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No 1030

# WARWICK ECONOMIC RESEARCH PAPERS

DEPARTMENT OF ECONOMICS

# Do Research Joint Ventures Serve a Collusive Function?

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September, 2012

(First version: October 2007)

**Abstract**

Every year thousands of firms are engaged in research joint ventures (RJV), where all knowledge gained through R&D is shared among members. Most of the empirical literature assumes members are non-cooperative in the product market. But many RJV members are rivals leaving open the possibility that firms may form RJVs to facilitate collusion. We examine this by exploiting variation in RJV formation generated by a policy change that affects the collusive benefits but not the research synergies associated with a RJV. We use data on RJVs formed between 1986 and 2001 together with firm-level information from Compustat to estimate a RJV participation equation. After correcting for the endogeneity of R&D and controlling for RJV characteristics and firm attributes, we find the decision to join is impacted by the policy change. We also find the magnitude is significant: the policy change resulted in an average drop in the probability of joining a RJV of 34% among telecommunications firms, 33% among computer and semiconductor manufacturers, and 27% among petroleum refining firms. Our results are consistent with research joint ventures serving a collusive function.

JEL Classification: L24, L44, K21,O32

Keywords: research and development, research joint ventures, antitrust policy, collusion

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*"People of the same trade seldom meet together, even for merriment and diversion, but the conversation ends in a conspiracy against the public, or in some contrivance to raise prices."*
Adam Smith in *Wealth of Nations*

# 1 Introduction

Every year thousands of firms are engaged in research joint ventures (RJV), an agreement in which all knowledge gained through research and development (R&D) is shared among members. RJVs often provide pro-competitive benefits, such as shared risk, increased economies of scale in R&D, asset complementarities, internalized R&D spillovers (i.e., overcoming free-rider problems), alleviated financial constraints, and shared cost. The majority of the literature focuses on the benefits of RJVs and assumes that members do not collude in the product market.[2] However, by construction, RJVs permit multiproject and multimarket contact and offer firms an opportunity to coordinate behavior. As Martin (1995) notes, "It is conceivable that firms that start to work very closely on R&D projects might start to extend the coordination of their behavior onto other spheres of the life of the firms."[3]

There are numerous ways in which R&D collaborations may lead to collusive product market behavior. For instance, RJV formation could centralize decision making by combining collaborative efforts with control over competitively significant assets, by imposing collateral restraints that restrict competition among participants, by including member firms' individual R&D in the collaborative effort, by facilitating the exchange of competitively sensitive information, or by functioning as a vehicle to signal cooperative behavior. Finally, production joint ventures, which involve jointly manufacturing a new or improved product,

[2] See for instance, Marin, et al (2003), Cassiman and Veuglers (2002), Kaiser (2002), Hernan, et al (2003), and Roller, et al (2007). Caloghirou and Vonortas (2000) and Hagedoorn, et al (2000) provide summaries of the RJV formation literature.

[3] Theoretical papers that address the potential for product market collusion among RJV members include d'Aspremont and Jacquemin (1988) who consider a duopoly model of R&D coordination and find that welfare is improved by R&D cooperation (when spillovers are high) but that in many cases welfare is reduced if firms collude in output; Martin (1995) who finds that self-enforcing R&D makes it more likely that tacit collusion can be sustained in the product market; and Greenlee and Cassiman (1999) who develop a model in which RJV formation and the decision to collude in the product market are endogenous. They find that RJVs should not be supported if they involve product market collusion.

typically involve agreements on the output level, the price of the joint product, or other competitive variables.

The collusive potential is even more pronounced when RJV members are product market rivals, as is frequently the case. Examples of direct product market competitors involved in joint RJVs include Xerox and Dupont who formed a RJV to develop copying equipment; Shell and Texaco to refine crude oil; General Motors and Toyota to produce a new type of car; Merck and Johnson & Johnson to develop new over the counter medicines; MCI and Sprint to provide enhanced telecommunications services; Samsung and Sony to develop LCD panels; and SEMATECH, a consortium of leading semiconductor manufacturers established to improve semiconductor manufacturing technology.

In many industries competitors are in numerous RJVs together. Multiproject contact is an anticompetitive concern, and a number of arguments for how it can facilitate tacit collusion are discussed in the theoretical literature.[4] In addition, Snyder and Vonortas (2005) show that multiproject contact can facilitate explicit collusion in that it serves to bundle markets, which reduces the heterogeneity of firms' private information making collusive agreements more efficient. Another avenue through which multiproject contact may be anticompetitive is that by participating in several markets together firms are able to punish deviations from collusion with price wars on all markets in which they meet.[5]

Firms in computer manufacturing, petroleum refining and telecommunications industries exhibit the highest multiproject contact via joint membership in numerous RJVs. Among RJVs registered with the antitrust authorities from 1985 to 1998, Amoco and Chevron were involved in more than 60 joint RJVs, resulting in the highest multiproject contact among all firms. Furthermore, over three-quarters of all RJVs exhibit multiproject contact in that they have at least one firm pair that is also in at least one other RJV during the same time

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[4] Bernheim and Whinston (1990) find that multimarket contact may reduce the incentive to deviate by pooling asymmetries among firms. Spagnolo (1999) shows that multimarket contact will facilitate tacit colllusion (when firms have concave utility functions over profit) because as markets are added the lost profits from deviation increases more than proportionately with the gain from deviation.

[5] Cooper and Ross (2009) present a theoretical model in which a joint venture between firms in one market can serve to facilitate collusion in another market. See also van Wegberg and van Witteloostuijn (1995) and Vonortas (2000).

period, where 60% of the cases involve firm pairs from the same industry.[6] A common justification for promoting RJVs is that R&D cooperation eliminates wasteful duplication, but the frequent occurrence of numerous RJVs with overlapping research agendas seems to suggest an alternative motivation for RJV formation.

The possibility that firms may undertake legal RJVs as a means to facilitate illegal product market collusion has generated regulatory scrutiny in a wide variety of industries and research areas.[7] For example, in the petroleum industry in 1990, antitrust authorities found evidence that six major oil companies, who were involved in numerous RJVs with overlapping membership, were sharing price information through direct contacts among competitors, press releases, and price postings.[8] More recently, an antitrust lawsuit was filed in 2006 against CITGO Petroleum and Motiva, a research joint venture between Shell, Texaco, and Saudi Refining, alleging that the defendants conspired with the Organization of the Petroleum Exporting Countries (OPEC) to fix the price of gasoline.[9] The following year a group of California gasoline station owners brought a suit against Equilon Enterprises, another RJV between Texaco and Shell, alleging that the RJV violated unfair competition laws and illegally fixed gasoline prices from 1998 to 2001. The suit states that the chairmen of the oil companies met privately starting in March 1996 for the "purpose of forming and organizing a combination," that the executives destroyed documents from the meetings, and that the (now-defunct) RJV violated antitrust laws and caused artificially high wholesale gas prices.[10] Texaco had to withdraw from Equilon and Motiva when it merged with Chevron to

[6] See Snyder and Vonortas (2005) for more analysis on multimarket contact among RJV members.

[7] For an extensive discussion see Brodley (1990), Jorde and Teece (1990), and Shapiro and Willig (1990).

[8] See Coordinated Proceedings in Petroleum Products Antitrust Litigation, 906 F2d 432 (9th Cir. 1990) and Petroleum Products Antitrust Litigation, 906 F.2d 432 (9th Cir.1990). The firms were Texaco, Inc., Union Oil Co. of California, Atlantic Richfield Co., Exxon Corp., Mobil Oil Corp., and Shell Oil.

[9] On January 9, 2009, the case was dismissed due to lack of subject matter jurisdiction. See Refined Petroleum Products Antitrust Litigation (MDL No. 1886) (2006).

[10] The lawsuit hinges on a marketing deal that allowed former rivals to collude on prices starting in 1998, when Shell and Texaco formed Equilon Enterprises and Motiva Enterprises. Equilon and Motiva began operating when inflation-adjusted crude oil prices hit their lowest levels post-1930 yet wholesale prices were higher by 20 to 40 cents a gallon. Franchises typically sign long-term contracts with oil suppliers, making it difficult to switch to another brand or an independent supplier. The suit is similar to one filed in 2004 (Texaco Inc. v. Dagher, 547 U.S. 1; 2006), which was dismissed in 2006 by the Supreme Court who ruled

satisfy federal regulators. In addition, European antitrust authorities required Mobil Corp. to withdraw from a refining and marketing RJV with BP Amoco as a condition for approval of its merger with Exxon Corp.

There have also been high profile cases in the computer industry. In one such case Addamax Corp., a producer of security software, alleged that the RJV formed among Hewlett-Packard, IBM, and Digital Equipment, called the Open Software Foundation, engaged in horizontal price fixing by conspiring to force input prices (the price of security software) below the competitive price.[11]

Recently, in the semiconductor memory market, the US Department of Justice (DOJ) charged four companies (Samsung, Infineon, Hynix, and Elpida) with fixing prices for dynamic random access memory (DRAM). The suit states that company executives discussed the price of DRAM at joint meetings, agreed to fix prices, and exchanged information with competitors. Micron, who was a coconspirator, sought amnesty from prosecution through the DOJ's leniency policy, and hence was not subject to criminal fines in exchange for information on the other conspirators. Samsung, Hynix, Elpida and Infineon plead guilty and agreed to pay more than $732 million in collective fines, the second highest total obtained in an investigation aimed at one industry. These companies had been involved in various RJVs with overlapping membership including SEMATECH, of which Micron was a member.

Another industry with a history of collusive behavior in which RJVs are commonplace is telecommunications, where nearly 40% of firms are involved in at least one RJV with another direct product market rival. Between 1984 and 1996, telecom firms were not permitted to offer both local and long distance services.[12] During this period of regulation, the long

that the unified price for the two companies' brands was not an antitrust violation under the rule of reason.

[11] Open Software Foundation (OSF) was founded to develop a version of the Unix operating system to compete with AT&T and Sun Microsystems. Addamax, was a producer of Unix based security software. OSF considered bids for security software from Addamax, AT&T, and SecureWare and selected SecureWare. Addamax then sued OSF alleging horizontal price fixing and unlawful joint venture conduct. The court ruled in favor of the defendents primarily based on the finding that the lower price of security software was not a substantial cause of Addamax's failure to succeed in selling security software. See Addamax Corp. v. Open Software Foundation, 964 F. Supp. 549 (D.Mass. 1997), aff'd, 152 F.3d 48 (1st Cir. 1998).

[12] In 1984, AT&T relinquished its hold on the local market when the Department of Justice ordered AT&T to divest its local telephony business. These companies became the Regional Bell Operating companies or RBOCs. Local operators were not permitted to offer long distance services until the Telecommunications Act of 1996.

distance market consisted of a regulated dominant firm (AT&T), two main competitors (MCI and Sprint), and hundreds of resellers. AT&T was required to provide services to all long distance customers, to file with the Federal Communications Commission (FCC) to add a new service, and to average its rates across consumer markets. MCI and Sprint were not regulated in their prices or provision of services. Despite being unregulated, MCI and Sprint charged prices a little lower than those of AT&T. Furthermore, almost every new rate decrease proposed by AT&T was challenged under the umbrella of predatory behavior. These observations have led some economists to classify the market for long distance services in the 1990's as collusive with AT&T as the price leader.[13] It is also notable that from 1984 to 1996, AT&T, MCI, and Sprint were involved in numerous joint RJVs.

In spite of the suggestive evidence, to our knowledge, this is the first study in the empirical literature to examine whether collusive behavior may be facilitated by RJVs.[14] Estimating the impact of the returns to collusion on the decision to join a RJV is difficult as there are many legal reasons to join a RJV which also result in increased market power of the members. One option is to consider a subset of firms engaged in RJVs and another subset not engaged in RJVs and test whether collusion is higher among the first group. However, such a test would only be able to tell us something about collusive behavior that was detected, but would not inform us about the prevalence of firms that form RJVs with collusive intentions but are not caught. An additional problem is the endogeneity of the choice to join a RJV.

