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

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Abstract

When consumers recycle a good, the future supply of intermediate inputs increases. If some of the inputs are used to manufacture a good that competes with the original good, the initial seller faces an incentive to reduce its supply to limit this source of future competition. I illustrate the incentive in a model of dynamic oligopoly, and test the predictions using novel data from the US paper industry between 1973 and 1993. I find that firms decrease quantity in response to policy changes that increase competition from firms using the recycled input. I then use the model to illustrate two implications: (i) horizontal mergers let firms internalize effects on future competition, resulting in a greater supply reduction post-merger, and (ii) policies designed to shift production to environmentally friendly firms are undercut by countervailing supply incentives. I also show that using measures of concentration to infer the exercise of market power will lead to antitrust authorities to underestimate both current market power, and the exercise of market power post-merger.

JEL Codes: L13, L14, L41, L73, Q21, Q23

Keywords: Imperfect Competition, Dynamic Incentives, Recycling, Input Markets, Merger Policy, Environmental Policy

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1 Introduction

A firm with market power may forgo current profits to alter future competition.[1] When consumers recycle a good, the future supply of intermediate inputs increases. If some of these inputs are used to create a good that competes with the initial good, this intertemporal link creates an incentive for the original producer to reduce supply below the optimal static level to limit future competition. In markets with many original sellers, a supply reduction by one of these firms also benefits the others in the future. Therefore, firms face a weaker incentive to reduce supply in an oligopoly than in a market with a single original seller.

The US paper industry provides a natural setting to study the dynamic effects caused by recycling on oligopoly competition. This industry includes two types of firms: primary firms that produce only from virgin wood and secondary firms that produce only from recycled paper. Between 1970 and 2015 the percentage of paper recycled increased from 25% to 67%, resulting in a significant increase in the availability of secondary firms' input. Greater recycling changed the competitive landscape with primary firms' market share declining from 76% in 1970 to 48% in 2015.

My analysis proceeds in 3 steps. First, I develop a theoretical model of dynamic oligopoly competition with a good that is recycled that generates empirically testable hypotheses. I then use data on the US Paper Industry to test whether primary firms reduce their quantity supplied in response to incentives created by increased competition from secondary firms. Finally, I use the model to illustrate the implications of the model's incentives on equilibrium outcomes of policy interventions.

I illustrate the strategic incentives faced by firms using a dynamic oligopoly model that captures key features of the US Paper Industry. The key assumptions of the model are: (i) a firm is harmed by rivals' production, and (ii) an increase in contemporaneous supply lowers secondary firms' future marginal costs. The combination of these forces causes primary firms to reduce quantity supplied.[2] Because other primary firms also benefit from a reduction in the future stock of recycled paper, the incentive for an individual firm to reduce supply is lessened relative to a market with a single primary firm.

To test the hypotheses of the model, I construct a unique dataset on each paper mill in the United States operating between 1973 and 1993. These data let me identify mills as either primary or secondary, and calculate these mills' quantity supplied. These two pieces of information let me match the empirical outcome to the theoretical predictions. I also collect information on government policies, demand and cost factors, and data on regional recycling markets. These variables let me account for other factors that more fully describe supply behavior.

[1] Shapiro (1989) and Besanko, Doraszelski, and Kryukov (2017) discuss a wide range of theoretical and empirical models that feature this incentive. Examples include behavior that lowers own marginal costs, such as R&D spending and learning by doing, and behavior that creates product differentiation, such as switching costs and network effects.

[2] Fudenberg and Tirole (1984) provide a taxonomy of dynamic incentives that my model fits into. In particular, (i) implies downward sloping best response functions and (ii) implies more supply today makes rival firms stronger in the future. Hence, my model is an example of their "lean and hungry look."

I organize the data such that the fundamental unit of observation is a primary firm in a given state and year. I run regressions that use variables that change the intensity of competition from the secondary firms as the key covariates of interest, and I take the primary firm's quantity supplied as the outcome of interest. I test the hypotheses of the model by investigating (i) whether firms respond to more intense competition from secondary firms in the contemporaneous period, and (ii) whether primary firms respond to how their current quantity choice changes future competition.

I use several key sources of variation in the empirical analysis. The first source comes from state subsidies for secondary firms. Thus, competition from secondary firms should be more intense in states with a subsidy, and primary firms should respond by reducing their supply. The enactment of these subsidies varied over time and across states in response to time varying electorate preferences for environmental regulation. I also exploit variation from the current stock of recycled inputs. An increase in the stock directly decreases secondary firms' costs and leads to a strategic reduction in primary quantity supplied. The final source of variation comes the paper recycling rate over time and across regions driven by differences in the opportunity cost of recycling. As the recycling rate increases, the stock of recycled paper is higher in the future for any given contemporaneous supply level, which lowers secondary firms' future marginal costs. Therefore, a primary firm's response to changes in the recycling rate let me study how firms respond to forward-looking incentives.

In my regressions, I find that a 10% increase in the stock of recycled inputs results in a 1.1% decrease in a primary firm's quantity supplied. This result provides direct evidence that primary firms reduce supply in response to a decrease in secondary firms' contemporaneous costs. I also find that primary firms in a state with a subsidy law have lower quantity supplied than comparable primary firms in states without a subsidy. These results provide further evidence that primary firms reduce supply in response to more intense current secondary competition. Further, I find a 10% increase in the contemporary recycling rate leads to a 4% reduction in a primary firm's quantity supplied if the firm is exposed to competition from secondary competition. In comparison, a firm not exposed to secondary competition does not reduce supply as the recycling rate increases. This response to the recycling rate provides evidence that primary firms reduce supply to soften future competition. Because the response is greater for firms that face more intense competition from the secondary sector, the regression results provide evidence that primary firms in the paper industry are forward-looking and reduce supply by a greater amount when future competition is more intense.

I use the model to study the interaction between dynamic incentives and policy design through a series of simulation exercises. For each exercise I compare the solution of the dynamic model to an alternative model in which firms behave myopically. The paper industry experienced a wave of horizontal consolidation with the top four firms' market share increasing from 20% to 51%. This change in market structure motivates an exploration of the incentives for and equilibrium effects of horizontal mergers in markets with dynamic incentives. I first simulate the model to study primary firm markups and market concentration, and I compare the difference in these measures in simulations with and without the dynamic incentive. The second set of simulations consider equilibrium outcomes of a merger between primary firms in the model. Annual government expenditures on paper increased eightfold over my sample period, reflecting the importance governments attached to the policy goal of limiting environmental damages from primary production. I simulate a range of policies that illustrate how the equilibrium outcome of different methods of influencing firms' behavior are affected by the dynamic incentives.

I find that dynamic incentives let primary firms exercise greater market power over a range of simulation exercises. For example, with one primary and one secondary, the primary firm's markup is 12% greater in the dynamic model. This result illustrates that the future competition softening incentive leads to a reduction in current supply that raises both price and the primary firm's markups. However, as I consider exercises with a greater number of primary firms, the difference in markups between the dynamic and myopic model decrease. This decrease provides evidence of the dynamic externality because other primary firms gain from a supply reduction, so an individual firm's incentive to reduce current supply is reduced relative to markets with a single primary firm. The strategic quantity reduction by primary firms also leads to a less concentrated market. Combining the results for markups and concentrate illustrate that using observable market shares can lead antitrust authorities to underestimate the exercise of market power. Because pre-merger market shares are often used to estimate market power post-merger, the underestimate of pre-merger market share will also incorrectly predict that the market will be more competitive after a merger.

Mergers also let primary firms internalize the competition softening effect of a supply reduction. In my simulations, this internalization results in a short run reduction in supply that is 25% greater in the dynamic relative to the myopic model. Therefore, standard antitrust analysis also underestimates anti-competitive behavior by ignoring the internalization of the competition softening incentive. In the long run, the quantity reduction by the merged firms is successful in softening competition, leading these firms to exercise greater market power in the long run. In the long run total quantity supplied decreases, so the anti-competitive effects of a merger are even worse in the long run post-merger, with a 50% reduction in Consumer surplus in my simulation of the dynamic model and a 40% reduction in my simulation of the myopic model.

I also simulate government policies to study the effectiveness of these policies in shifting production away from the more environmentally damaging primary production. Exercises that impose the subsidy observed in the empirical setting show these policies are more effective at reducing primary supply in the dynamic model. The greater reduction occurs because primary firms recognize the subsidy makes competition from secondary firms more intense in both the current and future periods. Thus, the primary firm reduces current supply to partially offset this competition in the dynamic model. In comparison, I show that increasing the recycling rate can be a more effective policy. Doubling the recycling rate leads to a short run reduction of primary quantity by 19% in the dynamic model but no effect in the myopic model. The ability to soften competition is reduced as the recycling rate increases; therefore, the primary firm must decrease its current supply by a greater amount to soften future competition.

My work contributes to several strands of literature. My theoretical model relates to work used to study the dynamic supply problem of Alcoa based on the famous antitrust ruling of Judge Learned Hand in United States v. Alcoa (1945). These models generate similar intertemporal supply incentives as created by durable goods and resale markets.[3] Gaskins (1974), Swan (1980), and Martin (1982) consider models in which a dominant firm producing from virgin inputs competes against a competitive fringe that recycles the good. I differ by allowing for multiple primary firms and the possibility of secondary firms exercising market power. The modeling extension lets me analyze the how dynamic incentives interact with merger policy.

Several other authors have developed models that explore the dynamic effects of recycling on oligopoly competition. Their work focus on the primary firm's foreclosure incentive (Hollander and Lasserre (1988) and Samba (2017)) or assume firms can commit to supply paths (Gaudet and Long (2003) and Sourisseau, Beir, and Ha-Huy (2017)). My work differs by focusing on competition softening incentives without assuming firms can commit to strategies, which lets me study mergers and changes in policy.[4]

The effect of recycling on firm behavior also has been explored in different industries. Suslow (1986) provides an empirical study of Alcoa's supply problem based on the previous theoretical literature. Sigman (1995) examines how different policy instruments affect equilibrium outcomes in the competitive lead battery industry. My empirical analysis estimates the reaction of firms using novel sources of variation in policy and the recycling rate.

My work also contributes to the analysis of competition in the US paper industry. Pesendorfer (2003) and Christensen and Caves (1997) focus on cost synergies from horizontal mergers and whether mills use capacity expansion announcements as cheap talk, respectively. Hervani (2005) studies the newsprint industry. He provides evidence that secondary firms have market power in purchasing recycled inputs but only considers static incentives.

Finally, the theoretical incentives I identify relate to analysis of competition across markets. In particular, I embed notions of how a firm's behavior interact with both the reaction to rivals' strategies, and how behavior in one market influences rivals' strategies in other markets developed by Bulow, Geanakoplos, and Klemperer (1985) and Fudenberg and Tirole (1984). I use recycling as a new channel to generate these strategic incentives in a dynamic oligopoly.

The rest of the paper is organized as follows. I provide a discussion of the data and industry in section 2. Section 3 discusses the theoretical model and derives the implication of the model. In section 4, I develop, estimate and discuss the empirical specifications. Section 5 setups and discusses the results of the simulation exercises. I conclude in section 6.

[3]The result that a monopolist creates its own competition by selling a durable good creating a dynamic pricing problem was proposed in Coase (1972). Other important contributions to this literature include Stokey (1981), Bulow (1982), Bulow (1986), and Gul, Sonnenschein, and Wilson (1986). See Waldman (2007) and the references therein for a survey of this literature.

[4]Belleflamme and Ha (2018) is the closest model to mine although they only let oligopoly competition occur in the second period.

2 Industry Background and Data

2.1 Paper Industry Background

Firms in the paper industry manufacture a collection of products. I follow industry sources and divide final products into mutually exhaustive categories such that within each category the good is homogeneous.[5] Production takes place at mills that transform the necessary intermediate input, pulp, into paper. Paper capacity is limited by the mill's number of paper machines, which are the key piece of capital equipment needed to create paper. Industry sources report that mills must incur a large, sunk cost to purchase new machines or expand capacity. These sunk costs provide incentives for mills to operate at full capacity and represent a significant barrier to entry.[6]

Two main sources of pulp accounted for 99% of all inputs during my sample period. The first is virgin wood. Firms harvest timber and then apply heat and chemicals to turn wood into pulp. The second source is recycled paper. This paper is collected from consumers and transformed back into pulp using chemicals.

The amount of inputs needed to produce a paper product differs depending on which type of input the mill uses. For example Farla, Blok, and Schipper (1997) surveyed paper mills across developed countries. These authors found that primary mills required between 2.5 and 6 gigajoules of electricity per ton of paper manufactured while secondary mills required approximately 1.4 gigajoules per ton of paper. Ince (1993) also estimated differences in labor intensity with a ton of newsprint requiring 0.46 hours of labor at a primary mill but only 0.13 labor hours at a secondary mill.

The paper industry generates several sources of environmental damages. This industry accounted for approximately 15% of US industrial energy usage in 2001 (US Department of Energy, 2005). Producing from secondary inputs instead of primary inputs is estimated to greatly reduce this energy usage.[7] The chemicals used to manufacture paper also damage water quality and are regulated under the Clean Water Act (1972). Finally, paper made up the plurality of tonnage in municipal solid waste (MSW) facilities, Franklin Associates (1988). Government agencies discussed how policies aimed at both encouraging the use of secondary paper and increasing recycling have an added benefit of limiting originating from MSW facilities.[8]

2.2 Mill Level Data

I combine two mill level datasets to study the effects of recycling on oligopoly competition. The first is the Lockwood Post Directory (LP), an industry source that collected annual data from each paper mill in the US. This information includes the mill's paper capacity level, the

[5] Ince et al. (2001) provide a detailed discussion of the similarities and differences both within and between product categories.

[6] The maximum number of entries, 10, occurring in 1992 while most years fewer than two mills entered.

[7] A special report on recycling estimated that producing paper from recycled instead of virgin inputs reduced energy usage by 40%. The Economist, "The truth about Recycling" June 7^{th} 2007.

