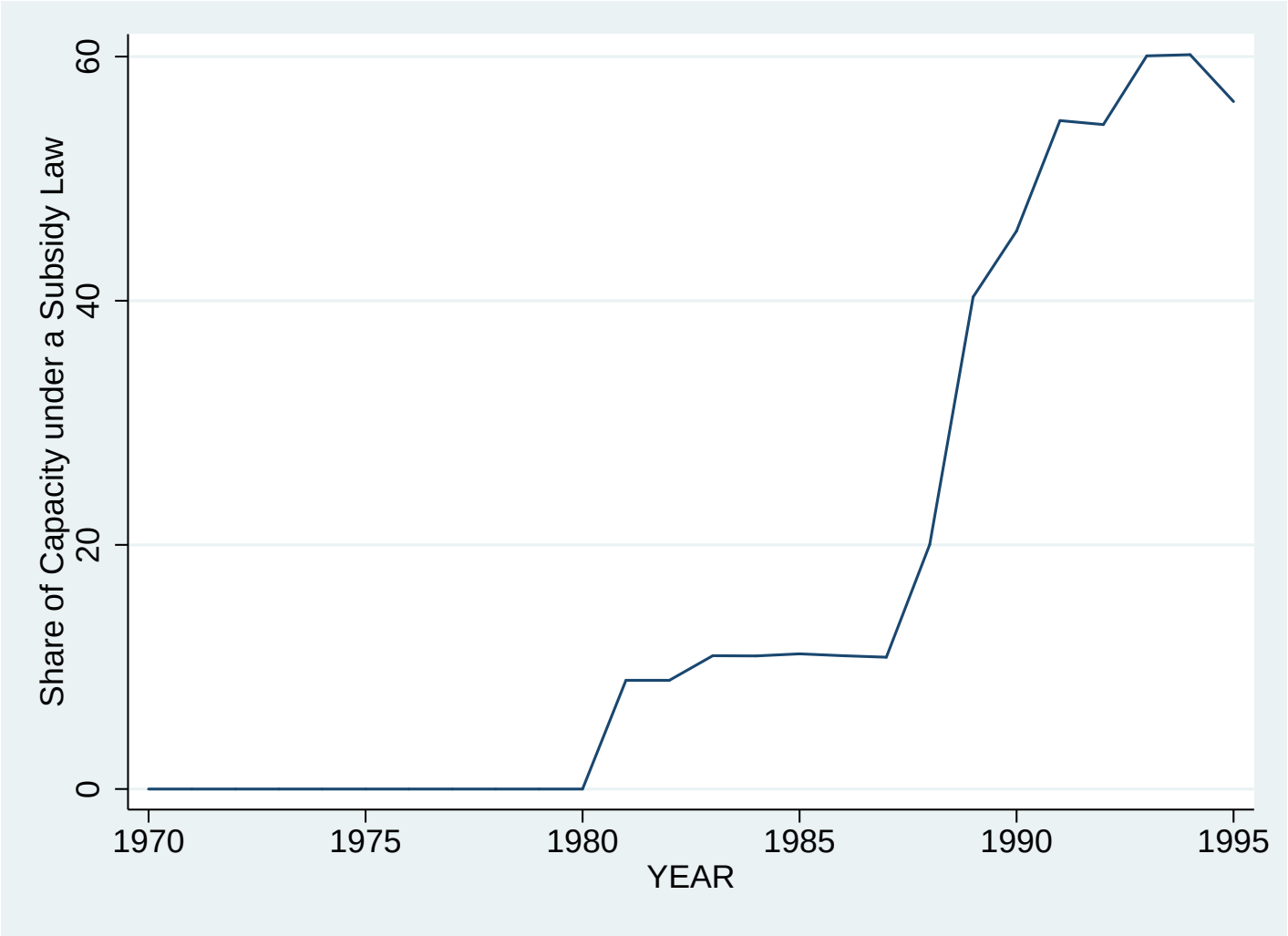

Figure 2: Share of Paper Capacity Covered by State Subsidy

Virgin and Recycled Capacity Cardboard over Time