In this paper we propose a test of whether the data are consistent with firms forming RJVs as a way to facilitate collusion in the final goods market. Rather than directly testing for collusion by firms engaged in RJVs we examine their potentially collusive function through a quasi-experiment. The quasi-experiment tests whether a 1993 revision of the antitrust leniency policy, which was enacted to detect collusive behavior, made firms more or less likely to join RJVs. We argue that the policy revision made applying for amnesty easier and

[13] See Huber, et al (1992) and MacAvoy (1995).

[14] The closest empirical work on this topic is that of Scott (1988, 1993), who examined all RJV filings over an 18 month period and found that collaboration may have resulted in less competitive markets. However, as Reinganum (1983) notes, RJVs influence R&D levels differently for those firms in the venture relative to those not in the venture. For instance, RJVs may exaccerbate initial asymmetries across firms, resulting in increased market power for those firms in the RJV. Hence RJVs may affect market structure and market power absent collusive product market behavior.

more attractive and, hence, reduced the gains from trying to establish a collusive relationship because coconspirators would be more likely to defect and seek amnesty. This change in the value of collusion should change the benefit of joining a RJV only if membership serves some sort of collusive function at the margin. Since the leniency policy applies to all firms after 1993 we are concerned that our results might be driven by some unobserved trends in the data. For this reason we construct a "treatment" group that consists of potential colluders in the sense that these are firms that have joined a RJV with other firms in the same final goods industry. Furthermore, we examine whether the policy revision differentially impacts firms for whom collusion might be more valuable. To do so, we develop a measure of the RJV's collusive value to a firm that is considering whether to join a particular RJV. The firm-specific measure of "RJV market power" allows us to obtain a heterogeneous treatment effect of RJV participation. Determining the entire shape of the curve relating the probability of joining a RJV to the market power of the RJV allows us to make a more precise inference on the collusive potential of RJVs. Our test of a RJV's collusive function is (i) whether the revised leniency policy changed the probability that firms join a RJV and (ii) whether the policy has a differential impact if the RJV market power is larger.[15] Our approach has the advantage that we are able to examine the collusive potential of RJVs without observing costs or prices.

Another obvious problem in measuring collusive intentions, which plagues the majority of studies of collusion, is defining the relevant product market. To this end we consider many definitions of the relevant market, ranging from very broad (e.g., 3-digit NAICS) to very narrow and industry specific (e.g., the market for long distance carriers under the period of telecommunications regulation). We apply our quasi-experiment to three industries with a history of antitrust suits coupled with high RJV participation: petroleum manufacturing, computer and electronic product manufacturing, and telecommunications.

[15] We cannot predict what direction the impact of the leniency policy will be. For example it is possible that the leniency policy makes all collusive arrangements less attractive and hence RJV are less common after the policy and even less common among RJV that would have had a higher collusive value before the policy. Alternatively the legal protection afforded by registering the RJV may make it a more attractive option following the leniency policy. While important for policy makers, the exact sign of the impact of the leniency policy is not important for our test since there is no reason why the leniency policy should impact RJV formation unless some of these ventures serve a collusive purpose.

We find that the decision to join a RJV is impacted by the policy change and that this impact is very significant across relevant market definitions. Specifically, we find that the revised leniency policy reduces the average probability that telecom firms join a given RJV by 34%; the reduction among computer and semiconductor manufacturers is 33%; and among firms in petroleum refining the probability decreases by 27%. Our results are consistent with RJVs serving (at least in part) a collusive function.

The rest of the paper proceeds as follows. In section 2 we provide background on the legal policies surrounding RJV formation and collusive behavior. We present the model and estimation technique in section 3. In section 4 we discuss the data. We present the results in section 5. In section 6 we conclude.

# 2 Antitrust Policy Background

## 2.1 Leniency Policy

The Sherman Act of 1890 makes it illegal for firms to agree to fix prices or engage in other agreements that restrict output or harm consumers. In 1978, the US Department of Justice (DOJ) Antitrust Division enacted the leniency policy program designed to detect firms engaged in collusive behavior. The DOJ substantially revised the leniency program, in August 1993, to make it easier and financially more attractive for firms to cooperate with the Division. According to a DOJ policy statement, "Leniency means not charging such a firm criminally for the activity being reported." There were three major revisions: (i) amnesty was made automatic if there was no pre-existing investigation (ii) amnesty could be granted even if cooperation began after the investigation was underway (iii) all directors, officers, and employees of the filing firm are protected from criminal prosecution. There is one important caveat: only the first company to file receives amnesty.

In addition to making it more attractive for cartel members to report illegal behavior, in 1995, the DOJ substantially increased the penalties for antitrust violations. Prior to 1995, the largest criminal fine was $6 million. In contrast, the *average* criminal fine was in excess of $6 million after 1996. Total fines imposed in 1997 and 1998 were "virtually identical to the total fines imposed in all of the Division's prosecutions during the 20 years from 1976 through 1995." In 1999, total fines imposed exceeded $1.1 billion.[16] Since the Division revised its leniency program, cooperation from leniency applications has resulted in numerous convictions and nearly $4 billion in criminal fines.

There is much evidence that firms reacted to the policy change. Most concretely, the revision resulted in a surge in amnesty applications. Under the old policy, the Division obtained about one amnesty application per year, whereas the new policy generates more than one application per month. Scott Hammond of the DOJ stated that leniency programs have been responsible for "detecting and cracking more cartels than all search warrants, secret audio or videotapes and FBI interrogations combined."[17] A Deputy Assistant Attorney General of the Division remarked "The early identification of antitrust offences through compliance programs, together with the opportunity to pay zero dollars in fines under the Antitrust Division's Corporate Amnesty Program, has resulted in a 'race to the courthouse,'..." Indeed, it is not uncommon for a company to request amnesty a few days after one of its coconspirators has already secured amnesty by filing first.[18] Miller (2009), who provides estimates from a structural model of cartel behavior, shows that the leniency policy reduced cartel formation by 59%, while it increased the detection rate by 62%.

Some well-known examples of collusive behavior thwarted via the leniency policy include markets for DRAM chips, marine hosing (used to funnel oil from tankers to storage facilities), air cargo transportation, graphite electrodes production, vitamin sales, fine arts auctions, and USAID construction. Each of theses cases involved multimillion dollar fines and in some cases criminal sentences, whereas the amnesty applicant incurred no fines and received prosecution protection. For instance, in the graphite electrodes investigation, the second company to file paid $32.5 million (10% of annual earnings), the third $110 million (15% of annual earnings), and the fourth $135 million (28% of annual earnings). Mitsubishi was later convicted at trial and was sentenced to pay $134 million (76% of annual earnings). Executives from these companies incurred fines and prison sentences. In the vitamin investigation, F.

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[16] See Brown and Burns (2000), Kobayashi (2001), and Spratling (1999) for more details.

[17] http://www.justice.gov/atr/cases/f202300/202397.htm

[18] Antitrust Division, US DOJ, Annual Report FY 2001.

Hoffmann-La Roche and BASF AG plead guilty and incurred fines of $500 million and $225 million, respectively. Again, executives from these companies served time in prison. In the fine arts auctions case Sothebys paid $45 million, and the chairman was sentenced to one year in jail and a $7.5 million fine. Finally, in the USAID Construction case, firms were ordered to pay fines of $140 million and to pay $10 million in restitution to the U.S. government. An executive for one of the companies received a three year prison sentence.[19]

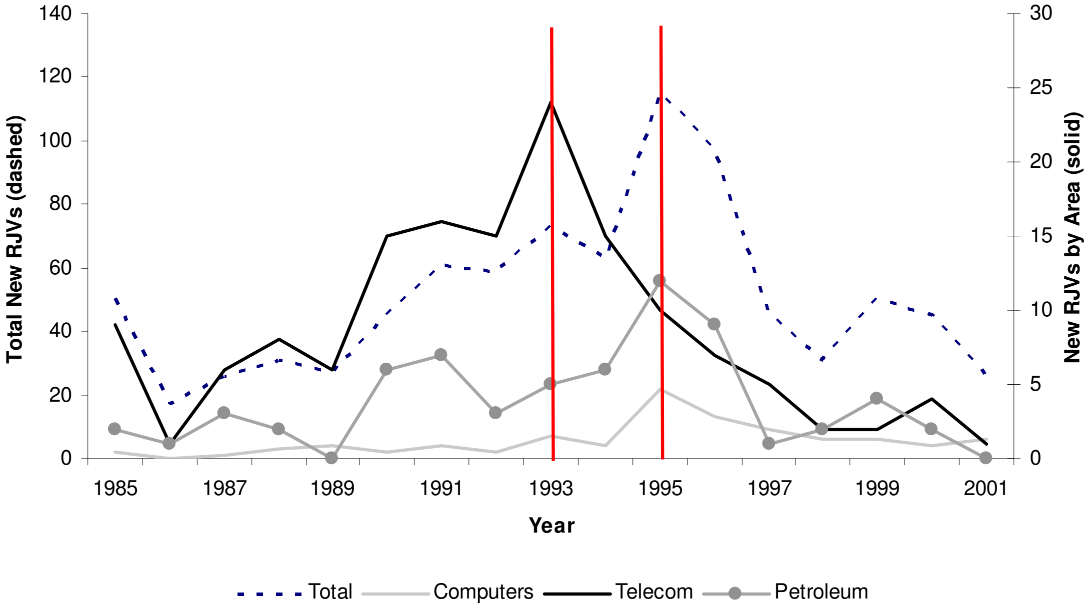


Figure 1: Number of New RJV Filings

Figure 1 shows the number of new RJV filings across research areas (RAs). The dashed line indicates all RAs, the dark solid line indicates telecommunications RAs, the light solid line indicates computer RAs, and the line with circles indicates petroleum RAs. The vertical lines are in 1993 (when the leniency policy was revised) and 1995 (when the fines increased sharply). The figure shows a dramatic drop in RJV filings across all RAs that is consistent with the fine increase, while the telecommunications RA's decline is consistent with the policy revision. Recall that the long-distance segment of the telecommunications industry was

[19] Due to a 2002 revision in the British Office of Fair Trading amnesty leniency policy there have been a number of high profile cartel breaking cases in the UK. These have involved bid rigging in construction business, supermarkets and dairies fixing milk prices, airlines setting fuel surcharges, and tobacco companies and supermarkets fixing the price of cigarettes.

under close scrutiny until 1996 (during the period of regulation) and, hence, telecom firms may have been more responsive to policy aimed at deterring collusive behavior. Whereas firms from non-regulated industries may have reacted more to an increase in guaranteed fines associated with collusive behavior and the further incentive this provided to defect from any future collusive arrangements. Obviously, there may be other (non-leniency policy related) reasons for firms to reduce their RJV applications. However, this figure suggests that the decline in RJV applications may be due, at least in part, to the changes in policies regarding detection and punishment of collusive behavior via the leniency policy.[20]

## 2.2 National Cooperative Research and Production Act

The National Cooperative Research Act (NCRA), established in 1984, requires all firms interested in forming a RJV to file with the Federal Trade Commission (FTC).[21] The NCRA was extended in 1993 to include all firms involved in production joint ventures (and was renamed the National Cooperative Research and Production Act, NCRPA). By filing, if member firms are subjected to criminal or civil action, antitrust authorities are required to apply the (more lenient) rule of reason that determines whether the joint venture improves social welfare rather than the per-se illegality rule.[22] If found to fail a rule-of-reason analysis, member firms are granted antitrust protection, which limits their possible antitrust

[20] While the empirical evidence to date suggests that the leniency policy is effective in curbing collusive behavior, it is theoretically possible that the policy could have the opposite effect. Cartels are illegal, and therefore, no written contract between member firms exists. As a result, colluding firms must rely on trust to enforce the collusive behavior. If firms deviate other members have a powerful punishing tool in the leniency policy: deviation is punished by another member reporting the cartel (and gaining antitrust protection). Hence, the leniency policy may foster cartel behavior in that it provides a tool that can be used to discourage deviations from collusive agreements. See Spagnolo (2000).