[8] See EPA (1988) and OTA (1989) for a more detailed discussion of these issues.

physical location of the mill, specific capital equipment owned at the mill, the corporate owner of the mill, and other information. The second source comes from United States Department of Agriculture's Forest Product Laboratory (FPL). The FPL data provides the specific paper product manufactured at each mill and the share produced from primary and secondary inputs. I collect data from these sources each year between 1973 and 1993.[9]

I create my sample of 546 mills by matching mills between the two data sources. This process drops approximately 300 mills from the LP dataset. The mills excluded from the sample are composed of two specific types of mills. The first are 40 pulp mills that do not manufacture paper so do not compete in the relevant product market. The second set of excluded mills manufacture construction board. FPL did not collect data on input usage from these mills, so I was unable to construct a measure of input usage for these mills. Construction board is intended for long-life cycles and is sold to the construction industry. In comparison, the paper products included in the sample are sold for a single use to households and businesses. Therefore, the time horizon and demand characteristics differ significantly between these types of mills. The construction board industry also experienced significant exit over this sample period, making it challenging to isolate the dynamic effects created by recycling from other dynamic incentives.[10]

Primary firms accounted for the majority of supply over the sample period. A similar pattern holds at the mill level with primary mills averaging 450 tons of paper per day while secondary mills averaging 125 tons per day.[11] Most primary production occurred at vertically integrated mills while secondary mills purchased secondary inputs from independent wholesalers. Plant and Steiker (1978) suggests that vertical integration created returns to scale in primary production providing an efficiency advantage. Integration along the supply chain also lets primary firms eliminate successive monopolization for inputs creating a further cost advantage.

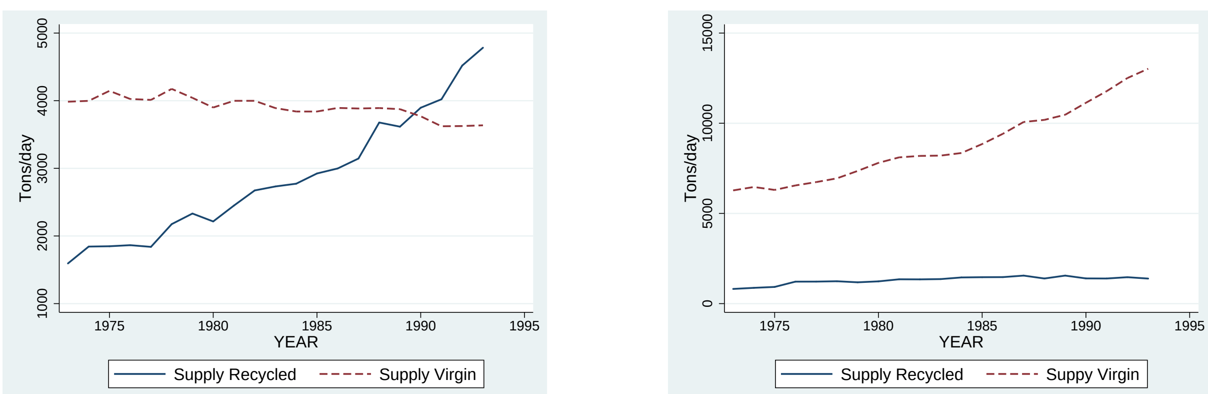

Figure 1: Difference in Supply by Input Used Between Final Product Categories. Cardboard Boxes (Left) and Printing Paper (Right).

[9]The FPL data is missing or of questionable quality outside this period necessitating this choice of sample period.

[10]A third of the construction paper mills manufactured roofing materials, which used asbestos based inputs. These mills experience a large demand shock as the health risks of asbestos became widely understood.

[11]This difference in capacity also holds across the distribution of capacity with the likelihood that a given mill uses primary inputs increases as the capacity of the mill increases.

Another source of heterogeneity in the paper industry comes from consumers' preference for primary instead of secondary products arising from aesthetic qualities of the products.[12] For example 21.1% of cardboard boxes were manufactured from secondary inputs in 1975 while only 6.7% of printing paper was. These differences also exist over time with Figure 1 showing that the supply was flat or declining for primary cardboard boxes but increasing for primary printing paper. In comparison, these trends are reversed for the secondary supply of these two paper products. Ince (1993) showed that the technological ability to produce paper from recycled input also differed across products. While most products were predicted to develop this technology after my sample period, only a subset of products were known to have this technology widely deployed during my sample period. I use this difference to construct the indicator for exposure to secondary competition in the empirical specifications.

Table 1: Mill-Product Level Summary Statistics

Product	Share Primary	Ave. Mill Capacity (tons)	Share West	Share Midwest	Share Northeast	# Mills	Obs
Coated Freesheet	95	306	5.6	46.7	26.1	37	645
Coated Groundwood	100	482	2.8	38.1	41.2	21	360
Kraft Paper	70.7	358	19.1	11.2	15.1	42	597
Newsprint	75.1	695	37.4	8.8	9.9	29	476
Tissue Paper	38.3	139	15.2	22.6	45.5	123	1979
Uncoated Freesheet	85.5	259	8.7	36	35.9	122	2187
Uncoated Groundwood	88.7	248	11.6	24.4	51.2	27	347
Special Paper	89.6	96	4.6	24.8	51.3	74	1398
Corrugating Medium	44.6	333	18.7	30.8	14.3	88	1245
Linerboard	64.4	722	24.4	15.7	3.1	84	1263
Solid Bleached Board	100	726	11.8	0	0	26	474
Recycled Paperboard	0	143	10.2	31.8	38.6	176	3078

Note: All calculations at the product-mill level. Share of primary calculated calculated from FPL data. For approximately 80% of these observations, the mill level and product level are the same. I adjust the remaining observations using the share of each product manufactured as weights.

Table 1 provides summary statistics at the product-mill level for paper capacity, the share of production using primary inputs, and the share of mills in each region of the country.[13] These statistics illustrate that the aggregate trends also hold at the product level because products that use a greater share of primary inputs also have greater capacity. For most goods, the majority of production at a given mill comes from primary inputs. There are exceptions for which secondary accounts for the majority of the share of production such as corrugating medium and tissue paper. Regional differences also exist across product categories. For example, most tissue paper mills (45.5%) are located in the Northeast while the rest of the tissue paper mills are relatively evenly spread across the other regions. This regional variation provides differences in demand, cost and features of the recycling market that influence supply incentives.

[12]For example consumers care about the brightness of printing paper, a characteristic that primary inputs are better at producing, while consumers derive little utility from the appearance of cardboard boxes that are used for shipping.

[13]In the Appendix, I reproduce this table using the firm-product category as the unit of observation. The average share of secondary production at this level of aggregation is similar while the average capacity level increases.

2.3 Market Level Data

I next discuss trends in the recycling market. The amount of paper recycled increased from 15.2 million tons in 1973 to 35.5 million tons in 1993. The tons of recycled paper used as secondary inputs at paper mills increased from 14.1 million to 28 million.[14] The total supply of paper increased from 65 million tons to 91.6 million tons over this time frame. Figure 2 illustrates that all three time series display an upward trend, but that year-to-year changes differ for each.

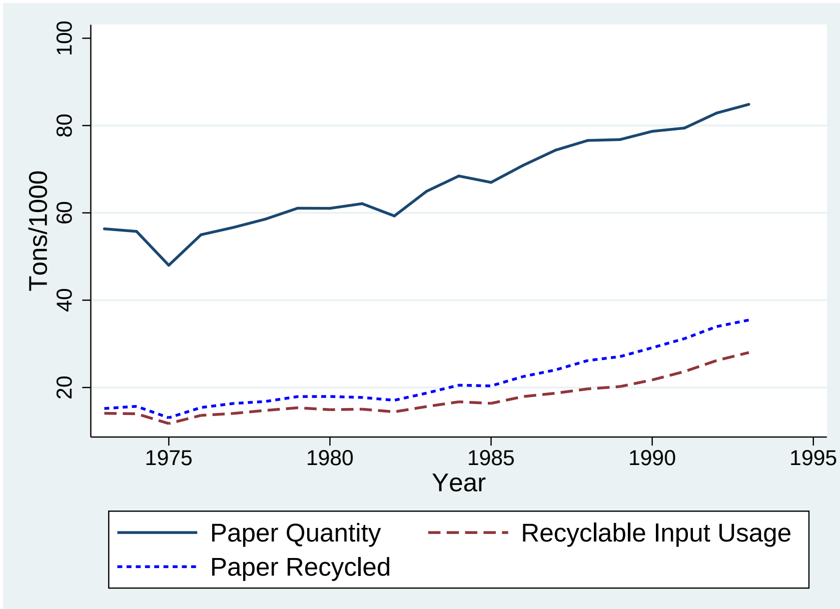

Figure 2: Total Paper Usage, Amount of Paper Recycled and Use of Recycled Inputs by Paper Mills over Time

The share of paper produced from secondary inputs varied over the sample; however, this share was essentially flat between 1973 and 1981, changing from 25% in 1973 to 24% in 1981. Starting in 1981, state governments began implementing policy aimed at shifting production to secondary firms. The share of paper produced from secondary inputs increased to 34% by 1993, Howard and Jones (2016). The timing of the increase in the share of secondary production provides preliminary evidence that policy contributed to the shift in production towards secondary firms. The Bureau of Economic Analysis reported that annual state and local government expenditures on paper rose from $546 million to $4 billion over this time frame, illustrating that implementing these policies involved significant spending. Federal government expenditures remained relatively flat over this period because the Federal government was not actively using policy to increase secondary production during my sample period. I illustrate these two purchasing trends in Figure 3.

The major government policy enacted during my sample involved providing a subsidy for

[14]The total amount of paper recycled continued to increase after my sample period; however, the usage of the secondary inputs at paper mills was relatively constant after the sample. The change in trends was driven by an increase in exports to met growing demand from new paper mills built in Asia.

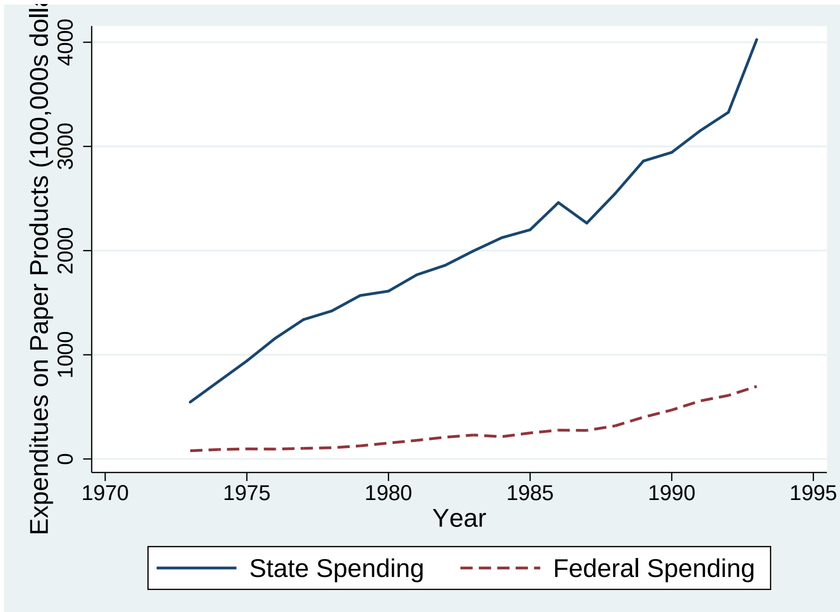

Figure 3: State and Federal Government Expenditures on Paper Products

Note: Based on authors' calculations using the Bureau of Economic Analysis' Input-Output Tables.

each unit of secondary paper purchased by the government.[15] I document the timing and level of subsidies in Table 6 in the Appendix. New York enacted the first subsidy in 1981 and starting in 1989 there was a rapid increase in states enacting subsidies with 19 subsidies enacted between 1989 and 1993. In Figure 4, I illustrate the share of paper produced in states with a subsidy law. This figure illustrates the timing and coverage of these subsidies. Large increases in the share covered came from both states that produce a large amount of paper, e.g. New York, and years in which many states enact a law, e.g. in 1989 when seven states enacted subsidies.

Differences in government policy and the opportunity cost of recycling created variation in the recycling rate across different regions of the US and over time as illustrated in Figure 5. Recycling became more common over time in all regions. However, the trends for recycling differ across regions. I also collected other variables that influence recycling such as the time varying opportunity cost of disposing of the good in a landfill, the landfill tipping fee. Several states also passed mandatory recycling laws during this time period, providing another source of variation in the recycling rate.

I construct the stock of recycled inputs for each product using information from industry sources. Each paper product uses a different combination of four types of recycled inputs: (i) old newsprint, (ii) old corrugated cardboard, (iii) mixed paper, and (iv) high grade pulp substitutes. The composition of each type of recycled inputs is a mixture of paper products. For example, newsprint is the only good that contributes to old newsprint, and the only recycled input used

[15]In particular, secondary firms receive a subsidy proportional to the price the government pays to primary firms.

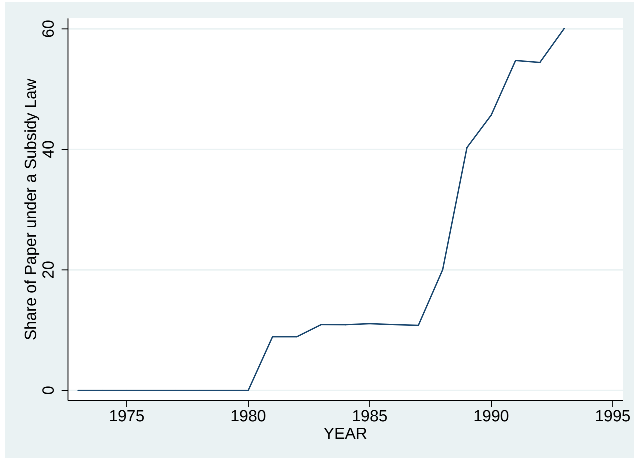

Figure 4: Share of Paper Covered by State Subsidy over Time

Note: Based on author's calculation using state subsidy laws and industry information on capacity.

by newsprint firms is old newsprint. Thus, the entire stock of recycled input for newsprint comes from previous supply of the product. At the other extreme, tissue paper does not contribute to any of the recycled inputs, so the entire stock for tissue paper comes from the supply of other products. In Table 8 in the Appendix, I display the input-output table used to construct the stock.