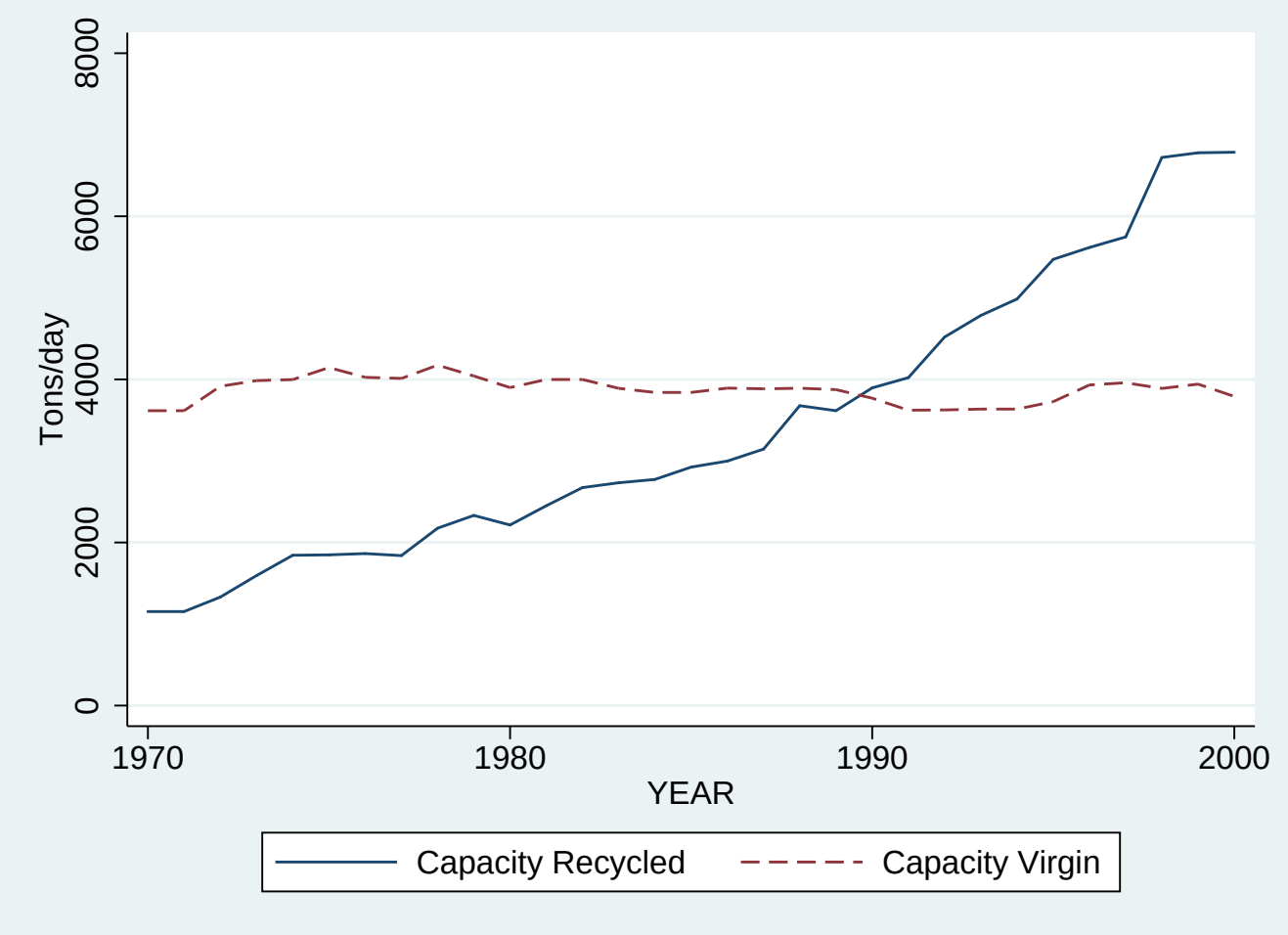

Figure 3: Corrugated Cardboard Produced from Virgin and Recycled Inputs over Time