[21] According to the NCRA, a RJV is "any group of activities, including attempting to make, making or performing a contract, by two or more persons for the purposes of (a) theoretical analysis, experimentation, or systematic study of phenomena or observable facts, (b) the development or testing of basic engineering techniques, (c) the extension of investigative finding or theory of a scientific or technical nature into practical application for experimental and demonstration purposes..., (d) the collection, exchange, and analysis of research information, or (e) any combination of the [above]."

[22] If a behavior is per se illegal then authorities need only prove the behavior exists, there is no allowable defense for the accused parties. Under the rule of reason authorities are required to examine the inherent effect and the intent of the practice.

exposure to actual (rather than treble) damages, plus costs and attorneys' fees with respect to activities identified in the filing.[23]

In deciding whether to approve a proposed RJV, the primary consideration of the FTC is whether the venture is likely to give member firms the ability to retard the pace or scope of R&D efforts. In practice, antitrust authorities are unlikely to challenge a RJV when there are at least three independent firms with comparable research capabilities to those of the proposed RJV.[24] Furthermore, authorities have indicated they will not challenge RJVs in certain research areas. For example, authorities will permit modifications to RJVs involving pharmaceutical firms engaged in cardiovascular research; those formed by the four US manufacturers of centrifugal pumps (used by electrical utilities) that focus on improving pump performance; or RJVs formed to conduct R&D relating to computer aided design and manufacturing.[25]

Finally, we should note that the broadening of the NCRPA coincides with the revision of the leniency policy. Note, however, that we would expect to see more RJVs formed due to the NCRPA broadened protection. If the effect of the leniency policy is to reduce RJV applications, the presence of the NCRA revision would make any negative significant results we find even stronger.

# 3 Theory

A RJV has the potential to facilitate collusion when member firms are rivals in the final product market. RJVs commonly involve a subset of all potential rivals. Hence a cartel formed among RJV members is likely to be partial in the sense that the cartel will involve a subset of all the firms in the industry. Partial cartels have been observed in many industries. For example, a cartel in carbonless paper production had combined market shares of about 85% (Levenstein and Suslow, 2006); a cartel among shipping firms in the North

[23] Prevailing defendents are entitled to recover costs and attorneys' fees if an action is found to be "frivolous, unreasonable, without foundation, or in bad faith." See 15 USC section 4304(a)(2)(2000).

[24] See Competitor Collaboration Guidelines, section 4.3. www.ftc.gov/os/2000/04/ftcdojguidelines.pdf.

[25] See US DOJ Business Review Letter to American Heart Association March 20, 1998; the Pump Research and Dev. Comm., 1985; and to the Computer Aided Mfg. Int'l Inc. 1985, respectively.

Atlantic constituted 75% of the market (Escrihuela-Villar, 2003); and, famously, petroleum manufacturing firms in the US and Russia are excluded from the OPEC cartel.

There is a growing theoretical literature that examines partial cartels. Included in this literature is work by Bos (2009) and Bos and Harrington (2010) (hereafter BH), who consider partial cartels among firms in dynamic differentiated products industries. BH endogenize cartel composition and show that, when firms are sufficiently patient, there exists a stable partial cartel that involves the largest firms in the industry.[26] BH prove that there is a positive correlation between firm size and the incentive to join a partial cartel, where the most profitable partial cartel comprises the largest firms in the industry.[27] They establish that firms have an incentive to form this cartel when its smallest member is sufficiently large. Bos (2009) shows that partial cartels are often dominant in terms of having a significant combined market share, while firms not included in the cartel are typically the small players in the market.

The link between Bos (2009) and BH's results to our work is straightforward: if the RJV is formed to facilitate (partial) collusion then (BH's results imply) the RJV will be the most valuable the larger is its size. RJV size (measured as the combined market share of its members) has a monotonic effect on the value of forming a RJV to collude. Our measure of the RJV market power is motivated by this theoretical result.

Specifically, suppose firm $i$ belongs to industry $k$, and let $\Gamma_j$ be the subset of firms in industry $k$ that are engaged in RJV $j$. The collusive value of a partial cartel $\Gamma_j$ (formed via RJV $j$) is given by $V_i(S_{\Gamma_j}, d)$, which is a function of the total size of the partial cartel ($S_{\Gamma_j} = \sum_{r\in\Gamma_j} s_r^2$, where $s_r$ is the market share of firm $r$ computed as sales of firm $r$ over total

[26] BH, and other papers in the theoretical literature, assume that a cartel member's demand is proportional to the pre-cartel size of the firm. This allocation rule is motivated by actual cases as cited in BH: these include the Norwegian cement cartel, several German cartels during the early 1900s, and other examples noted in Harrington (2006).

[27] BH provide the intuition: The price charged by the cartel is increasing its capacity, which implies that the price increases when a new member brings more capacity. On the other hand a new cartel member will have to produce below capacity once it joins the cartel and hence will experience a drop in sales. Since a cartel member's share of output is equal to its share of capacity, the percentage reduction in post-cartel sales is lower for a firm with more capacity. This gives larger firms more incentive to join.

sales in industry $k$)[28] and the probability the cartel is detected $d$. For a prospective cartel member, the antitrust leniency policy revision makes collusion more costly (by increasing $d$). When cartelizing is costly, BH show the collusive value of a partial cartel is the highest when the cartel is formed by the largest firms in the industry. We define the collusive value (i.e., the market power) of the RJV as

$$H_{ijt} = \frac{S_{\Gamma_j}}{HHI_{kt}} = \frac{\sum_{r \in \Gamma_j} s_r^2}{HHI_{kt}} \tag{1}$$

where $HHI_{kt}$ is the Herfindahl Index for industry $k$.[29] Why this is a measure of the RJV market power is best understood from the perspective of firm $i$ who is considering joining RJV $j$. When making this decision firm $i$ may be interested in how much collusive potential joining RJV $j$ will yield. The number and size of firms in his market is fixed (the denominator) so in assessing the collusive potential of the RJV he will consider his size as well as the size of the other firms in the RJV relative to the overall industry concentration. Notice the larger are the firms in RJV $j$ the higher is $H_{ijt}$, which reflects the higher collusive potential of the RJV. If there were only a few large firms in industry $k$ then the RJV would require fewer members to have substantial market power. A RJV in which most of the large firms in the industry are members has more collusive potential. That is, holding the HHI of the industry fixed, the greater the combined market shares of the participants the greater will be $H_{ijt}$ as consistent with the theory of partial cartels.[30] If the RJV consists of all firms in the industry (i.e., is an all-inclusive cartel) then $H_{ijt} = 1$.

# 4 Econometric Specification

In this section, we provide an econometric framework for a firm's decision to join a RJV, which we use to understand the implications of our quasi-experiment on firm RJV joining

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[28] As the collusive value is increasing in the sum of the market shares of the colluding firms, it is also increasing in the sum of the squared market shares of the colluding firms.

[29] Where the industry changes depending upon the relevant market we consider. We discuss this in more detail in section 5.

[30] Notice that we cannot use the measure of RJV market power to compare across industries. That is, holding fixed the participants and their market shares, the greater the HHI of the industry the lower is $H_{ijt}$.

behavior.[31] The model describes the behavior of a firm conditional on the characteristics of the firm, the characteristics of the RJV, and the characteristics of the industry, where we account for the endogeneity of RJV formation.

## 4.1 Model

We develop a model of a firm's decision to enter into a particular RJV. The unit of observation is a firm, RJV, time combination. Let $V^*_{ijt}$ be the (latent) value to firm $i = 1, ..., N$ of engaging in RJV $j$ at time $t$:

$$V^*_{ijt} = \alpha_1 L_{ij} + \alpha_2 L_{ij} H_{ijt} + \lambda H_{ijt} + \gamma_1 rd_{ijt} + \beta x_{it} + \delta z_{ijt} + \varepsilon_{ijt}. \quad (2)$$

If firms enter into a RJV to facilitate collusion, antitrust policy targeted at product market collusion could impact the decision to engage in a RJV (through an increase in the probability of detection and increased fines). The $L_{ij}$ term is an indicator variable taking on the value of 1 if firm $i$ joins RJV $j$ after the leniency policy revision or the increase in fines (see discussion in next paragraph). Furthermore, the potential payoff to collusion in the product market could depend upon the market power of the RJV (the $H_{ijt}$ term) as discussed in the previous section. This is best thought of as the collusive value to the firm of joining RJV $j$. We are primarily interested in the total effect of the leniency policy on RJV formation (determined by the $\alpha_1$ and $\alpha_2$ terms). The remainder of the terms in (2) capture other potential motivations for RJV formation. The $rd_{ijt}$ term represents the expected change in R&D intensity of firm $i$ after entering RJV $j$, $x_{it}$ are a vector of firm $i$ characteristics, $z_{ijt}$ are a vector of firm-RJV characteristics, and $\epsilon_{ijt}$ is an i.i.d. normally distributed mean zero stochastic term. We now discuss the terms of $V^*_{ijt}$ in more detail.

[31] The decision to enter into an RJV may depend upon the decisions of rival firms (Bloch 1995; Greenlee and Cassiman, 1999; and Yi and Shin, 2000). We do not estimate a structural model of firms' decisions because we would need to specify the game played among competing firms in R&D choices, RJV formation, and product market decisions. This game is best specified in a dynamic setting. Estimation would need to address the simultaneity of R&D decisions, RJV formation, and product market decisions, which would require assumptions on the nature of equilibrium and a means to choose among multiple equilibria. Second, addressing the nature of product competition would require estimates from competitive and collusive models of product market behavior. We could compare actual to predicted markups under both models (Nevo, 2000), but this requires cost data (not easy to obtain and often proprietary). Finally, the telecom industry was regulated. So the model would have to address strategic behavior in a regulated industry. The model presented in this section captures the collusive intent of firms absent the additional structure and data requirements needed to estimate a structural model.

**Leniency Policy Indicator**

There are reasons to believe that some firms may be more affected by an increase in fines than an increase in the probability of being caught in collusive behavior conditional on receiving a lower fine. For example, in some industries being able to punish your rivals (with a higher guaranteed fine) may provide more of an impetus to reveal the cartel activity and, hence, be more effective in curbing collusive behavior than the revisions alone. Indeed, as Figure 1 indicates the decline in RJV applications is most dramatic in 1993 for telecommunications firms (coinciding with the revision in the leniency policy) and in 1995 for the petroleum and computer firms (coinciding with the increase in fines). To determine which leniency policy tool (revision or fine increase) is most relevant to the industry under consideration we used the RJV data to identify structural breaks in formation behavior over time for each industry.[32] The results of these tests indicated that a break occurred in 1993 (1995) for the telecommunications RJVs (computer and petroleum RJVs). Therefore, $L_{ij}$ takes on the value of one post-1993 (post-1995) for the telecommunications (computer and petroleum) market definitions. We also conducted robustness checks *ex-post* where we estimated versions of our model with the leniency policy indicator defined for different years. We discuss these tests in more detail in section 7.

**RJV Market Power**

Our measure of the market power of a RJV, $H_{ijt}$, is motivated by the observation that the larger the joint market shares of the firms engaged in collusive behavior (via the RJV) relative to the other firms in the industry, the higher is the profit to split among members. Hence, the market power of the RJV is a function both of the market shares of the members as well as the overall level of industry concentration. Furthermore, because we wish to measure the potential for product market collusion, the market power of the RJV should be relevant only among product market competitors, even though RJV members may be in different industries.

Our primary measure of the RJV market power is given by equation (1), which is increasing in the fraction of firms in the industry that join the RJV but is non-increasing in the

[32] We computed Zivot-Andrews (1992) unit root test for a time series with one structural break.

fragmentation of the firms that join conditional on the fraction joining. This is reasonable if we believe that the RJV will be less effective in sustaining collusion relative to the status quo when the members are more fragmented. Alternatively, if it is more difficult to coordinate collusion across many firms, more fragmented firms may have more to gain from joining a RJV if the RJV also acts as a tool to coordinate. To allow for this possibility, we consider an alternative measure of the collusive potential of the RJV that is increasing in both the fraction of firms in industry $k$ that join the RJV and in their level of fragmentation (which we refer to as the fragmentation measure denoted $H_{ijt}^{frag}$). The fragmentation measure is defined as: industry concentration post-RJV if the RJV acts as a single entity normalized by the pre-RJV industry concentration.