Table 2: HHI by Final Product and Region

Product	National HHI	West HHI	South HHI	Midwest HHI	North East HHI
Coated Paper	638	8509	3084	1446	2197
Kraft Paper	1067	4499	1568	4763	3620
Newsprint	922	2379	2015	7716	7649
Tissue Paper	1281	4581	5915	3630	2596
Uncoated Freesheet	508	5020	2549	1315	1378
Uncoated Groundwood	1490	7928	7985	5880	2868
Special Paper	628	5273	2894	1667	1557
Corrugating Medium	476	2511	1175	1558	3144
Linerboard	553	2501	773	4803	8928
Solid Bleached Board	1086	5249	1175	-	-
Recycled Paperboard	388	1378	1067	575	503

Note: All calculations at the product level. Mill level capacity is adjusted for product. Ownership data constructed from LP.

One concern given the number of firms in the US paper industry is that firms may not be able to affect equilibrium outcomes. If firms instead behave as price takers, then changes in supply comes only from changes in market primitives. To investigate this possibility, I calculate the HHI at both the national and regional level. My preferred market definition takes the United

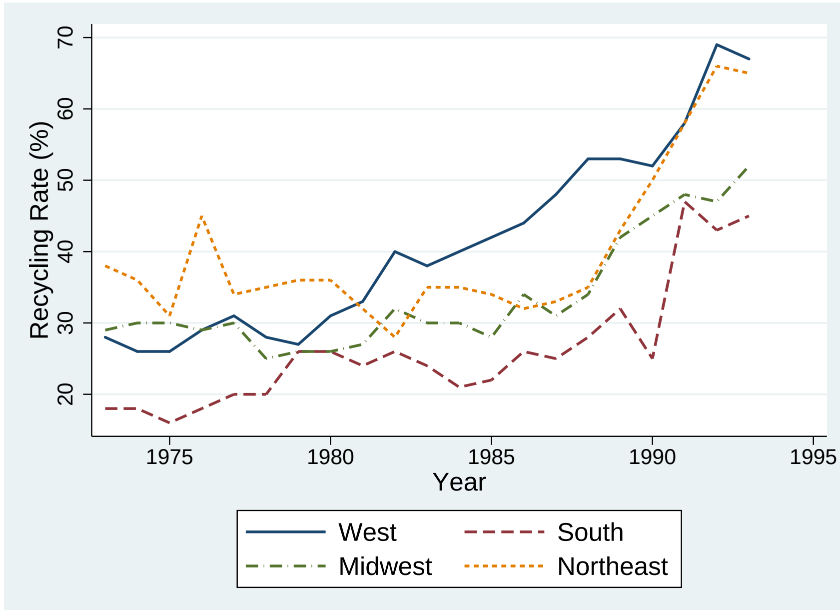

Figure 5: Recycling Rate over Time and Regions

States Forestry Service (USFS) regional definitions as the markets. I present the results of these specifications in Table 2. At the national level the market is relatively unconcentrated but within regions concentration is higher. For example the Uncoated Freesheet market is unconcentrated at the national level but is significant to highly concentrated in each region using the definitions in the Horizontal Merger Guidelines (2010).

To provide empirical justification for the regional market definition, I calculate shipment flows using the Public Micro Data from the 2012 Commodity Flow Survey (CFS).[16] At least 70% of shipments of paper originating at a mill in a specific region goes to a consumer within the same region. While there are cross-regional shipments, the regional definitions appear reasonable given the shipment data. I report the shipment information along with summary statistics of regional data in the Appendix. These regional definitions also agree with those used by the Federal Trade Commission (FTC) in evaluating horizontal mergers,[17] and industry price reports.[18]

[16] I compared these results to earlier shipment data in the 1967 and 1977 Census of Transportation. The flows for the paper industry are similar over these time frames. I use the 2012 sample because it allows more detailed study of trade patterns.

[17] See the discussion about market boundary definitions in the proposed acquisition of Menasha Corporations's corrugated medium assets in Oregon by Weyerhauser in 1980, Federal Trade Commission (1985).

[18] There are separate reports for the Southeast, Midwest, Southwest, Pacific Northwest, Los Angeles, San Fransisco, Buffalo, New York and New England these results are slightly finer that what I use in the model.

3 A Theoretical Model of Dynamic Oligopoly Competition

3.1 Model Set Up

I develop a dynamic model of oligopoly competition for a good that gets recycled. The supply side of the industry is composed of 3 types of firms. The first type are primary firms that use virgin intermediate inputs. The second type are price taking recycling wholesalers. Wholesalers collect the good from consumers and transform the recycled good into an intermediate input. The final set of firms are secondary firms that purchase the recycled input from the wholesalers. Primary and secondary firms move simultaneously with each firm, i, setting quantity $q_{i,t} \in \mathbb{R}_+$ in each period t.

I model the demand side as a representative consumer. This consumer views the good as homogeneous and has inverse demand based on the total quantity supplied, $Q_t = \sum q_{i,t}$, given by $P(Q_t)$. The consumer does not store the good and makes a myopic purchasing decision.[19] I assume the inverse demand function is continuous, decreasing, and concave in total quantity supplied.[20]

The cost of the recycled input in period t depends on both the stock of the recycled input carried over from the previous period, $\bar{Q}_{t-1}$, and the cost of using other inputs such as labor. An increase in the stock reduces the cost of using other inputs, so a wholesaler's supply increases as the stock increases. A sufficient condition for an increase in the stock to lower the cost of the recycled input is that the marginal productivity of other inputs, such as labor, increases in the stock.

There are $M \geq 1$ primary firms. The cost for a primary firm, m, to supply a unit of the good is $C_1(q_m)$, and this cost is increasing and convex in the quantity supplied by the firm. There are $N \geq 1$ secondary firms. The total cost of a secondary firm, n, to produce a unit of the good is $C_2(q_n) = \tilde{C}_2(q_n) + R(\sum_{j=1}^{N} q_j, \bar{Q}_{t-1})q_n$. There are two parts of this cost: (i) the cost of using inputs such as labor, $\tilde{C}_2(q_n)$, and (ii) the cost of using the recycled input $R(\cdot)q_n$. I also assume that $C_2(q_n)$ is increasing and convex in the quantity supplied by the firm. As demand for the recycled input increases, the price of this input increases. This assumption implies $R_1 \geq 0$ where R_1 is the derivative of the recycled input price with respect to secondary firms' demand for this input. The assumption that an increase in the stock of recycled input decreases price implies that $R_2 \leq 0$. I also assume that $R_{1,2} \leq 0$, so the marginal change in price from an increase in secondary demand is decreasing in the stock of recycled input. Intuitively, the increase in supply from an increase in the stock has a greater effect than the increase in demand, so the equilibrium input price decreases from a small change in both stock and demand.

[19] A dynamic demand model would let consumers base purchase decisions on inventories and the expected price path of the good. These incentives are not a major concern in the paper industry with most deliveries being "just-in-time" to the consumers.

[20] This condition can be relaxed to allow for more general demand functions. In particular, the results will hold if demand is convex provided each firm, i, $P'(q_i+Q_{-i})+P''(q_i+Q_{-i})q_i < 0$ where Q_{-i} is the quantity supplied by all other firms. This condition implies that the marginal revenue of each firm decreases as the aggregate amount produced by other firms increases.

After product market competition in period t, the consumer uses and then recycles a share ψ_t of the good. The consumer discards the rest of the good to a landfill. The recycling rate for consumers can be derived from a model of household behavior such as in Fullerton and Kinnaman (1995). The stock of the recycled input accumulates following $\bar{Q}_t = \psi_t Q_t + (1-\delta)\bar{Q}_{t-1}$ where Q_t is the amount of the good supplied in period t, i.e. the new inflow to the stock, and $(1-\delta)\bar{Q}_{t-1}$, the stock carried over from previous periods after accounting for the depreciation rate δ.

The flow profit of a firm i is given by

$$\pi_t^i(q_{i,t}, q_{-i,t}; \bar{Q}_{t-1}) = P(Q_t)q_{i,t} - C_i(q_{i,t}).$$

Each firm's payoff depends on its own action, $q_{i,t}$, the actions of its rivals, $q_{-i,t}$, and the payoff relevant state variable, $\bar{Q}_{t-1}$. To ensure uniqueness of the equilibrium in the static version of the game, I assume $|\pi_{i,i}| > \sum_{j \neq i} |\pi_{i,j}| \; \forall i, j$, where subscripts denote derivatives with respect to the supply of firm i. I define the value of firm i recursively as

$$V_i(\bar{Q}_{t-1}) = \max_{q_{i,t}} \quad \pi_{i,t}(q_{i,t}, q_{-i,t}, \bar{Q}_{t-1}) + \beta V_i(\bar{Q}_t),$$

where β is the common discount rate used by all firms. I assume that firms play a Markov Perfect Equilibrium and use strategies that only depend on firm type and the stock.

3.2 Analysis of Firm Incentives

I use the model to generate empirical predictions for the effect of recycling on a dynamic oligopoly. I establish the results in a series of steps. I first show how firms' quantity supplied change in response to changes in the current stock of the recycled input. Then I show how firms' profits change as the stock changes. I use these two results to show how the dynamic incentive caused by recycling affect firms' quantity supplied in the current period.[21]

Proposition 3.1. As the current stock of the recycled input increases, primary (secondary) firms reduce (increase) quantity supplied.

Proof. I derive the result for the case with 1 primary and 1 secondary firm below to illustrate the result. More general results can be derived at the expense of clarity of the proof. Applying the implicit function theorem to the first order conditions gives

$$\pi_{1,1}dq_m + \pi_{1,2}dq_n + \pi_{1,3}d\bar{Q} = 0$$

$$\pi_{2,1}dq_m + \pi_{2,2}dq_n + \pi_{2,3}d\bar{Q} = 0$$

where the partial derivatives are with respect to q_m, q_n, and $\bar{Q}$ respectively.

[21] I illustrate these results using specific functional forms that satisfy the conditions of the model in the Appendix for the interested reader.

Rearranging this expression gives

$$\begin{bmatrix} \frac{dq_m}{d\bar{Q}} \\ \frac{dq_n}{d\bar{Q}} \end{bmatrix} = \begin{bmatrix} \pi_{1,1} & \pi_{1,2} \\ \pi_{2,1} & \pi_{2,2} \end{bmatrix}^{-1} \begin{bmatrix} -\pi_{1,3} \\ -\pi_{2,3} \end{bmatrix} \tag{1}$$

which exists under the assumption used to ensure uniqueness. $\pi_{1,3} = 0$ because the stock has no direct effect on the primary firm's profit. Thus, $\frac{dq_m}{d\bar{Q}} \leq 0$ because $\pi_{2,3} \geq 0$, by the assumptions on the cost of using the recycled inputs, and because quantities are strategic substitutes. $\frac{dq_n}{d\bar{Q}} \geq 0$ because $\pi_{1,1} \leq 0$ from the necessary condition for primary firm optimality. □

The intuition for this result comes from the strategic substitutability of supply. An increase in the stock of recycled inputs decreases the secondary firm's marginal cost and shifts out the secondary firm's best response function. The primary firm strategically reduces supply in response. The result that an increase in recycled inputs makes competition more intense provides the first testable implication of the model.

Proposition 3.2. Aggregate supply increases as the stock of recycled input increases.

Proof. Rearranging the expressions used to sign the effect of stock of quantity shows that the condition required for the result is $|\pi_{1,1}| > |\pi_{1,2}|$ in the case with 1 primary and 1 secondary. This is the condition assumed for uniqueness. □

The intuition behind this result is that secondary firms react directly to the increase in the stock while primary firms only strategically react. Because the primary firm's reaction function is relatively flat, the strategic reduction by the primary firm is less than the direct supply increase by the secondary firm.

I next establish how profits change as the stock of recycled inputs increases.

Proposition 3.3. Primary firms' profit decrease as the stock of recycled inputs increases while secondary firms' profit increase.

Proof. Consider the case of 1 primary and 1 secondary firm. The change in profit from a increase in the stock of recycled inputs, $\Delta\bar{Q}$ is

$$(\Delta\bar{Q})\frac{d\pi_1}{d\bar{Q}} = (\Delta\bar{Q})[\frac{\partial\pi_1}{\partial q_1}\frac{dq_1}{d\bar{Q}} + \frac{\partial\pi_1}{\partial q_2}\frac{dq_2}{d\bar{Q}} + \frac{\partial\pi_1}{\partial\bar{Q}}].$$

From the first order condition the first term is zero and the last term is zero because the stock does not enter the primary firm's profit directly. Proposition 3.1 establishes the second term is negative. Thus, the primary firm's profit decreases as the stock increases.

Similarly the change in profit for the secondary firm is

$$(\Delta\bar{Q})\frac{d\pi_2}{d\bar{Q}} = (\Delta\bar{Q})[\frac{\partial\pi_2}{\partial q_1}\frac{dq_1}{d\bar{Q}} + \frac{\partial\pi_2}{\partial q_2}\frac{dq_2}{d\bar{Q}} + \frac{\partial\pi_2}{\partial\bar{Q}}].$$

The first term is positive from proposition 3.1, the second zero from optimality and the third is positive from the direct effect of stock of secondary profit. Combining these results establishes the result for the secondary firm. □

The intuition for this result is similar to how the stock affects supply. Primary firms reduce supply as the stock of the recycled inputs increase while secondary firms increase supply. Primary firms are supplying less, and proposition 3.2 establishes that price decreases. The combination of the price and primary quantity supplied responses result in a lower profit for the primary firm.

With the results for how firms react within a given period established, I derive how the dynamic incentives affect firm behavior. For comparison I consider a model in which the firms do not account for how current supply affects future periods. I term this alternative the myopic model and generate this alternative benchmark by assuming that firms have $\beta = 0$.

Proposition 3.4. Relative to the myopic model, primary firms supply less in the model with dynamic effects, and secondary firms supply more.

Proof. I combine the above results and assumptions on profits to establish this result. The problems of a firm in the dynamic and myopic models are

$$\max_{q_{i,t}} \pi_i(q_{i,t}, q_{-i,t}, \bar{Q}_{t-1}) + \beta V_i(\bar{Q}_t) \tag{D}$$

$$\max_{q_{i,t}} \pi_i(q_{i,t}, q_{-i,t}, \bar{Q}_{t-1}). \tag{M}$$

Under the assumptions on demand and costs, there exists a vector of strategies q^* that satisfy optimality for problem (M). The first order condition for a firm in the dynamic model is

$$\underbrace{P'(Q)q_i + P(Q) - C_i'(q_i)}_{Static\ F.O.C.} + \underbrace{\beta \frac{\partial V_i(\bar{Q}_t)}{\partial q_i}}_{Dynamic\ Effect} = 0.$$

Consider a primary firm solving (D) starting at the optimal supply for (M). At this supply level, the static F.O.C. equals zero while the dynamic effect is negative for a primary firm. From proposition 3.3, $\frac{\partial V_i}{\partial \bar{Q}} \leq 0$ for a primary firm because $\frac{\partial \pi}{\partial \bar{Q}} \leq 0$ for a primary firm. Therefore the first order condition of (D) for a primary firm is negative at q^*.