Virgin and Recycled Capacity Printing Paper over Time

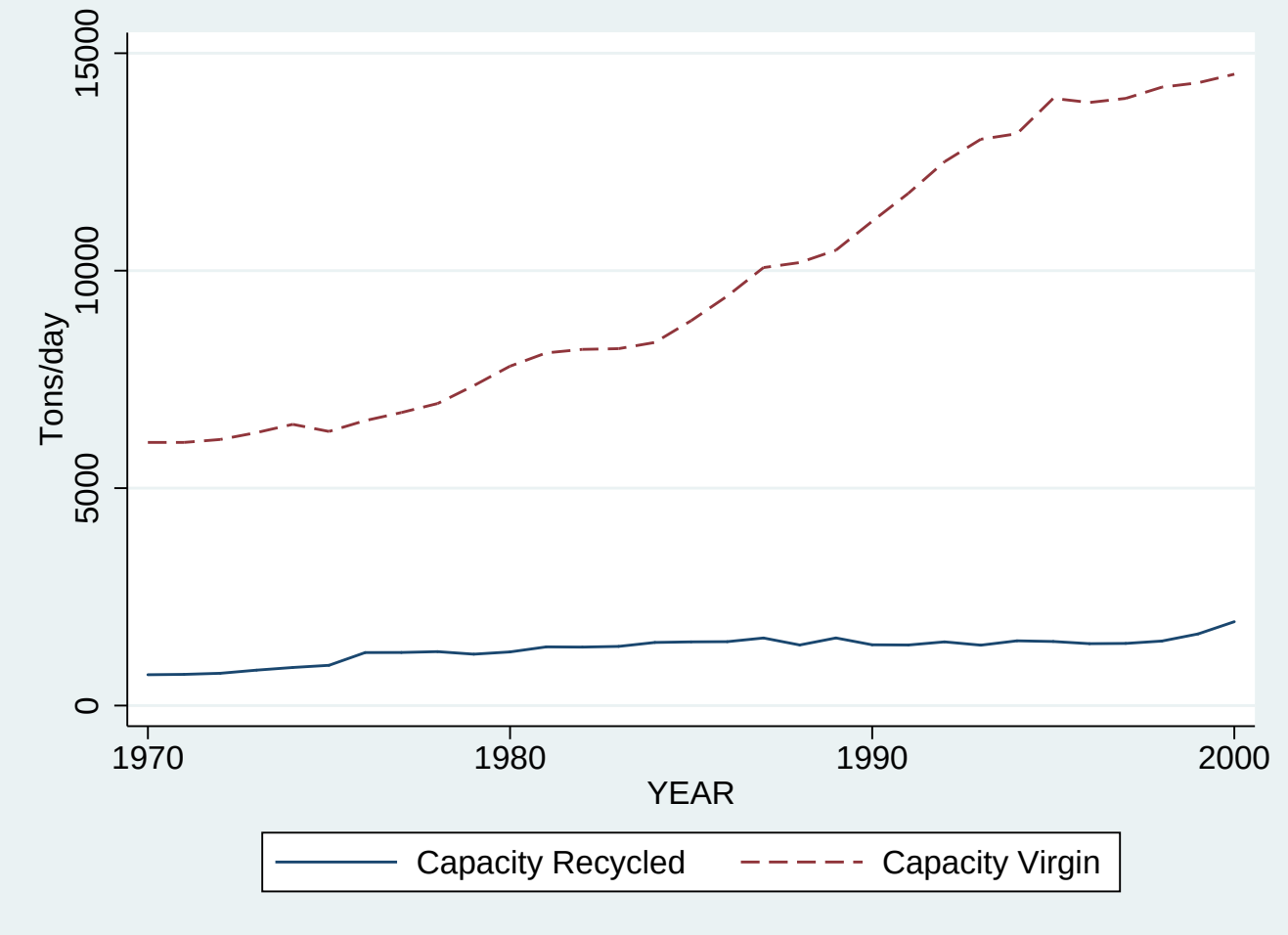

Figure 4: Uncoated Freesheet Produced from Virgin versus Recycled Inputs over Time

Mill Level Data

Table:Product-Mill Level Summary Statistics

Product	Share Virgin	Ave. Mill Capacity (tons)	$log(\bar{Q}_{j,t-1})$	Obs
Paper				
Coated Freesheet	95	306	8.69	645
Coated Groundwood	100	482	8.95	360
Kraft Paper	70.7	358	7.11	597
Newsprint	75.1	695	0	476
Tissue Paper	38.3	139	9.12	1979
Uncoated Freesheet	85.5	259	8.31	2187
Uncoated Groundwood	88.7	248	9.02	347
Special Paper	89.6	96	9.25	1398
Paperboard				
Corrugating Medium	44.6	333	8.4	1245
Linerboard	64.4	722	8.65	1263
Solid Bleached Board	100	726	-	474
Recycled Paperboard	0	143	8.84	3078

Author calculations from combined industry and government sources. The unit of

Comparison of Markups and Concentration with Dynamic Effects

1. Link between structure and performance comes from averaging Lerner Index
$$LI \equiv \sum_{i=1}^{M+N} s_i \frac{p - c_i'(q_i)}{p} = \frac{HHI}{\epsilon}. \quad (4)$$
2. With the dynamic effects add $\frac{-\delta\psi}{p} \sum \frac{\partial V_i(\bar{Q})}{\partial \bar{Q}}$ to average Lerner Index.
3. Market shares in the model with dynamic effects represent a mean-preserving contraction relative to the model without. The result follows because $HHI = N\sigma^2 + N\mu^2$.

Owner Level Capacity Regression

Table: Panel Regressions of Capacity on Covariates

VARIABLES	Virgin	Virgin
Subsidy Indicator	-0.43**	-0.44**
Recycling Rate	-0.013***	-0.013***
log(Stock)	-0.14***	-0.14***
# of Firms		0.015
Observations	3,957	3,957
R-squared	0.322	0.323
Number of Owners	200	200

*** p<0.01, ** p<0.05, * p<0.1

Note: Regressions using data from the Lockwood Post Directory. Ownership constructed from Lockwood Post Directory.