To motivate the value to considering both measures suppose there are two industry structures: Market Structure A (MSA) has eight equally-sized firms and Market Structure B (MSB) has four equally-sized firms. If four firms under MSA and two firms under MSB join a RJV, the first measure of the RJV collusive potential (referred to as the primary measure) is identical: $H_{ijt} = 1/2$. The fragmentation measure yields different results: the post-RJV HHI in MSA is 5/16 if the RJV acts as a perfectly collusive entity and 1/8 under the status quo, yielding $H_{ijt}^{frag} = 5/2$. The post-RJV HHI in MSB is 3/8 if the RJV acts as a perfectly collusive entity and 1/4 under the status quo, yielding $H_{ijt}^{frag} = 3/2$. The fragmentation measure indicates the RJV has higher collusive potential under the more fragmented MSA. To take a more extreme example if all the firms in an industry join the same RJV should the RJVs collusive potential be the same or different if there are four or two equally-sized firms in the industry? As this is an empirical question, we consider both the primary and fragmentation measure of the market power of the RJV in estimation.[33]

**R&D Intensity** Many papers in the RJV literature show that the expected impact on R&D may be an important motivation for joining a RJV (see for example, Kamien, Muller, and Zang, 1992). For instance, firms may engage in RJVs to take advantage of complementarities among member firms, share R&D related costs, or overcome free-rider problems. Following the RJV literature, we define $rd_{ijt}$ as the change in R&D intensity of

[33] We are grateful to an anonymous referee for the idea and motivation for the fragmentation measure of RJV market power.

firm $i$ that would result from joining RJV $j$ at time $t$. It is given by

$$rd_{ijt} = \frac{R\&D_{it-1}}{sales_{it-1}} - \frac{R\&D_{ijt}}{sales_{ijt}}, \tag{3}$$

where $R\&D_i$ represents R&D expenditures and $sales_i$ represents gross dollar sales.

**Firm Characteristics** Firm-specific terms are captured by $x_{it}$ and include firm size ($assets_{it}$), the number of other RJV's in which $i$ is currently engaged and the square, capacity constraints ($cash_{it}$), and industry fixed effects (when we consider definitions of markets with firms from many industries, such as research areas).[34] Firms may have different absorptive capacities, which in turn determine their willingness to form RJVs (Cohen and Levinthal, 1989). The absorptive capacity is impacted by factors such as size and past experience with research collaboration (Kogut, 1991). We use total assets as an exogenous measure of size and as a control for the capital and equipment that a particular firm brings to a RJV. This is consistent with the notion by Irwin and Klenow (1996) that larger firms gain more from RJVs and from R&D knowledge spillovers.[35] Much of R&D is funded from retained earnings, and we use free cash flow as a proxy for capital constraints. Firms with a high free cash follow should be more attractive partners in a RJV since they are able to sustain investment without loans or new equity issues (see Compte et al, 2002).

**RJV Characteristics** RJV-specific terms are included in the $z_{ijt}$. These are the number of members of RJV $j$, whether the intent is to patent the RJV outcome, measures of firm-RJV asymmetries, and the RJV market power measure. Baumol (2001) showed that the potential benefits of RJVs may increase with the number of participating firms since technological spillovers increase. The intent to patent is a measure of efficiency with which firms innovate and may proxy for absorptive capacity (see Gugler and Siebert, 2007). The theoretical literature suggests that the degree of asymmetries across firms may influence RJV participation (Petit and Towlinski, 1999). Previous empirical work (for instance, Roller et al, 2007) finds that size asymmetries and the degree of product complementarity between firms influences participation decisions. We include variables designed to capture

[34] For a summary of the literature see Caloghirou and Vonortas (2000) and Hagedoorn, et al (2000).

[35] Hernan, et. al. (2003) consider the decision to join a RJV in the European Union. They find that sectoral R&D intensity, industry concentration, firm size, and past RJV participation positively influence the probability of forming a RJV.

the attractiveness of a firm to other partners in the RJV, which consist of a measure of firm size relative to the average RJV member ($rasset_{ijt}$) and a measure of capital constraints relative to the average RJV member ($rcapcon_{ijt}$). We define the measure of firm size relative to the RJV as

$$rasset_{ijt} = \frac{assets_{it-1} - avgassets_{jt-1}}{avgassets_{jt-1}}, \tag{4}$$

where $avgassets_{jt-1}$ are average assets of all members of the RJV in the period previous to RJV $j$ formation. Relative capital constraints, $rcapcon_{ijt}$, are similarly defined, where we use $cash_{it}$ as a proxy for capital constraints.

**State of Economy** Ghosal and Gallo (2001) suggest that antitrust enforcement by the DOJ is countercyclical. R&D investments may also be counter-cyclical; when the economy is weak firms may lack sufficient internal resources to finance long-term R&D projects so they may be more likely to rely on cooperative research arrangements. We include year fixed effects to capture any economic or time-specific variables relevant to RJV formation that are not captured in other variables.

## 4.2 Estimation

Firms that join RJVs join on average more than one.[36] Hence, firm $i$ will form RJV $j$ at time $t$ if the value to doing so is larger than the value to not doing so. Let $V^*_{i0t}$ represent the value to firm $i$ of not joining a RJV :

$$V^*_{i0t} = \gamma_0 rd_{it} + \beta_0 x_{i0t} + \varepsilon_{i0t}, \tag{5}$$

where $rd_{it}$ is the average annual intensity of R&D undertaken by firm $i$ when it is not in a RJV. Hence, firm $i$ will join RJV $j$ if $V^*_{ijt} \geqslant V^*_{i0t}$ where $V^*_{ijt}$ is given in equation (2). Notice that the number of feasible alternatives does not impact the decision to join a particular RJV, although our model allows the number of RJVs a firm is currently engaged in to impact the value to joining a RJV.

[36] Our data indicate that the average number of RJVs firms join is 1.721 (with a standard deviation of 4.748) and the mean number of RJVs joined among joiners is 3.292 (with a standard deviation of 6.162).

We don't observe $V^*_{ijt}$ or $V^*_{i0t}$, instead we observe whether firm $i$ enters a RJV. Define

$$V_{ijt} \equiv \alpha_1 L_j + \alpha_2 L_j H_{ijt} + \gamma(rd_{ijt} - rd_{it}) + \beta(x_{it} - x_{i0t}) + \delta z_{ijt}. \tag{6}$$

Any model of RJV formation must address two issues regarding estimation, both relate to the observation that the value to firm $i$ of joining RJV $j$ is a function of $(rd_{ijt} - rd_{it})$. That is, firms consider the expected effect on R&D expenditures when considering whether to form a RJV. However, R&D intensity is influenced by RJV formation. Thus, the first issue to address concerns the endogeneity of R&D. The second issue concerns the effect on R&D from joining a RJV. We can construct $(rd_{ijt} - rd_{it})$ from the data when firm $j$ joins a RJV. However, we do not observe $rd_{ijt}$ if the firm is not engaged in a RJV. We need a consistent estimate of the expected effect of RJV formation on R&D intensity when a RJV is not formed. The endogenous switching model estimation procedure (see Lee, 1978) allows us to address the endogeneity and missing values issues and to obtain consistent parameter estimates. However, there is one more endogeneity concern related to the fact that $H_{ijt}$ is a function of the market shares of member firms and industry concentration and hence may be endogenous. For instance, if establishing a RJV raises barriers to entry it could increase the market power of the involved firms even if they do not collude. We have included the measure of the market power separately (in the $z_{ijt}$) as well as interacted with the leniency policy variable, but it is important to keep this caveat in mind when interpreting the results.

Estimation is based on the following equation of RJV formation

$$P_{ijt} = V_{ijt} + \eta_{ijt}, \tag{7}$$

where $\eta_{ijt} \equiv \varepsilon_{i0t} - \varepsilon_{ijt} \sim N(0, \sigma^2_\eta)$.[37] We observe $rd_{ijt}$ when firm $i$ is engaged in RJV $j$:

$$rd_{ijt} = \lambda_1 w_{ijt} + u_{1it} \text{ if } V_{ijt} \geqslant \eta_{ijt} \tag{8}$$

where $w_{ijt}$ includes a constant, the number of members of RJV $j$, firm size relative to the average RJV member ($rasset_{ijt}$), and capital constraints relative to the average RJV member ($rcapcon_{ijt}$). Note that the coefficient on the constant term will pick up other effects on R&D

[37] The parameters of $V_{ijt}$ are identified up to the factor $\sigma_n$, hence we normalize $\sigma_n = 1$.

of being in RJV such as cost-sharing. If firm $i$ is not engaged in RJV $j$ we observe:

$$rd_{it} = \lambda_0 v_{it} + u_{0it} \text{ if } V_{ijt} < \eta_{ijt} \tag{9}$$

where $v_{it}$ includes the assets and capital constraints faced by firm $i$. We assume the errors $(u_1, u_0, \eta) \sim N(0, \Omega)$. To obtain asymptotically efficient estimates, we simultaneously estimate all the parameters of the model by full information maximum likelihood. The parameters of the model are $\theta = vec\{\alpha_1, \alpha_2, \gamma, \beta, \delta, \lambda_0, \lambda_1, \Omega\}$.[38]

## 4.3 Identification

Our strategy to identify collusive intentions relies on the variation in RJV formation arising from the revisions in the leniency policy. For this to be a reasonable quasi-experiment, the leniency policy should impact collusive behavior but not affect the other motivations to form a RJV. As discussed in section 2.1, there is sufficient evidence that the revision to the leniency policy has been successful in curbing collusive behavior. Furthermore, there is no evidence that the DOJ changed the leniency policy with an intention to influence RJV formation or R&D investments directly.[39]

The leniency policy revision (fine increase) applies to all firms after 1993 (1995) so our results could be driven by some unobserved trends in the data. For this reason we construct a "treatment" group that consists of potential colluders in the sense that these are firms that have joined a RJV with other firms in the same final goods industry. Our definition of which firms are in the treatment group depends upon the level of aggregation (i.e., which relevant

[38] See Maddala (1983) p. 223-224. The model could be estimated in stages. First, consistent estimates of the predicted probabilities ($\widehat{P}_{ijt}$) come from a reduced form probit regression obtained by substituting equations (8) and (9) into (6). To control for the endogeneity of R&D, equations (8) and (9) are corrected by including control variables (constructed using the inverse Mill's ratio and the predicted probit probabilities $\widehat{P}_{ijt}$). Least squares yields consistent estimates of the corrected R&D equations. The predicted values from the corrected R&D equations are used to construct the predicted difference in R&D intensity, $(\widehat{rd}_{ijt} - \widehat{rd}_{it})$, from joining a RJV for all firm-RJV combinations. The probit selection equation in (7) could be estimated after including the predicted R&D difference as a regressor, which Lee (1978) shows yields consistent estimates of the parameters. However, to obtain asymptotically efficient estimates all parameters of the model should be estimated simultaneously.

[39] The revision appears to have been motivated by the desire to thwart international cartels. See www.usdoj.gov/atr/public/speeches/206611.htm.

market) we are considering. Note that firm $i$ from industry $k$ would be in the treatment group for a particular RJV $j$, if other firms from industry $k$ are in RJV $j$, but not in the treatment group for another RJV $m$, if there are no other firms from industry $k$ in RJV $m$.

We should also note that we do not have to rely on a discrete law change to identify potentially collusive efforts as the effect of the leniency policy revision on RJV formation is allowed to vary with a continuous measure of RJV market power ($H_{ijt}$). While it is possible that some unknown policy (that has not been controlled for) impacted the propensity to join a RJV at the same time the leniency policy was revised, it is less likely that this hypothetical policy would vary with the RJV market power measure as well.