Consider a decrease in supply by the primary firm to $q_i' < q_i^*$. The value of the static F.O.C. increases because profits are concave. The stock of the recycled input decreases, so the value for this firm also increases. Therefore, the first order condition of (D) strictly increases. The firm can further reduce supply until the first order condition of D returns to zero. A similar argument establishes that an increase in supply relative to q^* restores the first order optimality condition for the secondary firm. □

The intuition for the behavior of the primary firms in this model involves the intertemporal profit trade off. By decreasing supply in the current period, the primary firm sacrifices current profits and supplies a quantity such that the marginal revenue of its last sale is greater than the marginal cost on the unit. The reduction in current supply reduces the stock in the future period and raises the future cost of using the recycled input. The increase in cost softens future competition from secondary firms allowing for greater primary profits in the future. Secondary firms face two incentives to increase supply. First, increasing quantity supply results in a strategic reduction in primary firms' quantity supplied in the current period. Second, an increase in supply lowers the secondary firm's future marginal costs.

Collecting the results of the theoretical model yields two empirically testable hypotheses. First, an increase in the stock of recycled input increases contemporaneous supply of secondary firms, and primary firms respond by strategically reducing contemporaneous supply. Second, firms respond to the dynamic effects created by recycling. In particular, primary firms supply less than in the myopic model.

The strategic incentives identified in this theoretical model also depend on the number of firms in the market. Relative to the dominant firm model that has been previously studied, the oligopoly model introduces three sources of externalities. First is the standard Cournot externality that each firm does not account for how a reduction in supply affects the profits of other firms, so total quantity supplied is greater in an oligopoly relative to a monopoly. Second, there is an externality between secondary firms because when a secondary firm increases input demand the price of the recycled input increases for all these firms. Finally, there is a dynamic externality. If a primary firm decreases supply in the current period, other primary firms receive the benefit of the softer future competition. This last externality illustrates the strategic reaction to dynamic effects is weaker in the oligopoly model relative to a model with a single primary firm.

3.3 Extensions to the Theoretical Model

I first discuss how the policy variation in my empirical application interacts with the model. I modify the model so that secondary firms receive a proportional subsidy, $s \geq 0$, on each unit sold. The flow profit of a secondary firm j becomes

$$(1+s)P(Q)q_j - \tilde{C}_2(q_j) - R(\sum_{n=1}^{N} q_n, \bar{Q}_{t-1})q_j.$$

Because this policy does not change the sign of $\pi_{i,j}$ for either type of firm, the strategic supply incentives from the baseline model extend to the model with the subsidy. Therefore, the subsidy policy observed in the data does not change the prediction on the dynamic incentives although the magnitude of firms' response may change.

In the theoretical model I assumed that firms supply a single, isolated market. However, in the paper industry transportation costs are low enough that trade between markets occurs if arbitrage opportunities exist across markets. Trade between markets creates a concern because states pay subsidies based on the location of final consumers instead of the location of mill. In the Appendix, I use a model of regional trade based on Brander (1981) to illustrate that the dynamic effects can also hold in a model that allows trade between markets.

My model also assumes that consumers view primary and secondary products as homogeneous; however, consumer surveys provide evidence that consumers viewed primary goods as higher quality. These preferences create a degree of product differentiation and provide a further source of competition softening. In the Appendix, I show conditions on demand systems exist such that the dynamic effects hold when consumers view goods as differentiated.

The final extension accounts for the interaction between the dynamic effects caused by recycled inputs and capacity constraints. Because capacity constraints limit rivals' ability to respond, the incentive to soften future competition created by recycling is dampened. I provide numerical evidence in the Appendix that the response to the dynamic effects created by the recycled inputs still exist but are reduced when firms face capacity constraints.

3.4 Implications for Policy Makers

I motivate the policy exercises by exploring implications of the model. The first exercises relate to horizontal merger policy. Consider first the challenge of an antitrust authority that has access to data on pre-merger market shares and attempts to infer the exercise of market power after a merger. The Horizontal Merger Guidelines (2010) posit that rules based on the level and changes in concentration allow for inference on unobserved market power in Cournot models. Using concentration provides a measure of conduct under Cournot competition because there is a one-to-one mapping from the HHI to markups. See Shapiro (1989) for a detailed discussion of this issue.

To see that this relationship changes in the dynamic model, I rewrite the first order condition of a primary firm, i, as

$$LI_i \equiv \frac{p - C_i'(q_i)}{p} = \frac{-s_i}{\epsilon_D} - \frac{\delta}{p}\frac{\partial V_i(\bar{Q}_t)}{\partial q_{i,t}}. \tag{2}$$

The first term on the right hand side gives the standard relationship between a firm's markup and the share weighted inverse elasticity of demand. Summing over all firms gives the relationship between HHI and markups. From proposition 3.3, the addition of the dynamic term shows that primary firms exercise greater market power when these firms account for dynamic incentives. Thus, using only information on market shares and demand elasticity will lead antitrust authorities to conclude that primary firms are behaving more competitively than in actually. Because of this underestimate of market power, antitrust authorities are likely to be too permissive in allowing anti-competitive mergers when these incentives are important.

Another way to illustrate this issue comes from examining the market share of firms for the case in which primary firms have greater market share initially.[22] The supply reduction by primary firms, which yields the greater markup discussed above, also reduce their market share

[22]This case is more relevant for policy makers for two reasons. First, most industries that feature similar dynamic incentives are composed of large primary firms and small secondary firms. Second, the dynamic incentives lead to anti-competitive quantity reductions by primary firms and pro-competitive increases by secondary firms.

and increases secondary firms' market share. Holding fixed the number of firms, these changes in market shares imply that market share in the model with dynamic effects are a mean-preserving reduction of the shares in the myopic model. Thus, the variance of market shares are lower in the dynamic model. This result implies that the HHI will be lower in the model with dynamic effects than without.[23]

Antitrust policy makers also consider the equilibrium effect of horizontal mergers. Because oligopoly competition generates an externality between primary firms for softening future competition, this spillover between firms provides additional incentives for firms to merge. Therefore, there should be a greater reduction in supply after a merger if firms respond to the dynamic incentives because the merger allows the firms to internalize the effect of a supply reduction on their joint profits.

The other major policy issue in the paper industry is the effectiveness of different instruments in shifting production towards more environmentally friendly producers. To examine the motivation for these policies, I consider the problem of the social planner. The planner chooses the quantities of the primary and secondary goods accounting for consumer demand, the production technologies and environmental damages created by primary production. I focus on the case in which primary production creates a damage, $D(\sum_{i=1}^{M} q_i) \geq 0$, that is increasing and convex in primary supply. For example this function can represent the damages associated with the greater energy usage by primary mills. The total surplus in period t, in the case with 1 primary and 1 secondary firm, is

$$TS(q_m^t, q_n^t, \bar{Q}_{t-1}) = \int_0^{q_m^t + q_n^t} P(s)ds - C_1(q_m^t) - \tilde{C}_2(q_n^t) - R(q_n^t, \bar{Q}_{t-1}) - D(q_m^t). \tag{3}$$

For a two period version of the problem the planner chooses a sequence of primary and secondary supply to solve

$$\max_{q_m^1, q_n^1, q_m^2, q_n^2} \quad TS(q_m^1, q_n^1, \bar{Q}_0) + \beta TS(q_m^2, q_n^2, \bar{Q}_1)$$

$$s.t. \;\; \bar{Q}_1 = \psi_1 Q_1 + (1-\delta)\bar{Q}_0 \;\; and \;\; \bar{Q}_0 \geq 0 \;\; given.$$

There are several differences between the planner's problem and the Cournot model. The first term in the planner's problem is consumer surplus instead of the firms' revenue. Thus, the planner should produce a greater quantity in each period. The second difference is the planner also removes purchasing power for the recycled input. Removing purchasing power gives the planner an incentive to increase secondary supply. The third difference is the planner accounts for the environmental damages. Addressing these damages gives the planner an incentive to reduce the primary supply. Therefore, the planner produces a greater quantity than what occurs in the oligopoly, and the planner has an incentive to produce a greater share of the secondary good.

I illustrate the long run planner's solution in Figure 12 in the Appendix. As discussed above, the planner produces more in every period than the firms in the oligopoly. This production leads

[23]The last result derives from rewriting HHI as $HHI = N\sigma^2 + N\mu^2$.

to greater supply of the primary good. The planner's solution balances its goal of keeping total quantity high and produces just enough of the primary good to balance the environmental damages today with the increase in stock tomorrow. This increase in the future stock lets the planner substitute future production towards the less damaging secondary good.

4 Primary Firm Response to Dynamic Incentives

4.1 Empirical Specification of Firm Behavior

To study the incentives identified in the theoretical model, I take a firm, i, producing a final good, j, in state, s, and year t as the unit of observation in the empirical specification. I use firm level capacity as the dependent variable. This specification assumes that capacity proxies for the firm's quantity supplied. The assumption is reasonable in the paper industry because over the sample period aggregate capacity utilization was approximately 90% for each paper product.[24]

The theoretical model implies I can express the equilibrium quantity supplied by firm i as:

$$q_{i,t} = q(X_{i,t}, Subsidy_t, \bar{Q}_{t-1}, \frac{\partial V_i}{\partial q_{i,t}}, \frac{\partial V_{-i}}{\partial q_{-i,t}}). \tag{4}$$

Equation 4 specifies equilibrium quantity as a function of demand and cost parameters, $X_{i,t}$, the subsidy for secondary firms, the stock of the recycled input, and how firms' current supply affect future payoffs, $\partial V_i / \partial q_i$. The future value term includes variables that do not affect a firm's payoff in the current period, but do affect future payoff.

A complementary method to study the primary firms' incentive involves studying these firms' best response functions. The theory implies that I can specify the best response for a firm i as

$$q_{i,t}^{BR} = q^{BR}(X_{i,t}, Q_{-i,t}, \frac{\partial V_i}{\partial q_{i,t}}). \tag{5}$$

The best response function lets the increase in competition from secondary firms affect primary quantity through movement along the best response function. Using the best response function assumes the quantity of all other firms, $Q_{-i,t}$, enters the problem directly, and that the subsidy and stock variable only affect primary supply by changing total secondary quantity supplied. Other firms' future value also only enter the problem by changing secondary quantity supplied.

I base the empirical test for primary firm responses to the incentives created by recycling on regressions of the following form:

$$\log q_{i,j,s,t} = \alpha \log \bar{Q}_{j,s,t-1} + \beta Subsidy_{s,t} + \gamma Competition_j + \zeta Recycling_{s,t} + \xi_s Subsidy_{s,t} Recycling_{s,t} +$$

[24] I explore this assumption by regressing price on aggregate capacity and capacity utilization rate for each final product category, and report the results of these regressions in Table 9 in the Appendix. There is also a positive and significant relationship between capacity and price across all products except kraft paper. For half the products there is a positive and significant relationship between price and capacity utilization.

$$\xi_C Competition_j Recycling_{s,t} + \xi_{SC} Subsidy_{s,t} Competition_j Recycling_{s,t} + \mathbf{X}_{i,j,s,t}\eta + \epsilon_{i,j,s,t}. \quad (6)$$

The linear approximation in equation 6 preserves the predicted comparative statics from the theoretical model. I also include an indicator for exposure to competition from the secondary firm that differs across products.[25] I proxy for forward-looking behavior using the current recycling rate, and consider interactions between the recycling rate and other variables. I group the remaining sources of heterogeneity into the error term $\epsilon_{i,j,s,t}$.[26]

The two testable hypotheses from the theoretical model are that (i) primary firms reduce quantity supplied in response to more intense contemporaneous competition from the secondary sector, and (ii) primary firms further reduce quantity to soften future competition. Empirically testing the predictions of the theoretical model involves testing whether the coefficients on variables that increase secondary competition in the current and future period are negative in regression equation 6. Subsidy laws represent the first key source of variation in firms' incentives. These laws induce a direct increase in secondary firms' quantity, and primary firms should strategically react by reducing current quantity supplied. The second source of variation in incentives is the stock of recycled inputs. As the stock increases, secondary firms' marginal costs decrease, and primary firms react by reducing quantity supplied. The paper recycling rate provides the final source of variation. An increase in the recycling rate raises the future stock of the recycled input for any fixed contemporaneous total quantity supplied. The increase in stock lowers the **future** marginal cost of secondary firms, providing primary firms a strategic incentive to reduce their **current** quantity.

The empirical test of the hypothesis that primary firms decrease quantity supplied in response to current competition is that the coefficient on the subsidy indicator, and the coefficient on the current stock of recycled input are negative in equation 6. The empirical test of the response to changes in future competition is that the indicator on the interaction between the recycling rate and the indicator for secondary competition is negative. In particular, if this coefficient is negative but the coefficient on the recycling rate alone is not, this is evidence that firms are forward-looking. Intuitively, firms exposed to secondary competition face more intense competition in the future as the recycling rate increases while firms not exposed do not respond to more intense competition created by an increase in the recycling rate.

To control for other incentives, I include time varying demand and cost variables. Because there may still be unobservables that influence a firm's decisions, I conduct the analysis with fixed effects in some specifications of the model. I include year fixed effects to control for aggregate shocks to all firm's quantity. In some specifications I include product fixed effects to account for time invariant unobservables that affect incentives at the product level. Finally, I

[25] I use industry sources to create these indicators and test alternative definitions for robustness of these definitions.

[26] I take the empirical specification of best response functions as:

$$\log q_{i,j,s,t} = \alpha_B \log Q^P_{-i,j,s,t} + \beta_B \log Q^S_{-i,j,s,t} + \gamma_B Recycling_{s,t} + \mathbf{X}_{i,j,s,t}\eta_B + \epsilon^B_{i,j,s,t}. \quad (7)$$

Here the subscripts denote the coefficients are for the best response instead of equilibrium supply. I include interactions as in the equilibrium specification but suppress the variables for brevity.

include firm fixed effects to control for unobserved characteristics of firms that result in different quantity supplied.