To summarize, the parameters of the model are identified by i) the leniency policy exclusion restriction that should not impact R&D investments directly (equations (8) and (9)) rather only the decision to enter a RJV and ii) through nonlinearities in the model.[40]

# 5 Data

Our data cover the period 1986-2001.[41] Information on RJVs comes from the CORE database constructed by Albert Link (Link, 1996) and includes the name of the RJV, date of filing, general industry classification, and the nature of research to be undertaken. We augment the CORE data with the names of the member firms in each RJV in our time frame, as reported in the Federal Register.[42]

Firm-level data come from the U.S. Compustat database, which includes industry classification, assets, sales, free cash, and R&D expenditures for over 20,000 publicly traded firms. There are a few data issues to address. First, small firms are underrepresented. They are less likely to file a RJV application with the FTC since they are less likely to be the subject of antitrust investigation, and they are less likely to be in the Compustat database.[43] As

[40] These nonlinearities arise from the inclusion of the inverse Mill's ratio in the corrected R&D equations.

[41] Link and Bauer (1989) document that cooperative research efforts were occuring informally before the NCRA was implemented in 1984. It is likely that RJV applications in 1985 may capture a portion of the pre-1985 stock. For this reason we include all RJVs starting in 1986.

[42] See http://www.gpoaccess.gov/fr/index.html.

[43] The Compustat data do not contain information on non-publically traded firms or non-profit firms.

a result of losing small firms, we observe a few RJVs with only one member, which we drop.

If firms add members to the RJV they are required to refile with the FTC, therefore we observe changes in the composition of RJV membership across years. Unfortunately, firms do not refile when the RJV is terminated. As a result, we observe new RJVs and changes to RJV membership, but not end dates. In practice many RJVs do not span the period of our data; a RJV formed in 1986 is not likely to be around for new firms to join in 2001. We had to make some assumptions regarding the set of potential RJVs available for each firm to join (i.e., the choice set). We decided to "end" a RJV in the year that we last observe a member join.[44] Imposing this restriction, there were 386 RJVs in all industries with an average length of three years.[45]

The firm's choice set requires some additional explanation. One option would be to assume that every firm in the sample could join every RJV we ever observe in the data. Given that there are thousands of RJVs in the sample and tens of thousand of firm years this is computationally infeasible. It also assumes that all firms could contribute to any RJV. To narrow the viable options we assume a firm could join any RJV that was formed or that exists in a given year in which the firm exists. To make the explanation complete, consider an example involving AT&T starting in 1986. AT&T's choice set in 1986 includes all RJVs in 1986 in which at least one telecommunication firm has joined – there were three such RJVs of which it joined one. In 1987 two new RJVs that included telecommunications firms formed, so AT&T's choice set in 1987 is four (the two continuing from 1986 which it did not join and the two new RJVs). It joined two of these. No telecommunications firms joined a RJV in 1988, so AT&T choice set in 1988 consisted of two RJVs (the two continuing from 1987 which it did not join) of which it joined one. Hence, the number of RJVs in AT&T's choice set (and the total number of RJVs joined) in each consecutive year is 3(1), 4(3), and 2(4). AT&T's choice set continues to evolve over the sample period with new RJVs being created and entering the choice set while others exit either because the firm joins or our ending rule removes the RJV from all the choice sets.

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[44] Our results are robust to changes in our end date assumption.

[45] For more on RJVs filed under NCRA see Link (1996), who provides an overview; Majewski and Williamson (2002), who examine contract details of NCRA applicants; and Berg, et al (1982).

When considering the collusive intent of firms it is important to be certain that the level of aggregation is not too broad, so as to include more firms than the relevant antitrust market, nor to narrow, so as to exclude potential rivals.[46] This is difficult to address in a sample spanning many industries, therefore, we do not focus on estimates from the entire pooled sample.[47] Instead, we consider three industries in detail: telecommunications, computer manufacturing, and petroleum refining, which we discuss in turn.

## 5.1 Telecommunications Markets

The telecommunications sector is very important to the US economy and is a critical input in production as well as consumption. In addition to a history of potentially collusive behavior, RJVs are common among rivals, where 38% of firms involved in at least one RJV with another direct product market competitor. This history, coupled with an ability to construct a well-defined antitrust market (due to the telecommunications regulatory mandate), makes the telecom industry ideal for our study.

We consider five definitions of the relevant telecom antitrust market. At the most aggregate (3-digit NAICS) industry level we consider two potential markets: firms in "Broadcast Telecom" (NAICS 513) and firms involved in telecommunications research, "Telecom RA," stated as the primary research area in their RJV filing. There are reasons to believe that this level of aggregation may be too broad. For instance, Broadcast Telecom includes wired telecommunications carriers, radio stations, television broadcasters, cable providers, and wireless carriers, which are not always competitors with each other. The Telecom RA also includes firms that are often in very different competitive markets (e.g., firms in publishing as well as chemical manufacturing) . Indeed, the descriptive statistics presented in the top panel of Table 1 indicate the Broadcast Telecom market is less concentrated as given by the 3-digit Herfindahl Index (HHI, which is calculated as the sum of squares of the market shares of all firms in the relevant industry).

[46] See Werden (1988) and Pittman and Werden (1990) for a discussion of the divergence between industry classifications and antitrust markets.

[47] However, we do conduct robustness checks with the entire sample (see section 7).

| Source of Firm Data: | Compustat | | Compustat | | Other | |
|---|---|---|---|---|---|---|
| Level of Aggregation: | 3-Digit NAICS | | 6-Digit NAICS | | see details below | |
| | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| **Telecommunications Markets** | | | | | FCC Long Distance Firms | |
| | Broadcast Telecom | | Wired Telecom | | All Years | |
| HHI | 0.16 | 0.15 | 0.05 | 0.01 | 0.40 | 0.14 |
| Market Share | 0.08 | 0.13 | 0.02 | 0.03 | 0.03 | 0.11 |
| R&D Expenditures | 0.55 | 1.21 | 0.77 | 1.38 | 0.91 | 1.63 |
| Sales | 8.45 | 17.06 | 13.34 | 20.72 | 2.57 | 9.25 |
| Assets | 18.34 | 36.23 | 27.05 | 39.67 | 22.43 | 34.72 |
| Proportion join RJV | 0.02 | 0.14 | 0.03 | 0.14 | 0.07 | 0.25 |
| Number of RJVs | 94 | | 94 | | 72 | |
| | Telecom Research Area | | | | Regulated Years | |
| HHI | 0.25 | 0.22 | | | 0.46 | 0.11 |
| Market Share | 0.14 | 0.23 | | | 0.03 | 0.12 |
| R&D Expenditures | 0.37 | 0.73 | | | 1.20 | 1.85 |
| Sales | 5.03 | 9.30 | | | 2.45 | 9.43 |
| Assets | 5.63 | 10.24 | | | 22.24 | 24.20 |
| Proportion join RJV | 0.02 | 0.14 | | | 0.07 | 0.26 |
| Number of RJVs | 90 | | | | 53 | |
| **Computer Markets** | | | | | Compustat; Gartner; iSuppli | |
| | Computer/Electronic | | Computer Manufact | | Semiconductors | |
| Market Share | 0.003 | 0.01 | 0.05 | 0.11 | 0.06 | 0.14 |
| Sales | 2.92 | 9.98 | 2.34 | 6.92 | 1.16 | 3.18 |
| HHI | 0.04 | 0.01 | 0.22 | 0.12 | 0.21 | 0.16 |
| Assets | 3.19 | 11.46 | 2.45 | 7.80 | 1.30 | 3.87 |
| R&D Expenditures | 0.23 | 0.71 | 0.19 | 0.53 | 0.12 | 0.35 |
| Proportion join RJV | 0.01 | 0.10 | 0.01 | 0.11 | 0.01 | 0.09 |
| Number of RJVs | 246 | | 246 | | 246 | |
| | Software RA | | | | Memory/Microproc | |
| Market Share | 0.009 | 0.03 | | | 0.02 | 0.06 |
| Sales | 5.23 | 16.39 | | | 1.15 | 3.46 |
| HHI | 0.05 | 0.06 | | | 0.17 | 0.11 |
| Assets | 11.44 | 51.48 | | | 1.47 | 4.52 |
| R&D Expenditures | 0.28 | 0.87 | | | 0.14 | 0.40 |
| Proportion join RJV | 0.01 | 0.12 | | | 0.01 | 0.10 |
| Number of RJVs | 58 | | | | 246 | |
| **Petroleum Markets** | | | | | | |
| | Energy RA | | Petroleum Refining | | | |
| Market Share | 0.01 | 0.03 | 0.03 | 0.04 | | |
| Sales | 6.99 | 18.78 | 30.86 | 37.29 | | |
| HHI | 0.05 | 0.04 | 0.07 | 0.01 | | |
| Assets | 8.69 | 31.43 | 34.05 | 32.53 | | |
| R&D Expenditures | 0.30 | 0.80 | 0.33 | 0.33 | | |
| Proportion join RJV | 0.04 | 0.19 | 0.12 | 0.33 | | |
| Number of RJVs | 63 | | 135 | | | |
| | Coal/ Crude Extraction | | | | | |
| Market Share | 0.02 | 0.03 | | | | |
| Sales | 12.60 | 27.19 | | | | |
| HHI | 0.10 | 0.03 | | | | |
| Assets | 13.41 | 24.78 | | | | |
| R&D Expenditures | 0.23 | 0.31 | | | | |
| Proportion join RJV | 0.09 | 0.29 | | | | |
| Number of RJVs | 140 | | | | | |

Notes: An observation is a firm-year pair. Sales, assets and R&D expenditures are in billions of chain weighted $2004 Gartner and iSuppli shares are from published reports. HHI are calculated at either the 3- or 6-digit NAICs depending on the market definition.

Table 1: Descriptive Statistics

As we refine the market definition to "Wired Telecom" (6-digit NAICS) we find a less concentrated market, where firms have even smaller market shares on average and engage in more R&D relative to their 3-digit counterparts, although they spend approximately the same as a percentage of their sales (7%). While significantly narrower, this definition may still be too broad to be the relevant antitrust market. Wired Telecom consists of all firms offering local and long distance telephony, which were not overlapping markets during the period of telecommunications regulation (prior to 1996).

Our final definitions of the relevant market uses data from the FCC's Report of Common Carriers,[48] which permits us to further divide telecom firms into those offering long distance versus local service. Furthermore, the FCC data include all firms in telephony regardless of size. Our final two definitions of the relevant market consist of all firms offering long distance services. Over all years of the data (1986-2001) the market of long distance firms may be too narrow since after 1996 long distance carriers were permitted to offer local services. Therefore, we also consider a subset of the long distance market restricted to the years of regulation. Although the latter is a relatively small sample, this market definition is particularly attractive since, by law, the market includes only these firms and these firms are not permitted to enter other telecom markets. Table 1 indicates that the market for long distance services is much more concentrated relative to our other antitrust telecom market definitions. Furthermore, the long distance market was more concentrated during the period of regulation with an HHI suggesting it operated similar to an industry with two equally sized firms. Finally, on average more firms join a RJV (7%) relative to other telecom antitrust market definitions.

## 5.2 Computer Markets

The computer industry is a highly-evolving, rapidly-changing industry. It is characterized both by upstream firms (such as semiconductor producers) selling inputs to PC firms, as well as PC firms selling to final users. The industry consists of several large companies with worldwide sales and a high degree of capital intensity. RJVs started to play a large role in computer markets starting in the late 1980s with the formation of SEMATECH, and they continue to play a large role with over 10% of all RJV filings registered in computing related markets. Unlike the telecommunications markets, the computer industry is unregulated

[48] See www.fcc.gov/Bureaus/Common_Carrier/ Reports/.

during our sample period and, hence, subject to competitive pressures that have increased the pace of technology (Jorgenson, 2001). Indeed, recently firms in this industry have been convicted of collusive behavior, which was revealed via the leniency policy, making it directly relevant to our study.

We consider five relevant market definitions and present descriptive statistics in the middle panel of Table 1. A broad definition consists of firms engaged in the computer software research area, "Software RA." Most RJVs in memory-related industries are associated with the software RA. However, this market definition is likely to be too broad as there are firms from more than ten 3-digit NAICs industries engaged in software related research. The other 3-digit market definition, "Computer and Electronic Product Manufacturing," encompasses firms with NAICS classifications that begin with 334. These consist of firms that manufacture computers (such as Dell), computer peripherals, and communications equipment as well as firms that manufacture components for such products (such as Intel). As these firms are not always rivals, indeed Dell is a customer of Intel, the Computer and Electronic Product Manufacturing market is also likely to be too broad a market definition.

A narrow definition comprises establishments that engage in manufacturing or assembling of electronic computers (such as mainframes, personal computers, servers, etc.). The "Computer Manufacturing" definition consists of all 6-digit NAICS starting with 33411 and encompasses firms such as Dell, HP, Sun, and Apple. This is a more convincing relevant market, as it does not contain semiconductor manufacturers and hence is more likely to consist of product rivals to the extent that firms selling mainframes compete with PC firms.

The second 6-digit definition includes firms that are engaged in manufacturing semiconductors and other components for electronic applications. The "Semiconductors" definition consists of all 6-digit NAICS starting with 3344 and includes firms such as Intel, AMD, Micron, and Motorola. Semiconductors are used as inputs in computer products, in communications equipment, and in electronics. Semiconductor production, which consists primarily of memory chips and microcomponents, constitutes the largest component of the computer industry. Examining the market at this narrow level is particularly worthwhile given the recent antitrust case against semiconductor/DRAM memory producers who were involved in many joint RJVs. However, one drawback of narrowing the relevant market definition is that the number of observations are fewer and perhaps not sufficient to estimate our model. Furthermore, there are two issues with using the Compustat data at this level. First, Compustat provides total sales data for publicly traded US firms, but does not break sales down at the level of detail we require. For instance, IBM's Microelectronics division was involved in semiconductor sales during the 1990s. However, IBM is one of the world leaders in mainframe computers, thus using the Compustat sales data (which is for all of IBM's divisions) will lead us to over-estimate the importance of IBM in the semiconductor industry. Second, there are many foreign firms in the semiconductor industry, some of which are major players, such as Samsung, Toshiba and Infineon. If firms in the US enter RJVs to facilitate international collusion then the Compustat data will not give us an accurate measure of the RJV market power if it does not take into account sales of international firms. To overcome these problems, we augment the Compustat data with sales data for semiconductor firms published by Gartner Group and iSuppli Corporation.[49] These data are provided for the top worldwide semiconductor firms (constituting 50% to 70% of worldwide sales) and are limited to sales of semiconductors.[50] We use the data on non-US firms to get an accurate measure of the RJV market power as we have information on all worldwide members of the RJV. We use the Gartner/iSuppli sales data from US firms together with Compustat data (on R&D expenditures, etc.) to estimate the model.

While much more narrow than the other relevant markets, the Semiconductor definition consists of firms that manufacture and sell their chips (such as Intel and Samsung) as well as firms that outsource the manufacturing to other companies (such as Qualcomm). The manufacturing of microprocessors (CPUs) and memory chips (such as dynamic random access (DRAM), static random access, and flash memory) accounts for approximately half of the sales of semiconductors. Our final narrow market definition consists of firms that manufacture microprocessors and memory chips. This market encompasses producers of DRAM who were involved in the recent antitrust amnesty case. Furthermore, RJVs play a large

[49] Prior to 2000 the sales data are from Gartner Dataquest Press Releases (www.gartner.com) and post-2000 data are from iSuppli Corporation (www.isuppli.com). Sales data are released in March.

[50] The press releases report the sales for the top 20 firms (approximately 70% of total semiconductor sales) in all years except 1997, 1998, and 1999 when only the top 10 firm sales are reported (approximately 50% of total semiconductor sales).

role in microprocessor and memory production. Indeed, the largest firms in the market for Flash memory products are AMD and Fujitsu, who are the only members of a joint venture in this area (named Spansion Inc.). We again use the firm level sales data provided by Gartner/iSuppli combined with the Compustat data to estimate this market definition.

As Table 1 indicates, firms have high R&D intensities (ranging from 8 to 12%, on average). Indeed, semiconductor companies rank highest in R&D intensity: approximately 13% worldwide, which is higher than R&D intensity in pharmaceutical markets. In our data firms in the semiconductor industry spend 10% of their sales on R&D, with firms in memory and microprocessing spending 12%. Furthermore, as the market definition narrows the number of RJVs stays the same or increases and market concentration grows substantially with industry concentrations at the 6-digit level consistent with moderate concentration levels.

## 5.3 Petroleum Markets

Our final set of markets involves firms in petroleum related production, where the prevalence of numerous overlapping RJVs involving product market rivals is most pronounced. The importance of oil production worldwide, the existence of an international cartel, and the high degree of multi-market contact make this industry worthwhile to consider.

The petroleum industry is organized into four broad sectors: exploration and production of crude oil and natural gas; transport; refining; and marketing and distribution. Due to data limitations common to studies in this industry, we are only able to examine three market definitions.[51] Our first broad 3-digit definition contains firms engaged in "Coal and Crude Oil Extraction" who focus on the transformation of crude petroleum and coal into usable products. The dominant process in the transformation is petroleum refining that involves the separation of crude petroleum into components. In addition, this subsector includes establishments that further process refined petroleum and coal products to produce related products such as asphalt coatings and petroleum lubricating oils. Our more narrow definition focuses on firms engaged in petroleum refining (defined at the 6-digit NAICS).

[51] Unfortunately due to the presence of the OPEC cartel it is difficult to find accurate data on sales of worldwide petroleum producers. The capacity data that are available are not representative of sales due to the fact that firms often do not operate up to capacity.

Finally, we also consider a definition based on the primary research area, the "Energy RA." Most RJVs classified as being in the energy RA are associated with crude petroleum and natural gas production, and a large portion are associated with petroleum refining.

A few notable aspects of the industry are apparent from the descriptive statistics in the bottom panel of Table 1. First, there are a large number of RJVs active in each relevant market coupled with high probabilities of joining a RJV. Furthermore, across all market definitions, R&D intensity is lower than overall R&D spending as a percentage of sales in other industries (5%). Finally, there are relatively few firms compared to the number of RJVs suggesting that, like telecommunications, there is high multi-market contact via RJVs among rival firms. Also similar to the telecommunications industry, the petroleum industry is highly concentrated, however this is not reflected in our descriptive statistics due to the presence of a large number of foreign firms.

There are a few drawbacks to using the petroleum industry to examine the impact of the leniency program. First, the industry has several large international players, often with substantial government support, that are not publicly traded in the US and so are not in our data. For example, in 1998 the largest oil producer was the Saudi Arabian Oil Co., and the top five were all state owned firms.[52] As a result our sample (regardless of how the market is defined) will omit important players in the industry, most notably members of OPEC. This important drawback of the data is balanced to some extent, by the fact that the leniency policy was specifically aimed at thwarting cartels that include international firms. So, while we aren't able to construct a sample of all the relevant competitors, the behavior of the US-based firms, that we do observe, will still be influenced by the leniency policy even when (or perhaps especially when) they are engaged in international cartels.

# 6 Results

In this section we present the results for each industry for different definitions of the relevant antitrust market. As discussed in section 4, we include the following controls in all regressions: a constant, firm assets, firm capacity constraints, number of RJVs that the firm

[52] Source: Energy Information Admin http://www.eia.doe.gov/.

is a member of and its square, number of RJV members, relative assets, relative capital constraints, whether intent is to patent R&D outcome, industry fixed effects (for research area markets), and year fixed effects. As a result of including year-effects the parameter estimate for the level effect the leniency policy dummy (defined as equal to one in all post-leniency years) will be the effect of a dummy variable for the year of the leniency policy effect. However, the interactions of the RJV market power measures with the leniency policy indicator will take on a non-zero value for all post-leniency years.

Our parameter estimates for the control variables are intuitive and consistent with the majority of the RJV formation literature findings. For instance, we find that firms with more assets are significantly more likely to engage in RJVs. The more RJVs a firm is engaged in the more likely they are to join another RJV but there are decreasing returns to joining. Firms in industries where patents are not as important are significantly more likely to form RJVs. Finally, more relatively capital constrained firms are more likely to join a RJV. Given that the focus of this paper is on the collusive intent underlying RJV formation, we do not report the parameter estimates for the controls across the specifications and samples.[53]

If the primary motivation for a firm to join a RJV is to foster collusion in the product market, the impact of RJV formation on R&D is a second-order consideration, at best. For this reason, we estimate two different model specifications for all market definitions and samples. The first, the "Without R&D Effects" specification, consists of a model of RJV formation without predicted change in R&D intensity as a regressor. Note that this specification is equivalent to the first stage in a two stage endogenous switching regression estimation procedure. Estimates of the control variables from the Without-R&D-Effects specification will not be consistent if firms consider the predicted change in R&D when making RJV formation decisions. Our second specification, "With R&D Effects", addresses this by correcting for the endogeneity of R&D and RJV decisions as outlined in section 4. This is worthwhile to consider because our experiment may affect R&D through the "back door." For example, because the collusive benefits of the RJV are reduced, the R&D benefits that would have occurred (in the absence of the leniency policy) are not realized

[53] Parameter estimates for control variables and a subset of specifications are at iew.uzh.ch/institute/people/mgoeree/Research.html. All other estimates are available upon request.

in the revised leniency policy environment. Controlling for R&D endogeneity allows us examine the impact of the policy holding R&D intensity constant. Thus, we have estimates of collusive behavior that are not contaminated by the potential "back door" effects of the leniency policy on R&D. We present the results from both R&D-Effects specifications for all industry samples.[54] We report robust standard errors from White's correction clustered by firm (in parenthesis). We now discuss the estimates from each market in turn.

## 6.1 Telecommunications Markets

Table 2 presents the results from both R&D-Effects specifications under various levels of aggregation in telecommunications markets. The top panel presents the estimates from the first-stage probit "Without R&D Effects" specification; the lower panel presents the results from the endogenous switching regression "With R&D Effects" specification. We estimated three models for each market definition and R&D effect specification: (i) a model that includes the primary RJV market power measure (RJV HHI), (ii) a model that includes the fragmentation RJV market power measure (RJV HHI Fragmentation), and (iii) a model that is estimated using only firms in the treatment group.

To reiterate our test is whether the leniency policy and leniency policy interacted with the RJV measures of market power coefficients are statistically significant. For policy purposes, however, the overall effect of the leniency policy is of particular interest since it will tell us the average impact of the leniency policy on RJV formation. We report the predicted total effect of the revised leniency policy on the probability of joining a RJV in the final rows of the upper and lower panels. The total effect is the difference in the predicted probability of joining a RJV under a revised leniency policy versus the probability of joining under no leniency policy, evaluated at the mean of the regressors.

Columns (1)-(3) give the estimates for firms that join a RJV in the Telecom RA.[55]

[54] We do not present the parameter estimates for the R&D equations due to space considerations. For most specifications we find that the more RJVs a firm is a member of and the more capital constrained is a firm the lower is its R&D intensity. In many specifications, correcting for endogenous R&D is necessary (i.e., the parameter estimates for the inverse mills correction terms are significant).

[55] Firms in the Telecom research area span many industries so the regressions for all specifications include dummy varibles for 3-digit NAICS.

The coefficient estimates for the level and/or RJV HHI interactions with the leniency policy dummy, when they are significant, are negative. The negative coefficients indicate that firms are less likely to join a RJV after the revised leniency policy and that the effect is more pronounced as the market power (RJV HHI) of the RJV increases. The first specification yields a predicted total effect of the leniency policy revision of about −0.01, which implies the revision resulted in a 40% reduction in the 1.6% probability of joining a Telecom RA venture in the firm's choice set.[56] As column (3) indicates, the effect is more pronounced among firms that enter RJVs with other rivals (i.e., the treatment group). The results are consistent and of a similar order of magnitude whether or not we control for the endogenous nature of RJV formation (top or bottom panels) indicating the "back door" effect is not very important. However, when we consider the fragmentation measure of RJV market power (column (2)) we do not find a significant effect of the leniency policy in the Telecom RA.