4.2 Identification

Identification of the model's prediction comes from response to exogenous variation that affects primary firms' supply incentives. I require that the unobservable sources of variation are conditionally independent after controlling for the variables in the regression. I discuss the assumptions for identification below.

Theoretical models of the consumer recycling decision such as Fullerton and Kinnaman (1995) show that the recycling rate responds to the opportunity cost of recycling a good. Because this opportunity cost is set to address general concerns with landfill space, the recycling rate is independent of the time varying unobservables in the firm's problem. I construct the stock variable for each product such that this variable varies across products and over time. I use industry sources to construct an indicator of whether a specific product was exposed to competition from the secondary industry.[27] The definition of the indicator is based on both whether the technological ability to manufacture from recycled inputs was in widespread use before the recycling rate began to increase steadily in the middle 1980s.

The main threat to identification of the subsidy laws is that political economy concerns led states to enact subsidies based on unobservables that also affect firms' quantity supplied decisions. I use a probit model to estimate the probability that a state enacted a subsidy as a function of the number of secondary mills in the state, voters' preference for environmental policies, and a time trend. I also consider alternative specifications that account for the number of previous states that have enacted a subsidy law. I report the results in Table 3. I find that the number of secondary mills in a state does not have a significant effect on whether a state passes a subsidy law. Instead general consumer preference for environmental regulation, which I proxy for using each state's League of Conservation Voter (LCV) score, have a positive and significant effect on the probability that a state passes a subsidy. Finally, environmental concerns increased over time as the time trend has a positive and significant effect on the probability a state passes a subsidy. I take the passage of these laws as exogenous because the probability of passage appears to be explained by general environmental concerns and not the count of secondary mills in the state.

The last empirical challenge involves identifying whether firms are forward looking. I use variation in the contemporaneous recycling rate as a variable that only affects a firm's future value. An increase in the recycling rate increases the stock of future recycled input but leaves the current stock unchanged. From the first order condition of the myopic problem, equation (M), firms do not respond to variation in the future value term. The recycling rate enters the dynamic problem through the effect on the future value, and an increase in the recycling rate

[27] The specific products included in this indicator are Corrugating Medium, Newsprint and Tissue Paper. Alternative robustness tests include a broader set of products.

Table 3: Probability Subsidy Law Enacted and Environmental Concerns

	(1)	(2)	(3)
LCV House Score	0.014***	0.049	0.013**
	(0.0036)	(0.13)	(0.0053)
# Secondary Mills	-0.00041	-0.029	-0.026
	(0.018)	(0.031)	(0.031)
Trend	0.25***	2.48	0.21***
	(0.023)	(6.07)	(0.074)
# Laws in Effect			-0.029
			(1.01)
Observations	896	796	796
Only Use Pre-Law Years	No	Yes	Yes

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

Note: Results for regressions of enactment of subsidy law on variables explaining passage. Only use pre-law years specifications drops all observations after a subsidy is passed to account for the fact that no subsidy was repealed during this period.

lowers the future value of primary firms. These firms recognize that a higher recycling rate leads to a greater future stock, and hence more intense competition from secondary firms. The primary firm responds by decreasing current quantity to soften future competition. This timing assumption matches the facts of the paper industry with Coet, Poganietz, and Schebek (2014) reporting that the average time between when paper is sold to the first consumer, and when secondary paper manufactured from the original paper is sold is at least one year.

4.3 Primary Quantity Response

I report the results of the primary quantity regression supplied specification in Table 4. Column (1) includes the indicator for whether a subsidy law is in effect, whether the product was exposed to secondary competition, an interaction between these indicators, and an interaction between the competition indicator and the recycling rate. Column (2) adds interactions between the subsidy and the recycling rate, and an interaction between both indicators and the recycling rate. Column (3) adds product fixed effects. Finally, column (4) adds firm fixed effects to the regressions. All specifications include the regional GDP as a demand shifter, the industrial energy price as a cost shifter and year fixed effects.

The coefficient on the indicator for exposure is positive and significant in column (1). This result suggests that all else equal, a primary firm exposed to secondary competition produces a greater quantity than a firm not exposed to this competition. The coefficient on the subsidy indicator is positive in column (1); however, after controlling for interactions and the fixed effects, the coefficient is negative and significant. This result suggests that primary firms in a state with a subsidy for secondary firms supply a lower quantity than comparable firms in a

Table 4: Primary Firm Quantity Supplied and Secondary Competition

	(1)	(2)	(3)	(4)
Sec Comp	0.63*	0.67*		
	(0.35)	(0.37)		
Subsidy	0.28***	-1.97***	-1.36***	-1.44***
	(0.057)	(0.65)	(0.53)	(0.41)
Regional GDP	3.59***	3.59***	2.26***	1.53***
	(0.16)	(0.16)	(0.16)	(0.13)
Electricity Price	-1.11***	-1.11***	-0.75***	-0.32***
	(0.036)	(0.037)	(0.038)	(0.033)
Stock	-0.12***	-0.11***	-0.063***	-0.085***
	(0.006)	(0.006)	(0.017)	(0.018)
Recycling Rate	-0.11	-0.18	0.042	0.083
	(0.11)	(0.11)	(0.093)	(0.073)
Sec CompXRecycling Rate	-0.37***	-0.45***	-0.51***	-0.27***
	(0.11)	(0.12)	(0.11)	(0.084)
Observations	6,126	6,126	6,126	6,126
R-squared	0.282	0.284	0.459	0.420
Year FE	YES	YES	YES	YES
Prod FE	NO	NO	YES	YES
Owner FE	NO	NO	NO	YES

Robust standard errors in parentheses

Note: Results for regressions of primary owner supply on covariates. All results are for fixed effect regressions with the coefficients on fixed effects omitted for brevity. Secondary competition indicator created using end sample share of secondary firm for each product.

state without a subsidy.

I also find in column (1) that a 10% increase in the stock of recycled input leads to a 1.2% reduction in a primary firm's quantity supplied, and that this result is statistically significant. This result provides further evidence that an increase in the competition from the secondary firms leads to a reduction in primary production. In particular, this response is evidence that primary firms reduce supply as the contemporaneous cost of secondary firms decreases. The coefficient on the stock remain negative and significant across specifications.

My estimated coefficient on the recycling rate for a firm not exposed to competition is -0.11 but is not statistically significant. In comparison, the coefficient for recycling rate for a firm exposed to secondary competition is -0.37 and statistically significant. This result provides evidence that primary firms are forward-looking. In particular, firms differ in their response to the recycling rate based on whether the firm is exposed to secondary competition. While all primary firms are theoretically harmed by a greater recycling rate, only the firms that are most exposed to future competition from the secondary firms respond by reducing current quantity supplied. The differential response to recycling based on exposure to secondary competition holds across specifications.

To put the estimated effects in perspective, I provide a back of the envelope calculation of the change in profit. The average primary firm produces approximately 430 tons of paper per day. The coefficient on the interaction between secondary competition and the recycling rate in column (1) implies this firm will decrease its quantity by 16 tons per day in response to a 10% increase in the recycling rate. Assuming that price does not adjust to this change, I calculate an upper bound on the revenue forgone by multiply this change in quantity by the price of the most expensive paper product during this period.[28] This exercise implies that the average firm forgoes an upper bound of $16,000 from the forward-looking response to an increase in the recycling rate. Scaling up to annual level, this result implies an upper bound of $5.6 million of revenue forgone. During the year used for this calculation, each of the 20 largest firms had revenue greater than $1 billion. The predicted reduction is approximately 5.6% of this amount.

4.4 Primary Best Response

I report the results of the primary best response regression specifications in Table 5. Column (1) includes the total quantity supplied by the secondary firms as a direct test of the change in current competition. Column (2) adds the recycling rate to test the response to the dynamic incentive. In column (3), I add product fixed effects, and in column (4) I add firm fixed effects.

The coefficient on the quantity supplied by secondary firms is -0.06 and statistically significant in column (1). This coefficient implies that a 10% increase in secondary supply lowers a primary firms quantity by 0.6%. This result is consistent with a primary firm reducing quantity in response to more intense competition from the secondary firms. The coefficient is of similar

[28] Ince (1993) reports list prices on each product in 1986. I use these prices because the only available time series of prices are price indices that cannot be used to quantify the magnitude of these effects.

Table 5: Primary Firm Best Response and Secondary Competition

	(1)	(2)	(3)	(4)
Total Secondary Supply	-0.060***	-0.054***	-0.048***	-0.041***
	(0.0056)	(0.0058)	(0.0055)	(0.0047)
Sec Comp		1.92***	2.30***	1.65***
		(0.33)	(0.30)	(0.23)
Recycling Rate		0.068	0.14	0.22***
		(0.11)	(0.090)	(0.069)
Sec CompXRecycling Rate		-0.58***	-0.61***	-0.46***
		(0.096)	(0.086)	(0.065)
Regional GDP	3.16***	3.06***	1.74***	0.96***
	(0.10)	(0.16)	(0.14)	(0.11)
Electricity Price	-1.06***	-1.08***	-0.66***	-0.24***
	(0.034)	(0.037)	(0.036)	(0.032)
Observations	6,126	6,126	6,126	6,126
R-squared	0.252	0.257	0.462	0.42
Year FE	YES	YES	YES	YES
Prod FE	NO	NO	YES	YES
Owner FE	NO	NO	NO	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: Results for regressions of primary owner supply on covariates. All results are for fixed effect regressions with the coefficients on fixed effects omitted for brevity.

sign and significance across the specifications. These regression results provide further evidence that primary firms reduce supply in response to more intense current competition from the secondary firms.

Similar to the equilibrium quantity regression specifications, I find that the coefficient on the interaction between secondary competition and the recycling rate is negative and significant across specification. In comparison, the coefficient on recycling is positive and not significant in most specifications. These results provide further evidence that firms are forward-looking. That is, a primary firm's best response decreases in response to a greater recycling rate if the firm is exposed to secondary competition, but not if the firm is not exposed to this source of competition.

5 Simulation of Policy Exercises

5.1 Simulation Motivation and Setup

While my regression results provide suggestive evidence that the incentives identified in the theoretical model exist in the Paper Industry, these results are composed of several channels. To explore the mechanisms behind these results in more detail, I turn to simulations exercises using the theoretical model. I use parameters estimated from a range of sources in the exercises. In Table 13 in the Appendix, I list the parameters I use in the exercises, and the source of these parameters. By simulating the model, I can also study different policy interventions in the model. Analyzing these policies let me illustrate implications of the dynamic incentives on equilibrium outcomes.

Recall that the theoretical model specifies the problem of a firm i as

$$V_i(\bar{Q}_{t-1}) = \max_{q_{i,t}} \quad P(Q_t)q_{i,t} - C_i(q_{i,t}) + \beta V_i(\bar{Q}_t)$$

where the state variable evolves as $\bar{Q}_t = \psi Q_t + (1-\delta)\bar{Q}_{t-1}$, and a secondary firm's cost function is $C_i(q_i) = \tilde{C}_i(q_i) + R(\sum_{j=1}^{N} q_n, \bar{Q}_{t-1})q_i$. For each exercise, I solve the model, collect equilibrium objects, and construct other policy relevant statistics along the equilibrium path of play. To make the results comparable to previous works, I focus on the case of linear demand, constant marginal costs and a recycled input supply function derived from Swan (1980). In the Appendix, I provide the results for alternative functional forms. For all exercises I assume that firms use a common discount rate $\beta = 0.95$.

I use two data generating processes for these exercises. The first process assumes firms play the dynamic game and solve problem (D). The second process assumes that firms only account for the static strategic incentives. That is, this process assumes firms are instead solving the myopic problem (M). Comparing the outcomes of the models lets me separate the dynamic incentives created by recycling from the static strategic incentives.

The first set of exercises studies the implication of the competition softening incentives on inference about market power. For these exercises, I calculate each firm's markup and the HHI for the market, two measures commonly used to infer market power. I compare these measures from the dynamic and myopic model over a range of market structures.

I also simulate horizontal mergers to explore how the competition softening incentive impacts the incentives for and equilibrium effects of mergers. These exercises focus on changes in quantity supplied by the merging firms and the total quantity supplied. I consider the merger model of Salant, Switzer, and Reynolds (1983) that isolates the merger effects from any efficiency gains. In the Appendix, I consider alternative merger models such as Perry and Porter (1985) that let mergers affect marginal costs.

The final set of exercises studies the interaction between competition softening incentives and policies designed to shift production away from environmentally damaging firms. These exercises include the observed policy of subsidizing secondary firms, a pigouvian tax on primary production, an increase in the recycling rate, and a one-time increase in the stock of the recycled input.[29] The first two exercises are alternative market based methods to affect firm behavior. The last two exercises illustrate attempts to use the dynamics of the problem to incentivize behavior. For each of these experiments I calculate the path of primary behavior.

[29]This last policy can help illustrate the effect of the recent ban on recycled inputs by China. After this ban, the recycled paper was increased significantly. For a discussion of this policy see https://www.wsj.com/articles/u-s-recycling-companies-face-upheaval-from-china-scrap-ban-1533231057. Accessed 10/12/2018.

5.2 Results and Discussion of Simulations

Market Power. I first discuss the results of the simulations on inference about market power. I compare markups and concentration in the dynamic and myopic model over different market structures. I then discuss how the dynamic incentives explains the difference in these measures. For each exercise I analyze the incentives faced by the firms in the long run.