Among firms in Broadcast Telecom (in columns (4)-(6)) the total effect of the leniency policy is significant in the Without R&D Effect specification, where now the greater the fragmentation measure of RJV market power the more pronounced the impact of the policy revision. The total effect of the leniency policy results in a reduction in the observed 2.1% probability of joining of about 52%. Firms in the treatment group (who join at a higher rate of 3.8% in the data) are again more affected by the leniency policy. However, as the bottom panel shows, this effect disappears once we correct for the endogeneity of R&D. When we narrow the definition to consider firms offering local or long distance, Wired Telecom (in columns (7)-(9)), again we find the effect of the leniency policy is to reduce RJV applications, with a significant effect at the 10% level in one specification and at the 5% level in two specifications. The impact on firms that join RJVs with rivals is a reduction of 43%, which remains once we control for the endogeneity of R&D in specification (8). This definition is narrow, but it is not ideal in that it involves firms that are not in the same antitrust market over a period of the data (due to federal regulations).

We now turn to the narrowest of our definitions, and the ones for which we have additional

[56] Given the method used to construct our sample we may be underestimating this probability. If no firm joins a RJV then we remove it from the choice set of all firms. Thus if RJVs are systematically exiting the sample due to the leniency policy we would underestimate the impact of the revision on RJV formation.

data from the FCC. The revision has a highly negative and significant effect on RJV formation across almost all specifications (columns (10)-(16)). The results indicate the revision reduced the probability of entering a RJV by about 20%, which is more pronounced among firms in the treatment group (23% reduction). The market over all years may be too narrow post-1996 as it does not include local providers. During the regulated years (columns (13)-(16)), we find the leniency policy significantly lowers the probability of joining (across all specifications). The 6.9% observed probability of joining is reduced by 17 to 24%. In column (16) we control for if AT&T is a member of the RJV. We anticipate that RJVs formed without AT&T would have the most collusive potential since the firms that needed to coordinate were the non-AT&T firms. We don't have enough data to estimate this specification for the With R&D effects specification, but the Without R&D Effects specification indicates that the leniency policy revision had a significant negative impact on the probability of joining a non-AT&T RJV (a reduction of 17%).

Our results are consistent in sign, significance, and magnitude across all but one relevant market (which is insignificant). The show the leniency policy revision resulted in a drop in the probability of joining a RJV, where the mean drop across definitions drop is 34%. The effect is more pronounced among firms that join only with product market rivals (the treatment group), where the mean reduction is 38%. In many specifications the total effect under the fragmentation measure of RJV market power is not significant. This is not surprising given there are only two large firms (MCI and Sprint) that need to coordinate and many small re-sellers. The theory of partial collusion indicates that smaller firms don't have an incentive to join the cartel,[57] and it is not as difficult to coordinate with two firms. Hence, there is not a need for a coordination device to facilitate collusion.

The total effect, while informative, is calculated at the mean of the regressors including the mean of the RJV market power measures. Figure 2 illustrates the total effect of the leniency policy revision on the probability of joining a RJV for all values of RJV market power ($H_{ijt}$).

[57] Following the results in BH, a small firm brings low capacity to the partial cartel so the impact on the cartel price will be negligible. However, the firm will be required to reduce production to below capacity. The small firm will not find it worthwhile to join the partial cartel as the increase in price does not offset the decrease in sales.

| Level of Aggregation: | 3 Digit NAICS | | | 3 Digit NAICS | | | 6 Digit NAICS | | | Long Distance Carriers | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Relevant Market Definition: | Telecom Research Area | | | Broadcast Telecom | | | Wired Telecom | | | | All Years | | | Regulated Years | | |
| Sample: | All | All | Treatment | All | All | Treatment | All | All | Treatment | All | All | Treatment | All | All | Treatment | No ATT |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) |
| **Without R&D Effects** | | | | | | | | | | | | | | | | |
| Post Leniency Dummy | -0.286*** | -0.22 | -0.281*** | -0.422* | -0.35 | -0.599** | -0.416 | -0.308 | -0.622* | -0.460*** | -0.238 | -0.497*** | -0.767*** | 0.172 | -0.829*** | -0.848*** |
| | (0.080) | (0.158) | (0.088) | (0.235) | (0.246) | (0.283) | (0.285) | (0.276) | (0.367) | (0.119) | (0.254) | (0.136) | (0.155) | (0.333) | (0.167) | (0.164) |
| RJV HHI | 0.483*** | | 0.564*** | 1.040* | | 0.665 | 1.110* | | 0.869 | 0.785*** | | 0.697*** | 0.793*** | | 0.739*** | 0.774*** |
| | (0.129) | | (0.129) | (0.545) | | (0.476) | (0.627) | | (0.542) | (0.125) | | (0.134) | (0.148) | | (0.156) | (0.164) |
| RJV HHI*Post Leniency | 0.0646 | | -0.0496 | -0.305 | | -0.11 | 0.112 | | 0.193 | 0.471*** | | 0.449** | 1.044*** | | 1.426*** | 1.255*** |
| | (0.126) | | (0.125) | (0.354) | | (0.424) | (0.381) | | (0.486) | (0.168) | | (0.188) | (0.297) | | (0.285) | (0.316) |
| RJV HHI Fragmentation | | -0.0907 | | | 0.660*** | | | 0.766*** | | | -1.285*** | | | -1.362*** | | |
| | | (0.166) | | | (0.141) | | | (0.164) | | | (0.183) | | | (0.223) | | |
| RJV HHI Fragmentation* | | -0.0637 | | | -0.274*** | | | -0.252** | | | -0.24 | | | -0.958*** | | |
| Post Leniency | | (0.140) | | | (0.096) | | | (0.099) | | | (0.222) | | | (0.352) | | |
| Leniency Policy Total Effect | -0.010*** | -0.011 | -0.015*** | -0.020* | -0.037*** | -0.041** | -0.022 | -0.044** | -0.054* | -0.010*** | -0.013 | -0.015*** | -0.011*** | -0.013*** | -0.014*** | -0.011*** |
| Wald Test Statistic | 13.35 | 14.62 | 13.71 | 5.718 | 22.9 | 8.924 | 3.104 | 9.292 | 6.008 | 21.77 | 1.184 | 18.44 | 26.41 | 27.79 | 36.68 | 30.99 |
| P-Value | 0.001 | 0.001 | 0.001 | 0.057 | 0.000 | 0.012 | 0.212 | 0.010 | 0.050 | 0.000 | 0.553 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **With R&D Effects** | | | | | | | | | | | | | | | | |
| Post Leniency Dummy | -0.190* | -0.0848 | -0.222* | -0.544 | -0.453 | -0.613 | -0.501 | -0.264 | -0.292 | -0.503*** | -0.172 | -0.539*** | -0.848*** | 0.335 | -0.953*** | See |
| | (0.099) | (2.991) | (0.114) | (5.702) | (10.460) | (1.836) | (39.530) | (0.825) | (1.003) | (0.125) | (0.273) | (0.143) | (0.164) | (0.334) | (0.185) | Note |
| RJV HHI | 0.938*** | | 0.979*** | 1.691 | | 1.603 | 0.78 | | 1.727** | 0.764*** | | 0.664*** | 0.774*** | | 0.677*** | |
| | (0.174) | | (0.171) | (61.870) | | (12.480) | (54.230) | | (0.674) | (0.131) | | (0.141) | (0.164) | | (0.162) | |
| RJV HHI*Post Leniency | -0.286* | | -0.419*** | -0.347 | | -0.275 | 0.138 | | -0.22 | 0.546*** | | 0.547*** | 1.255*** | | 1.750*** | |
| | (0.153) | | (0.158) | (43.710) | | (4.222) | (47.760) | | (1.925) | (0.179) | | (0.202) | (0.316) | | (0.305) | |
| RJV HHI Fragmentation | | -0.0893 | | | 0.565 | | | 0.828*** | | | -1.245*** | | | -1.345*** | | |
| | | (2.490) | | | (47.300) | | | (0.236) | | | (0.191) | | | (0.237) | | |
| RJV HHI Fragmentation* | | 0.0273 | | | -0.28 | | | -0.312* | | | -0.346 | | | -1.190*** | | |
| Post Leniency | | (0.266) | | | (36.180) | | | (0.180) | | | (0.236) | | | (0.349) | | |
| Leniency Policy Total Effect | -0.011* | -0.002 | -0.020*** | -0.032 | -0.060 | -0.052 | -0.040 | -0.052* | -0.034 | -0.011*** | -0.014 | -0.016*** | -0.011*** | -0.014*** | -0.014*** | |
| Wald Test Statistic | 8.867 | 0.573 | 13.47 | 2.245 | 1.163 | 0.281 | 0.0559 | 4.955 | 0.103 | 25.55 | 2.037 | 21.14 | 30.99 | 31.85 | 42.61 | |
| P-Value | 0.012 | 0.751 | 0.001 | 0.326 | 0.559 | 0.869 | 0.972 | 0.084 | 0.950 | 0.000 | 0.361 | 0.000 | 0.000 | 0.000 | 0.000 | |
| Number of Observations | | | | | | | | | | | | | | | | |
| Without R&D Effects | 52377 | 52377 | 36184 | 11704 | 11704 | 6466 | 6460 | 6460 | 3346 | 1627 | 1627 | 1397 | 844 | 844 | 744 | 257 |
| With R&D Effects | 37899 | 37899 | 27006 | 2389 | 2389 | 1346 | 1650 | 1650 | 886 | 334 | 334 | 295 | 257 | 257 | 226 | |

Notes: Robust standard errors clustered by firm are in parentheses. * indicates significant at the 10% level; ** at 5% and *** at 1%. The total effect is computed at the mean of the independent variables. An observation is a firm-year-RJV combination. We include the following controls in all regressions: constant, firm assets, firm capacity constraints, number of RJVs the firm is a member of and its square, number of RJV members, relative assets, relative capital constraints, industry fixed effects (for research area markets), and year fixed effects. There were not enough observations to run specification (16) with R&D effects.

Table 2: Estimates for Join a RJV in Telecom Markets

We present the results for one broadly defined market, the Telecom RA, and one narrowly defined market, Long Distance providers during the period of regulation.[58] The light gray lines show the total effect for the Telecom RA and the dark black lines for Long Distance Carriers during the regulated period (both for the With-R&D-Effects specification). The figure reveals that the higher the market power of the RJV, the more an impact the leniency policy has on the decision to join a RJV. The figure reiterates the previous results namely the probability of joining a RJV is lower after the leniency policy is implemented. Furthermore, it shows that as RJV market power increases, the probability of joining a RJV increases when there is no leniency policy (both solid lines). When there is a revised leniency policy the probability of joining a RJV is lower (both dashed lines). The figures for the other market definitions with significant total effects are very similar to the Telecom RA figure. These results suggest that the higher the market power of the RJV the more collusive potential it has, which results in a differential effect of the leniency policy on the probability of joining a RJV.