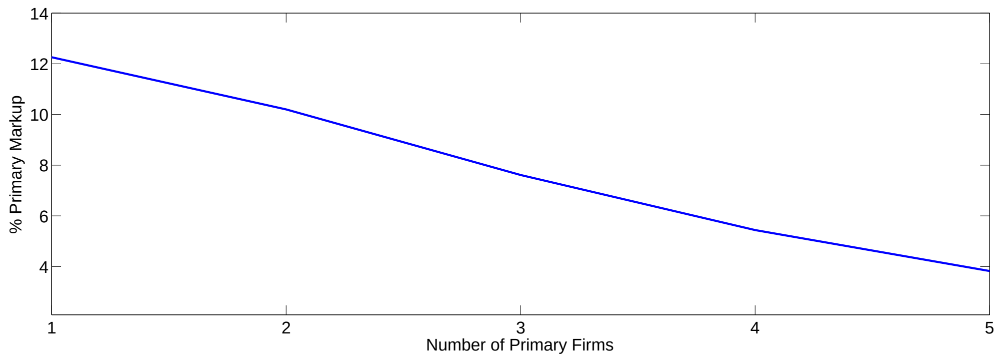

Figure 6: % Difference in Primary Markups between Dynamic and Myopic Models, holding Fixed the Number of Secondary Firms at 1 and varying the Number of Primary Firms.

I illustrate the percentage difference in a primary firm's markup over market structures in Figure 6. Primary firms charge higher markups in the dynamic model relative to the myopic model across market structures. The intuition for the difference is that the competition softening incentive leads primary firms to reduce contemporaneous quantity supplied, which further raises the equilibrium price. In my simulation of a market that includes one primary and one secondary firm, the primary firm's markup is approximately 12% higher in the dynamic model. However, as the number of primary firms increases, the competition softening incentive decreases. Holding fixed the number of secondary firm at one, the difference in a primary firm's markup decreases as I consider exercises with a greater number of primary firms. Therefore, the myopic strategic incentives become more important, relative to the dynamic incentive, as the number of primary firms increases. This result illustrates the dynamic externality between the primary firms because an individual primary firm's incentive to reduce current supply is reduced as the number of other primary firms increases.

Measures of market concentration such as the HHI are lower in the dynamic model than in the myopic model. The intuition for this result is that the reduction in supply caused by the competition softening incentive both reduces primary market share and increase secondary market share. In the simulation of a market with one firm of each type, the HHI is approximately 6% lower in the dynamic model relative to the myopic model. Similar to the effects on markups, the difference between the HHI in the two models decreases as I consider exercises with a greater number of primary firms. I illustrate this result in Figure 13 in the Appendix.

Because the dynamic model causes markups to rise and concentration to fall, relative to the myopic model, inferring market power from concentration may lead antitrust authorities to underestimate market power when these dynamic incentives are important. These market shares are used to predict the exercise of market power post-merger, so the underestimation can also lead authorities to assume firms will behave more competitively post-merger. However, the externality between primary firms suggests that the underestimate of market power becomes less important as the number of primary firms increases.

Horizontal Mergers. The second set of exercises investigates how the competition softening incentive interacts with horizontal mergers. I study the case with 2 primary firms and 1 secondary firm pre-merger, and I simulate a merger between the primary firms. I examine the outcomes of the model in the periods before the merger, the short run effect that occurs the period of the merger, and the long run effects in the periods after the merger. For all both the dynamic and myopic models, I normalize the pre-merger quantities to 100, so I can isolate the changes caused from the merger from any pre-merger differences between the models.

The primary firms in the dynamic model decrease their combined quantity by 35% immediately after the merge. In the myopic model, the primary firms only decrease their quantity by 28%. Therefore, there is a greater reduction in the dynamic model. In both models the primary firm internalizes how a quantity reduction raises their current joint profit; however, the primary firms in the dynamic model also recognize that reducing current quantity also raises profits in the future. This latter incentive leads to the greater quantity reduction in the dynamic model. Combined with the results of the market power exercises, these merger exercises show that antitrust authorities that do not account for the dynamic incentives can miss a further source of anti-competitive behavior caused by horizontal mergers. In both models the long run reduction by the primary firms is lower than the short run reduction. The intuition for this result is the short run reduction in quantity raises secondary costs in the long run. This increase in costs lets the primary firms exercise greater market power in the long run. I illustrate primary supply in these merger exercises in Figure 7.

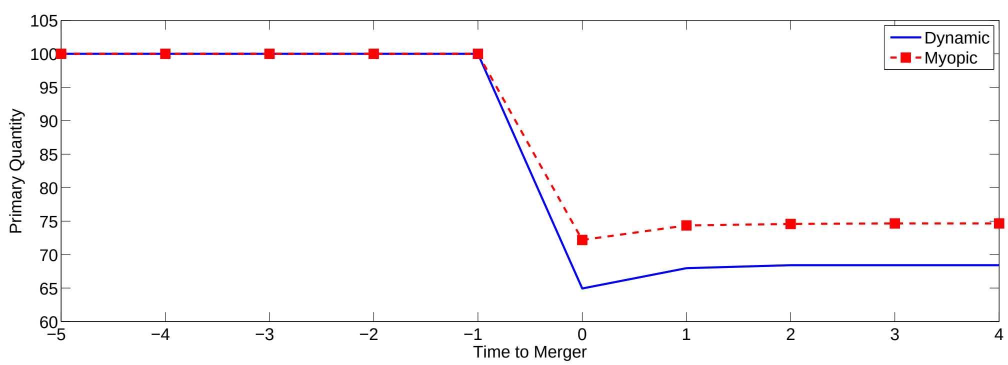

Figure 7: Primary Quantity Before and After Merger. Pre-Merger Structure 2 Primary and 1 Secondary.

The secondary firm directly respond to the merger by expanding quantity. In the myopic model the secondary firm increases its quantity by 9% in the short run, and the response is similar in the dynamic model. However, in the long run, the secondary firm's quantity decreases relative to the pre-merger case. This reduction occurs because the quantity reduction by the primary firms successful softens competition in the long run. Because the primary firms reduces quantity more in the dynamic model, the reduction in long term secondary quantity is greater in the dynamic model. This reduction is approximately 22% relative to pre-merger in the dynamic model and 15% in the myopic model.

I illustrate the change in total quantity to show that mergers are worse for consumers in the dynamic model in Figure 8. The total quantity decreases by approximately 25% in the dynamic model and 20% in the myopic model in the short run. The competition softening caused by the primary firms' supply reduction leads to an even greater reduction in total quantity in the long run. This reduction is approximately 30% in the dynamic model and approximately 23% in the myopic model. Thus, the harm to consumers is greater in the long run through the competition softening channel. In Figure 14 in the Appendix, I show the change in Consumer Surplus from the reduction in total quantity supplied in each model.

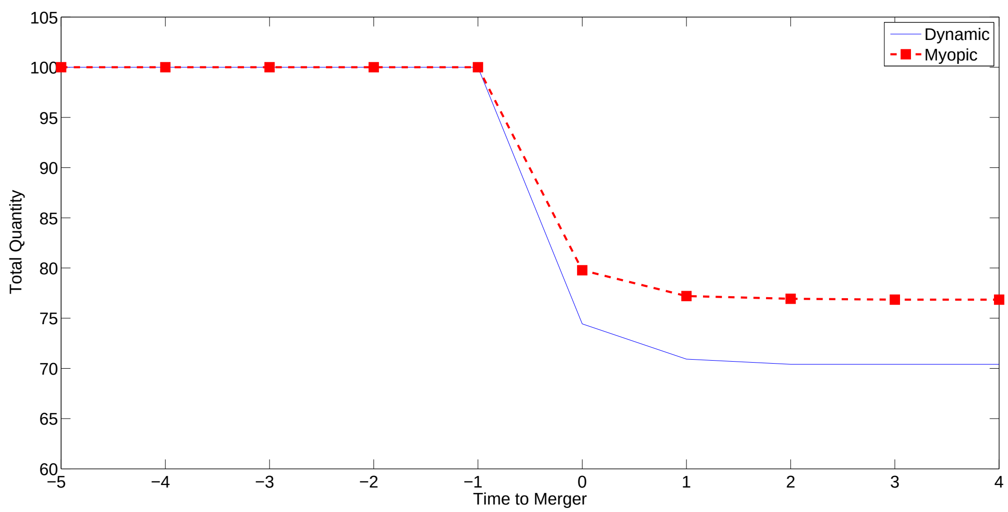

Figure 8: Total Quantity Before and After Merger. Pre-Merger Structure 2 Primary and 1 Secondary.

Policy. The last set of exercises investigates how the dynamic incentive interacts with policies aimed at shifting production away from primary firms. To illustrate the results, I show the primary quantity before the policy comes into effect, the short run response to the policy and the quantity in the long run. I discuss exercises with 1 primary and 1 secondary firm and compare outcomes in the dynamic and myopic models. I normalize all quantity to 100 before the policy intervention as in the merger exercises.

I first discuss a subsidy for the secondary firm.[30] I illustrate the results of this exercise in

[30] I consider a 50% price premium rather than the 5% premium observed in the data. Increasing the magnitude of the subsidy makes the subsidy comparable to the other exercises.

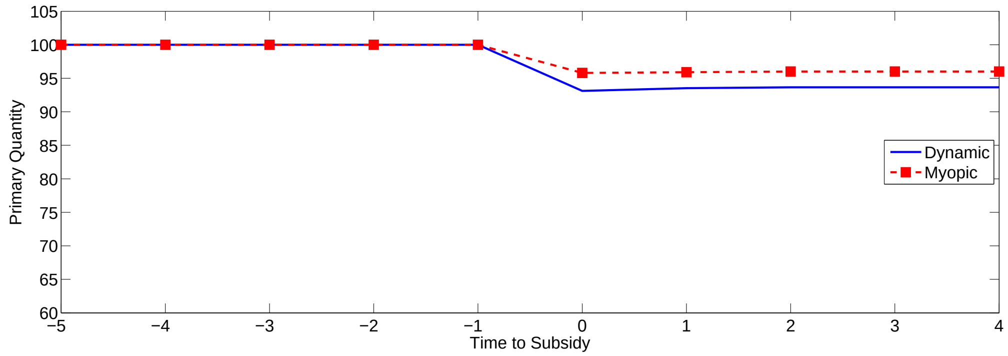

Figure 9: Primary Quantity Before and After Subsidy for Secondary Firm.

Figure 9. The subsidy raises the marginal revenue of secondary firms so only affects primary behavior through strategic interaction. The effectiveness of the subsidy is limited because the primary firm strategically reduces supply because competition has become more intense. The current reduction raises the future cost of the secondary firm and partially offsets the benefit of the subsidy to the secondary firm. The short run and long run reduction in primary quantity are of similar magnitude. The reduction is greater in the dynamic model, approximately 6%, than the myopic model, approximately 4%. The intuition for the greater reduction in dynamic model is that the primary firm realizes that competition will be more intense in the future because of the subsidy. Therefore, the primary firm react by further reducing quantity.

The next exercise studies a $5 per-unit tax on primary production to illustrate the interaction between incentives and a standard policy response to environmental damages. This policy changes behavior by directly raising the primary firm's marginal cost. The primary quantity reduction is similar in the dynamic and myopic model. The reduction is approximately 8% in the short run and 7% in the long run. The response is similar in the two models because the policy does not make the competition from the secondary firm more intense in the future. Therefore, the incentive to further reduce quantity to soften future competition is relatively less important than the direct incentives created by the tax. I illustrate the change in the primary firms quantity supplied in Figure 15 in the Appendix.

I also study a doubling of the recycling rate. This exercise illustrates an attempt to change behavior by exploiting the dynamics of the problem. Increasing the recycling rate raises the stock of the recycled input for any given quantity supplied in the current period, and hence lowers the future cost of the secondary firm. I illustrate the primary firm's quantity response to this policy in Figure 10. The short run quantity reduction by the primary firm is approximately 19% in the dynamic model and exactly 0% in the myopic model. This difference occurs because the primary firm in the dynamic model must reduce its quantity by a greater amount to soften competition as the recycling rate increases. The primary firm in the myopic model does not account for the effect of current supply on future competition so does not respond in the period in which the recycling rate changes. In the long run the primary firm decreases its quantity in

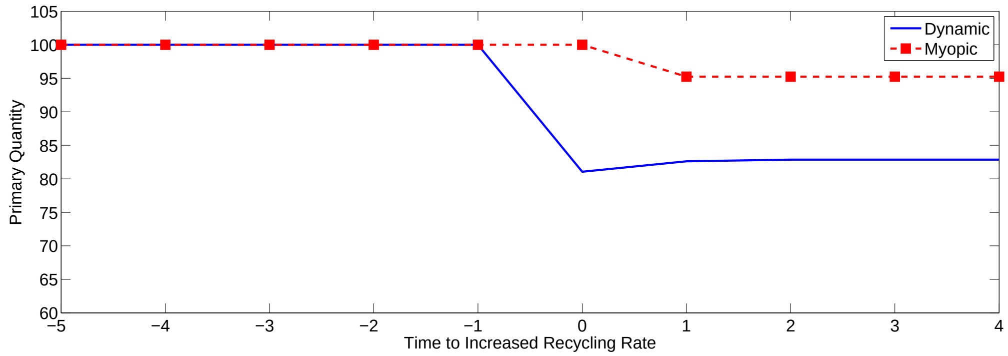

Figure 10: Primary Quantity Before and After an Increase in Recycling Rate.

the myopic model by approximately 5% because the policy lowers the secondary firm's marginal cost and leads to a strategic reduction by the primary firm.

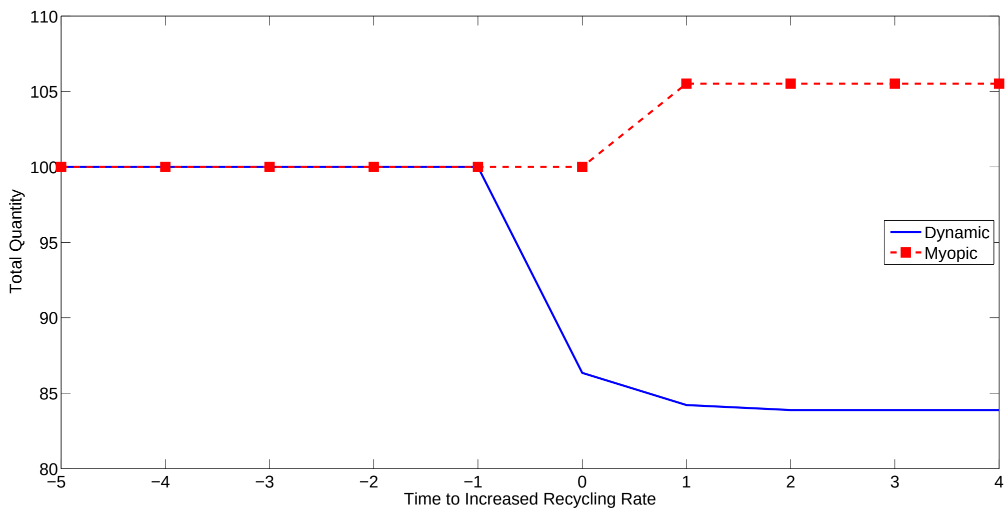

Figure 11: Total Quantity Before and After an Increase in Recycling Rate.

I also illustrate the change in total supply after the recycling rate increases in Figure 11. The total quantity supplied increases by about 5% in the long run in the myopic model. In comparison, the total quantity **decreases** by about 16% in the dynamic model. The difference in total quantity illustrates that the dynamic behavior of the primary firm also affects the total quantity. The difference in total quantity illustrates that the strategic primary behavior not only reduces the quantity of supply below the socially optimal level, from the exercise of market power, but also leads to a greater share of primary than is optimal.

The final exercise explores a one-time 5% increase in the stock of recycled input. This policy directly lowers the cost of secondary firm in one period and induces a strategic reduction by the primary firm. There is a short run reduction of approximately 3% in both the dynamic and myopic model. However, this policy has almost no effect on the long run quantity of the primary in either model. The short run reduction by the primary firm offsets the short run decrease in the secondary firm's marginal cost. Figure 16 in the Appendix, shows the change in quantity supplied from the one-time increase in the stock.

6 Conclusion

I develop a theoretical model of oligopoly competition in which the good is recycled as an intermediate input for future periods. This model illustrates that firms face an incentive to reduce current quantity supply and soften future competition. I test the prediction using data on firm behavior in the US paper industry and find that firms using primary inputs reduce their quantity supplied as predicted.

Simulations of the model illustrate several novel implications of the model. The first implication concerns the competition softening incentive between primary firms. Because a reduction in supply by one firm also benefits other firms in the future, primary firms face an additional incentive to merge and internalize the benefit of a supply reduction. Firms reduce quantity supplied by a greater amount post-merger when they respond to the dynamic incentive. The greater increase in profits over time generate by the reduction could help explain the pattern of consolidation observed in the paper industry. Secondly, the simulations illustrate that strategic supply reduction can undermine the ability of the government to shift production towards the more environmentally friendly secondary paper. This result may help explain why the share of secondary firms remained low over my sample period despite policy interventions that involved significant expenditures. The final implication is that the competition softening incentive results in the primary firms exercising greater market power; however, the market appears less concentrated when firms respond to these incentives. Combining these results shows that using concentration based measures such as specified in the Horizontal Merger Guidelines (2010) will lead antitrust authorities to incorrectly infer that markets are more competitive than in actuality.

The environmental policy simulations particularly illustrate the difficulty of designing policy when dynamic effects are important and agents can behave strategically. The observed subsidy policy in the paper industry appears to be relatively ineffective in moving the outcome towards the planner's solution. However, exploiting the dynamics of the problem, for example by increasing the recycling rate, can have a greater impact on firm behavior. A future line of research suggested by this result is how to design policy to shift production when firms can take strategic action to counteract the policy. For example in my setting primary firms can limit their supply and prevent secondary firms from expanding supply. Similar incentives exist in other dynamic oligopoly settings and in single agent problems when consumers can behave strategically, e.g. timing the purchase of a durable good with a time varying subsidy as in Langer and Lemoine (2018). Understanding the incentives in settings similar to the one analyzed in my work can help illustrate on incentives in related settings and help policy makers design more effective policies.

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Appendix

Proofs

Example of Model Under Specific Functional Forms

I use this model to demonstrate how recyclable materials affect firm behavior in an oligopoly. I make the following assumptions for explication. I assume that the inverse demand for the final good is linear, $P(Q) = a - bQ$, and that the costs, net of the recycling inputs, are quadratic in supply, $C_1(q_m) = \frac{c_1}{2}q_m^2$, $\tilde{C}_2(q_n) = \frac{c_2}{2}q_n^2$. The recycled stock evolves linearly as $\bar{Q}_t = \psi * (\sum_{n=1}^{N} q_{n,t} + \sum_{m=1}^{M} q_{m,t})$. The cost of using secondary inputs for a firm j in period t is given by $Rq = \phi * (\sum_{n=1}^{N} q_{n,t}/\bar{Q}_{t-1})q_{j,t}$ where ϕ is the parameter governing wholesalers' production efficiency. I study a two-period game in which firms cannot commit to supply paths and show how the strategies of the Subgame Perfect Equilibrium of this game differ from a model with the same primitives but in which firms to not account for the affect of current supply on future profit.

I solve the game backwards with each firm taking as given the stock of the recycled input from the first period, $\bar{Q}_1$. The problem of a primary firm, m, is

$$\max_{q_m} \quad (a - b\sum_{i=1}^{M} q_i - b\sum_{j=1}^{N} q_j)q_m - \frac{c_1}{2}q_m^2.$$

The first order condition for this firm is

$$a - 2bq_m - b\sum_{i \neq m} q_i - b\sum_{j=1}^{N} q_j - c_1 q_m = 0.$$

Similarly, the problem for a secondary firm, n, and the associated first order condition are

$$\max_{q_n} \quad (a - b\sum_{i=1}^{M} q_i - b\sum_{j=1}^{N} q_j)q_n - \frac{c_2}{2}q_n^2 - \phi * (\sum_{j=1}^{N} q_j/\bar{Q}_1)q_n$$

$$a - 2bq_n - b\sum_{i=1}^{M} q_i - b\sum_{j \neq n} q_j - c_2 q_n - (\phi/\bar{Q}_1)((\sum_{j=1}^{N} q_j) + q_n) = 0.$$

I solve for a symmetric equilibrium in which all firms of the same type use the same strategy. In this equilibrium the best response functions are

$$q_m(q_n) = \frac{a - bNq_n}{b(M+1) + c_1}$$

$$q_n(q_m) = \frac{a - bMq_m}{b(N+1) + c_2 + (\phi/\bar{Q}_1)(N+1)}.$$

The negative slope of best response functions shows that quantities are strategic substitutes in this setting. Solving the system of equations yields equilibrium strategies as a function of the stock of recycled materials as

$$q_m(\bar{Q}_1) = \frac{a(b + c_2 + (\phi/\bar{Q}_1)(N+1))}{D}.$$

$$q_n(\bar{Q}_1) = \frac{a(b+c_1)}{D}.$$

The denominator of these expressions is

$$D = b^2(M+N+1) + b(N+1)c_1 + b(M+1)c_2 + c_1c_2 + (\phi/\bar{Q}_1)(N+1)(b(M+1)+c_1).$$

These strategies yield equilibrium flow profits

$$\pi_m(\bar{Q}_1) = \frac{a^2(2b+c_1)(b+c_2+(\phi/\bar{Q}_1)(N+1))^2}{2D^2}$$

$$\pi_n(\bar{Q}_1) = \frac{a^2(b+c_1)^2(2b+c_2+2(\phi/\bar{Q}_1))}{2D^2}.$$

To check that the supply and profits of a primary (secondary) firm decreases (increases) I take the derivative of the supply and profit of these firms. To keep the notation relatively simple I use $f(\bar{Q}_1) = \phi/\bar{Q}_1$ with $f' < 0$. I sign the effect of stock on the supply of primary and secondary firms using

$$\frac{\partial q_m}{\partial \bar{Q}} = \frac{a(N+1)f' * D - f' * (N+1)(b(M+1)+c_1)a(b+c_2+f*(N+1))}{D^2} = f'\frac{a(N+1)bN(b+c_1)}{D^2} < 0$$

$$\frac{\partial q_n}{\partial \bar{Q}} = \frac{-a(b+c_1)(N+1)(b(M+1)+c_1)}{D^2}f' > 0.$$

Performing a similar exercise for the effect of stock on profits I sign $\partial\pi_1(\bar{Q})/\partial\bar{Q}$ by signing the numerator of this term. Signing this term follows from

$$2a^2(2b+c_1)(b+c_2+2f\phi(N+1))f' * \phi(N+1)2D^2$$

$$-4\phi(N+1)(b(M+1)c_1)f' * Da^2(b+c_1)^2(2b+c_2+2f\phi)$$

which simplifies to

$$f' * 4a^2(2b+c_1)\phi(N+1)D(b+c_2f\phi(N+1))b(b+c_1) < 0.$$

Thus, the profit of a primary firm decreases in the stock as claimed.

The sign of $\frac{\partial\pi_2(\bar{Q})}{\partial\bar{Q}}$ is the same as the sign of

$$-f' * 4a^2(b+c_1)^2\phi D(b^2(1+M+N+2MN) + c_1(c_2N + f\phi(N+1)))$$

$$-f' * 4a^2(b+c_1)^2\phi D(b(c_1(N+1) + (M+1)(c_2N + f\phi(N+1)))).$$

All the terms except for f' are positive; therefore, both the first and second terms have the same sign as $-f'$. This establishes that $\frac{\partial\pi_2(\bar{Q})}{\partial\bar{Q}} > 0$, so the profit of secondary firms increases as the stock increases.

Heterogeneous Goods

Consider a differentiated goods oligopoly with firms choosing quantity as the strategic variable as in Singh and Vives (1984). The system of (inverse) demand functions for a primary firm m

and secondary firm n in this setting are

$$p_m = a_1 - b_1 \sum_{m=1}^{M} q_i + \gamma \sum_{j=1}^{N} q_j$$

$$p_n = a_2 + \gamma \sum_{i=1}^{M} q_i - b_2 \sum_{j=1}^{N} q_j.$$

Using the results from the above proof, the effect of recyclable material on profits has the same sign as in the homogeneous goods case if $\pi^n_{1,2}$. This condition holds if

$$\pi^n_{1,2} = \gamma \leq 0.$$

Therefore, the main result for the effect of recyclable material still holds when goods are differentiated if best response functions slope down.

Incentives Preserved in Regional Model

Because the conditions necessary to demonstrate that the dynamic effects can generate similar incentives in a model with regional trade are more complex, I illustrate this channel using specific functional forms to show that the results can still hold. The regional model adds to extra issues. Shipping a good outside the firms' home market requires this firm to incru an additional marginal cost $t \geq 0$. Each market k also sets its own subsidy for the purchase of secondary goods, originating in any market, $s_k \geq 0$.

Consider the case of 2 markets with 1 primary and 1 secondary firm in each market k. I specify the functional forms as $P_k = A_k - bQ_k$, $C_{i,k} = c_{i,k}q_{i,k}$, and $R_k = r_k(\bar{Q}_k)q_{i,k}$. Here i denotes whether the firm is primary or secondary, k denotes the market, and r_k denotes the recycled input price in market k with $r' \leq 0$. I also shut down purchasing power in the recyclable materials market in this setup. I denote the supply of the primary firm located in market 1 to market k by x_k $k \in \{1, 2\}$, the supply of the secondary firm located in market 1 by y_k, the supply of primary firm located in market 2 by z_k and the supply of the secondary firm located in market 2 by w_k.

This setup gives a system of 8 first order equations in 8 unknowns. The equilibrium supply are of the form

$$x_1 = \frac{A_1(1+s_1) - 4c_{1,1}(1+s_1) + c_{1,2} + c_{2,1}(1+s_1) + c_{2,2} + r_1 + r_2 + t(2+s_1)}{5b(1+s_1)}$$

and similar expressions for the other supply. Similar to the baseline model a decrease in secondary firms' costs causes a strategic reduction by the primary firms. With the supply in hand, I can show that the demand for a primary firm is of the form

$$\pi_x = b(x_1^2 + x_2^2)$$

and for a secondary firm

$$\pi_y = b((1+s_1)y_1^2 + (1+s_2)y_2^2).$$

Taking derivatives of the profit functions with respect to each secondary input price gives the claimed sign. Finally, as in the baseline model, the sign of the derivative of profit with respect to first period production plus the concavity of the profit function gives the claimed behavior.

Alcoa Model Implies Recycled Cost Satisfying Conditions

In this section I establish that the recycling wholesaler model considered in the dominant firm competitive fringe literature satisfies the assumptions of my theoretical model. Following Swan (1980) the profit of a representative wholesaler is

$$\pi_w = (p^R r(z) - z)\bar{Q}$$

where p^R is the price received by wholesalers and z the inputs used to produce the secondary input. I normalize the price of these inputs to 1. Thus, the wholesaler choses its usage of inputs to maximize profits where an increase in inputs increases the share of the stock of recyclable materials that it recovers for sale to the secondary firms. I follow his discussion by assuming $r(z)$ is increasing and concave in input usage, and in particular examine the case of $r(z) = 1 - e^{-kz}$. Here k is a parameter governing the wholesalers' efficiency.

Maximizing the wholesaler's problem with respect to z and plugging back into the recycling function gives the optimal rate $r(z^*) = 1 - \frac{1}{kp^R}$. Wholesalers recovery more as the price they receive increases or they become more efficient. To derive the input cost function, I substitute this expression into secondary supply, equate supply to demand and solve for the input price. This exercise gives

$$Q_R = \bar{Q}(1 - \frac{1}{kp^R}) \implies p^R = \frac{\bar{Q}}{k(\bar{Q} - Q_R)}.$$

Finally, I establish that this expression satisfies the conditions from the theoretical model. These are the derivatives of the secondary input price and the total cost of a secondary firm n using the secondary input. These are respectively

$$\frac{\partial R}{\partial Q_R} = \frac{\bar{Q}}{k(\bar{Q} - Q_R)^2} \geq 0$$

$$\frac{\partial R}{\partial \bar{Q}} = \frac{-Q_R}{k(\bar{Q} - Q_R)^2} \leq 0$$

$$\frac{\partial^2 R}{\partial Q_R \partial \bar{Q}} = \frac{-(Q_R + \bar{Q})}{k(\bar{Q} - Q_R)^2} \leq 0$$

$$\frac{\partial R q_n}{\partial q_n} = \frac{\bar{Q}}{k(\bar{Q} - Q_R)} + \frac{\bar{Q}}{k(\bar{Q} - Q_R)^2} q_n \geq 0$$

$$\frac{\partial^2 R q_n}{\partial q_n^2} = \frac{2\bar{Q}}{k(\bar{Q} - Q_R)^2} + \frac{2\bar{Q}}{k(\bar{Q} - Q_R)^3} q_n \geq 0.$$

Tables and Figures

Table 6: Timing and Level of State Secondary Paper Subsidy Laws

State	Subsidy Level	Year
AZ	5%	1990
AR	10%	1991
CA	10%	1989
CT	10%	1988
FL	10%	1983
GA	8%	1991
ID	5%	1985
KS	5%	1990
ME	10%	1989
MD	5%	1988
MI	10%	1989
MN	10%	1989
MS	10%	1990
MO	10%	1989
NH	5%	1989
NJ	10%	1993
NM	5%	1990
NY	10%	1981
OR	5%	1991
PA	5%	1988
SC	7.5%	1991
VT	5%	1989
VA	10%	1993
WA	10%	1990
WV	10%	1989

Table 7: Product-Company Level Summary Statistics

Product	Share Primary	Share Secondary	Ave. Mill Capacity (tons/day)	N
Coated Freesheet	94	6	555	347
Coated Groundwood	100	0	822	182
Kraft Paper	65.9	34.1	456	463
Newsprint	76.8	23.2	993	329
Tissue Paper	29.9	70.1	228	1015
Uncoated Freesheet	84.5	15.5	480	1127
Uncoated Groundwood	86.3	13.7	289	287
Special Paper	85	15	135	934
Corrugating Medium	45.2	54.8	481	852
Linerboard	67.7	33.3	1195	760
Solid Bleached Board	100	0	1001	314
Recycled Paperboard	0	100	271	1583

Note: All calculations at the product level. Share of primary and secondary calculated from FPL. For approximately 80% of these observations, the mill level and product level are the same. I adjust the remaining observations using the product share as weights.

Table 8: Recycled Input Input-Output Table

Recycled Input	Final 1	Final 2	Final 3	Final 4	Final 5
Old Newsprint (ONP)	NP				
Old Corrugated Cardboard (OCC)	LB	CM			
Mixed Paper (MP)	CG	UG	SP	KP	SB
Pulp Substitute (PS)	CF	UF	KP	SB	
Final Good Usage (%)	ONP	OCC	MP	PS	
Newsprint (NP)	100	-	-	-	
Coated Freesheet (CF)	-	-	-	100	
Uncoated Freesheet (UF)	-	-	-	100	
Coated Groundwood (CG)	-	-	68	32	
Uncoated Groundwood (UG)	-	-	69	31	
Tissue Paper (TP)	10	15	15	60	
Kraft Paper (KP)	-	85	10	5	
Special Paper (SP)	-	-	29	71	
Corrugating Medium (CM)	-	95	5	-	
Linerboard (LB)	-	100	-	-	
Solid Bleached Board	-	-	-	-	
Recycled Paperboard	14	61	16	9	

Note: Information on relationship between inputs and final products based on industry sources such as Plant and Steiker (1978) and author's calculation.

Table 9: Regressions of Price on Capacity Level and Utilization Rate

	NP	GWP	UF	TP	CP	KP	SP	CM	LB
Capacity (tons/100)	1.82***	5.37***	0.94***	2.31***	1.41***	-4.48***	4.89***	2.55***	0.96***
Utilization (%)	0.013**	0.0034**	-0.0017	0.014***	0.013***	-0.012***	0.0073	0.0079	0.0084
Observations	21	13	20	13	20	18	13	21	21
R-squared	0.856	0.939	0.770	0.923	0.884	0.829	0.573	0.720	0.832

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

Note: All calculations based on available aggregated data over the sample period. Capacity and capacity utilization were available for the entire period while some price series are only available for a subset of years.

Table 10: Recycling Rate and Previous Production

	(1)	(2)
Paper and Paperboard Production	0.28***	0.31***
	(0.039)	(0.044)
Observations	44	44
R-squared	0.965	0.570

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

Note: Regressions to estimate the recycling rate. Column (1) assumes the recycling process is i.i.d. over time and column (2) assumes an AR(1) process.

Table 11: Stock of Recycled Paper and the Recycling Rate

	(1)	(2)	(3)
$Recycling_{t-1}$	1.26***	0.97**	1.15**
	(0.14)	(0.35)	(0.40)
$Recycling_t$		0.30	0.056
		(0.39)	(0.41)
Recycling Input Price			0.026
			(0.042)
Trend	0.019***	0.018***	0.020***
	(0.0038)	(0.0044)	(0.0042)
Observations	21	21	20
R-squared	0.976	0.977	0.979

Note: Aggregate relationship between the stock of recycled inputs, recycling rates and recycled paper price.

Table 12: Regional Variables

Region	O to D Final (%)	D to O Final (%)	O to D Recycled (%)	D to O Recycled (%)	Wage ($/week)	GDP ($1000s)	Wholesalers (Count)	Population (/1000000)
North East	69.5	59.6	78.2	83.5	550	584.7	285	49.7
North Central	71.4	73.4	84.3	82.9	559	327.1	266	58.4
West	74.9	90.6	92.2	91.5	626	458	191	43.6
South	76.2	74.6	85.2	84.2	596	573.1	156	73.9

Note: The states in each regions are defined below. West: Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. South: Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia. North Central: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. North East: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island and Vermont.

Table 13: Parameters and Sources

Parameter	Value	Source
ψ	0.3	Estimated from Data on Recycling and Production
b	0.5	Average inverse demand elasticity estimated in Pesendorfer (2003)
(c_1, c_2)	(10,8)	Cost ratio in Ince (1993) scaled to level of demand
a	100	Normalized demand intercept

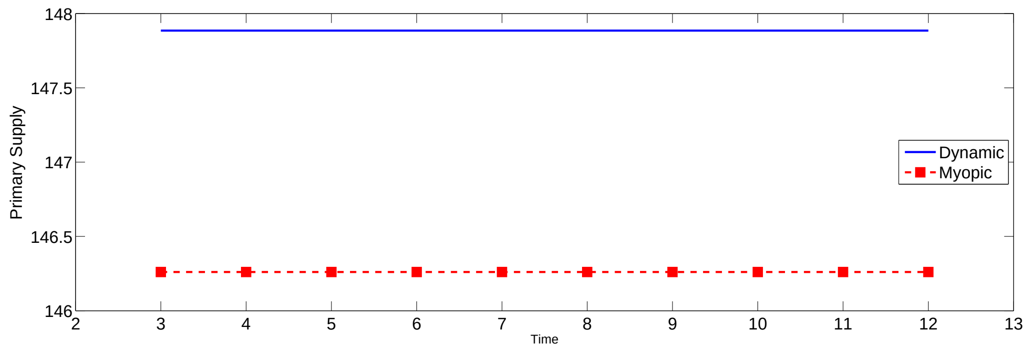

Figure 12: Dynamic Planner Solution for Primary Supply

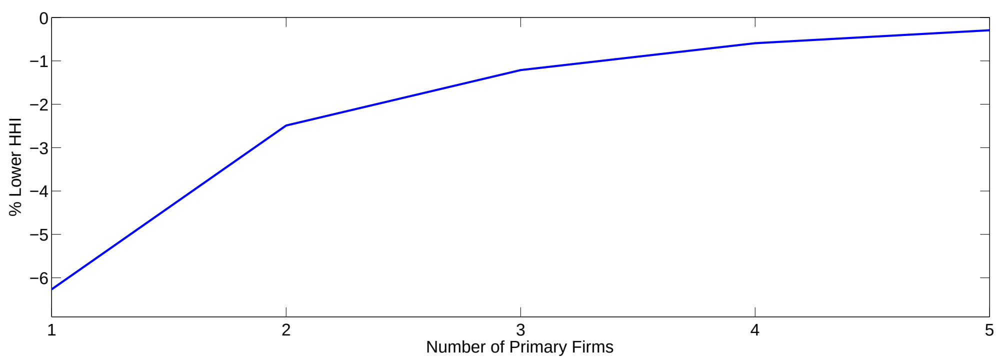

Figure 13: % Difference HHI Dynamic versus Myopic holding the number of Secondary Firms fixed at 1 and varying the number of Primary Firms.

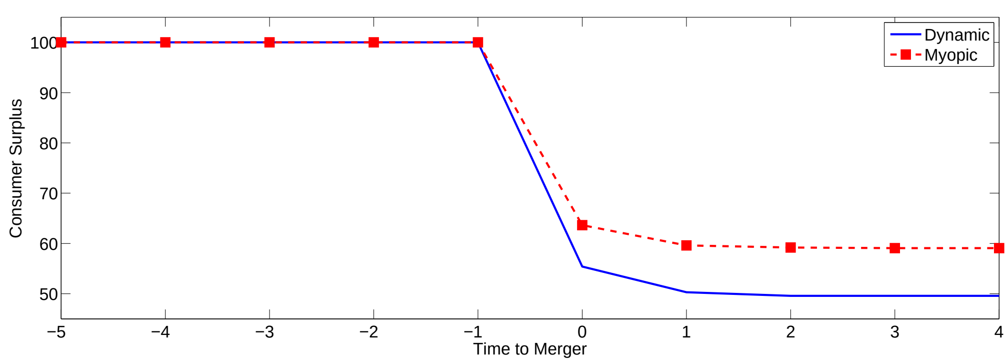

Figure 14: Consumer Surplus before and after merge. Pre-merger market structure 2 primary firms and 1 secondary firm.

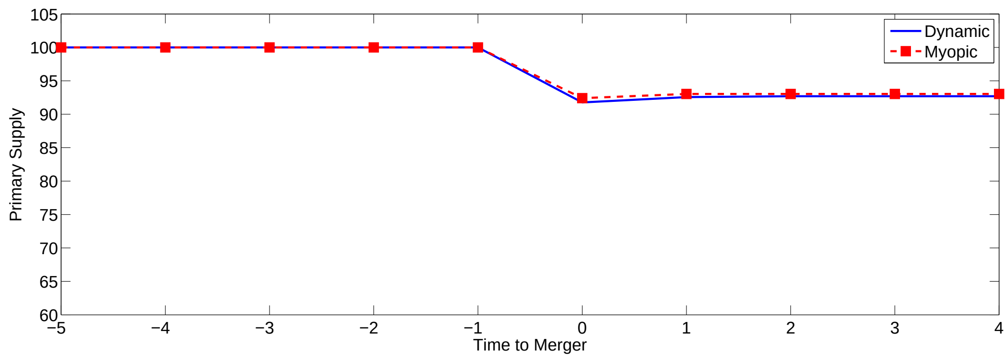

Figure 15: Primary Quantity: Tax Exercise

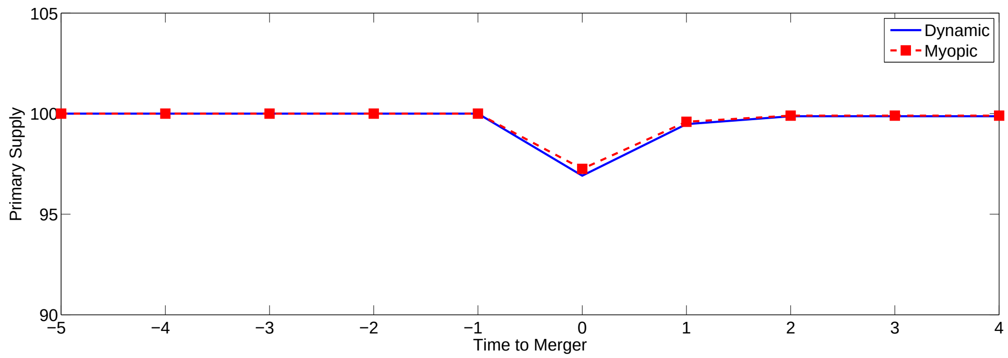

Figure 16: Primary Quantity: Increase Stock

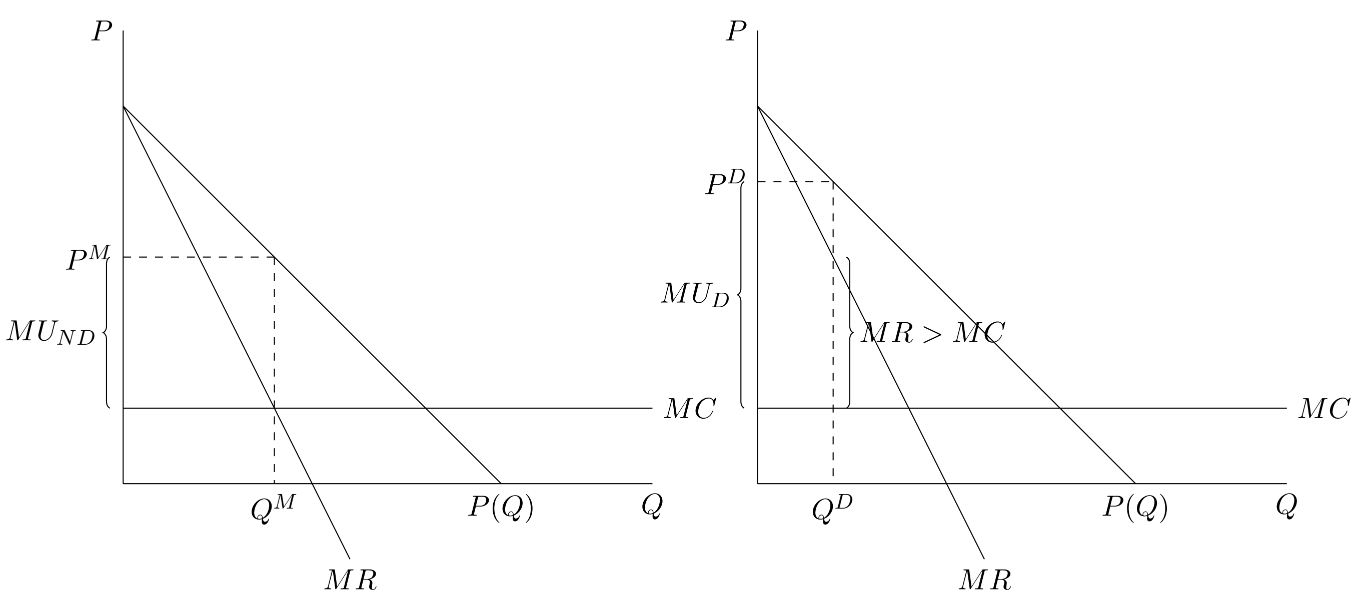

Figure 17: Markups Illustration without Dynamics (Left) and with Dynamic Effects (Right)