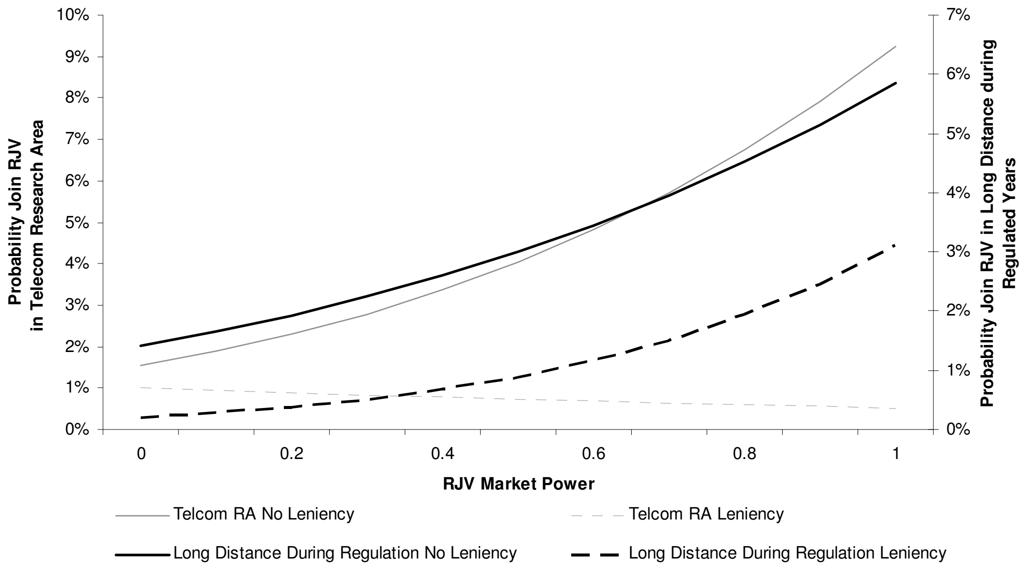


Figure 2: Leniency Policy Effects on Probability Join RJV in Telecom

[58] Recall, if all firms in industry $k$ are in RJV $j$ then the RJV Herfindahl would be the highest possible ($H_{ijt} = 1$) indicating the RJV has very high market power in that industry. If there were only a few large firms in industry $k$ then the RJV would require fewer members to have substantial market power.

## 6.2 Computer Markets

We report the estimates for the leniency policy and RJV market power variables for the computer markets in Table 3. The results show a significant and negative impact of the leniency policy fine increase across all five market definitions and all specifications. Recall we posit that if firms enter RJVs to collude then the impact on R&D is secondary. If our conjecture is correct then, when the leniency policy has a significant effect on the decision to join, the results should be similar across R&D specifications (if the "back door" impact on R&D does not matter). Indeed, the results indicate the total effect is identical or very close across the R&D effects within specifications.

The most broad 3-digit NAICS definition of the relevant market is Computer and Electronic product manufacturing, which consists of firms that manufacture computers, computer peripherals, and components. The estimates are given in columns (1)-(3). They show that the predicted total effect of the leniency policy is between $-0.002$ and $-0.003$, which implies the revision resulted in a 19 to 28% reduction in the 1% observed probability of joining a RJV in the firm's choice set. The effect is of a similar magnitude among firms that enter RJVs with other rivals, where the 1.5% probability of joining is reduced by 23%. As we narrow the market definition to the Software RA (columns (4)-(6)) we again find significant negative effects across all specifications. However the effects are larger in magnitude, where the total effect of the revision serves to reduce the probability of joining by between 16 and 36%. Again, within specifications the results are of similar magnitudes (when both are significant) whether or not we control for endogenous R&D. Both measures of RJV market power show negative and significant impacts on the probability of joining. The previous market definitions included firms that manufacture computers together with those that manufacture inputs for computers. We consider the subsets individually in the next three market definitions.

| Level of Aggregation: | 3 Digit NAICS | | | 3 Digit NAICS | | | 6 Digit NAICS | | | 6 Digit NAICS | | | 6 Digit NAICS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data source: | Compustat | | | Compustat | | | Compustat | | | Compustat, Gartner/iSuppli Sales | | | Compustat, Gartner/iSuppli Sales | | |
| Relevant Market Definition: | Computer/Electronic Manuf | | | Software Research Area | | | Computer Manufacturing | | | Semiconductors | | | Memory/Microprocessor | | |
| Sample: | All | All | Treatment | All | All | Treatment | All | All | Treatment | All | All | Treatment | All | All | Treatment |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) |
| **Without R&D Effects** | | | | | | | | | | | | | | | |
| Post Leniency Dummy | -0.408*** | -0.0586 | -0.414*** | -0.521*** | -0.910*** | -0.443*** | -0.446*** | -0.462** | -0.381** | -0.367** | -0.474** | -0.455** | -0.619*** | -0.787*** | -0.614** |
| | (0.0915) | (0.105) | (0.0939) | (0.118) | (0.173) | (0.124) | (0.137) | -0.212 | (0.149) | (0.165) | (0.210) | (0.215) | (0.204) | (0.260) | (0.251) |
| RJV HHI | 0.653*** | | 0.706*** | 0.435*** | | 0.315*** | 0.332*** | | 0.383*** | 0.173 | | 0.737*** | 0.314* | | 0.927*** |
| | (0.0648) | | (0.0626) | (0.111) | | (0.114) | (0.122) | | (0.124) | (0.147) | | (0.237) | (0.176) | | (0.275) |
| RJV HHI*Post Leniency | 0.461*** | | 0.302*** | 0.340*** | | 0.426*** | 0.114 | | 0.00340 | 0.477*** | | 0.197 | 0.407** | | 0.0575 |
| | (0.0904) | | (0.0914) | (0.107) | | (0.115) | (0.178) | | (0.183) | (0.165) | | (0.257) | (0.187) | | (0.287) |
| RJV HHI Fragmentation | | -0.972*** | | | -0.354*** | | | 0.527*** | | | 0.404*** | | | 0.452*** | |
| | | (0.0983) | | | (0.105) | | | -0.0895 | | | (0.0801) | | | (0.0998) | |
| RJV HHI Fragmentation* | | -0.358*** | | | 0.481*** | | | 0.0245 | | | 0.294*** | | | 0.305*** | |
| Post Leniency | | (0.109) | | | (0.131) | | | -0.12 | | | (0.0928) | | | (0.109) | |
| Leniency Policy Total Effect | -0.002*** | -0.003*** | -0.003*** | -0.004*** | -0.010*** | -0.004*** | -0.004*** | -0.004*** | -0.004** | -0.002** | -0.001*** | -0.014** | -0.006*** | -0.004*** | -0.020*** |
| Wald Test Statistic | 29.61 | 24.03 | 20.23 | 25.07 | 27.94 | 20.35 | 10.68 | 9.677 | 7.146 | 8.888 | 10.05 | 4.879 | 9.256 | 9.629 | 10.79 |
| P-Value | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.008 | 0.028 | 0.012 | 0.007 | 0.087 | 0.010 | 0.008 | 0.005 |
| **With R&D Effects** | | | | | | | | | | | | | | | |
| Post Leniency Dummy | -0.460*** | -0.105 | -0.448*** | -0.585*** | -0.839*** | -0.521*** | -0.465*** | -0.494** | -0.390** | -0.412** | -0.572*** | -0.497** | -0.620*** | -0.774*** | -0.579** |
| | (0.0964) | (0.112) | (0.0977) | (0.140) | (0.189) | (0.147) | -0.146 | (0.221) | (0.157) | (0.178) | (0.217) | (0.233) | (0.210) | (0.266) | (0.264) |
| RJV HHI | 0.667*** | | 0.725*** | 0.438*** | | 0.345** | 0.343*** | | 0.392*** | 0.257 | | 0.858*** | 0.364** | | 1.032*** |
| | (0.0680) | | (0.0665) | (0.134) | | (0.134) | -0.13 | | (0.132) | (0.162) | | (0.260) | (0.173) | | (0.268) |
| RJV HHI*Post Leniency | 0.470*** | | 0.313*** | 0.401*** | | 0.464*** | 0.0993 | | -0.00775 | 0.401** | | 0.104 | 0.337* | | -0.0708 |
| | (0.0962) | | (0.0983) | (0.120) | | (0.129) | -0.191 | | (0.196) | (0.183) | | (0.286) | (0.195) | | (0.298) |
| RJV HHI Fragmentation | | -0.994*** | | | -0.249** | | | 0.527*** | | | 0.405*** | | | 0.473*** | |
| | | (0.105) | | | (0.105) | | | (0.0946) | | | (0.0838) | | | (0.101) | |
| RJV HHI Fragmentation* | | -0.368*** | | | 0.376*** | | | 0.0290 | | | 0.314*** | | | 0.283** | |
| Post Leniency | | (0.116) | | | (0.130) | | | (0.127) | | | (0.0987) | | | (0.112) | |
| Leniency Policy Total Effect | -0.003*** | -0.003*** | -0.003*** | -0.005*** | -0.005*** | -0.006*** | -0.004*** | -0.005** | -0.005** | -0.002** | -0.001** | -0.015** | -0.007** | -0.005** | -0.020*** |
| Wald Test Statistic | 29.83 | 26.52 | 21.39 | 23.52 | 19.82 | 19.88 | 10.260 | 9.267 | 6.824 | 6.238 | 10.28 | 6.358 | 8.921 | 8.588 | 13.06 |
| P-Value | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.006 | 0.010 | 0.033 | 0.044 | 0.006 | 0.042 | 0.012 | 0.014 | 0.001 |
| Number of Observations | | | | | | | | | | | | | | | |
| Without R&D Effects | 415712 | 415712 | 338000 | 254763 | 254763 | 144425 | 93125 | 93125 | 75714 | 91565 | 91565 | 16515 | 52195 | 52195 | 15141 |
| With R&D Effects | 340343 | 340343 | 276726 | 148821 | 148821 | 88757 | 80048 | 80048 | 65033 | 70145 | 70145 | 13787 | 43934 | 43934 | 13027 |

Notes: Robust standard errors clustered by firm are in parentheses. * indicates significant at the 10% level; ** at 5% and *** at 1%. The total effect is computed at the mean of the independent variables. We include the following controls in all regressions: constant, firm assets, firm capacity constraints, number of RJVs the firm is a member of and its square, number of RJV members, relative assets, relative capital constraints, industry fixed effects (for research areas), and year fixed effects. An observation is a firm-year-RJV combination.

Table 3: Estimates for Join RJV in Computer Markets

The first narrow definition, Computer Manufacturing consists of firms that manufacture or assemble mainframes, personal computer, servers, etc. The estimates are given in columns (7)-(9). The revised leniency policy again has a significant and negative effect of a similar magnitude across specifications. The total effect of the leniency policy is to reduce the probability of joining that ranges from 27 to 37%. Among semiconductor firms (such as Intel, AMD, Micron, and Motorola) the total effect of the leniency policy is again negative and significant across specifications, indicating a reduction in the probability of joining ranging from 18 to 33%. A further classification of semiconductors into its relevant 6-digit components: microprocessors and memory yields a much larger significant impact of the revision. Indeed, among this subset the total effect of the leniency policy revision is predicted to have reduced RJV formation by 42 to 67%. In summary, we find evidence of collusive behavior among computer manufacturers, but evidence that the behavior is more pronounced among memory and microprocessor producers, which is supported by evidence on collusive cases reported via the amnesty policy in the market for DRAM memory.

Again, our results for the computer markets are consistent in sign, significance, and of similar magnitude across all relevant markets. Across all specifications and market definitions the leniency policy revision resulted in an average drop in the probability of joining a RJV of 33%. It is also interesting to note that the estimated total effect is the same across specifications for both measures of the RJV market power, even though the coefficient estimates for the RJV HHI measures differ. Unlike telecommunications, the computer industry consists of firms of various sizes, and the significant coefficient estimates for the RJV fragmentation measure suggest that the RJV functions as a mechanism to coordinate more firms with large combined market shares.

Figure 3 illustrates the total effect of the leniency policy revision on the probability of joining a RJV for all values of RJV market power. Again, we present the results for one broadly defined 3-digit market, Computer and Electronic Manufacturing (dark line), and one narrowly defined market, Memory and Microprocessors (light line), both for the With-R&D-Effects specification. The figure reveals the same pattern as with Telecommunications, suggesting that the higher the market power of the RJV, the more an impact the leniency policy has on the decision to join a RJV in computer markets. Again, as RJV market power increases the probability of joining a RJV increases when there is no leniency policy (both solid lines). When there is a revised leniency policy, the probability of joining a RJV is lower (both dashed lines) and is impacted very little by the market power of the RJV. Notably, even though firms in the computer industry are distinct from those in the telecommunications industry, Figures 2 and 3 show a similar pattern.

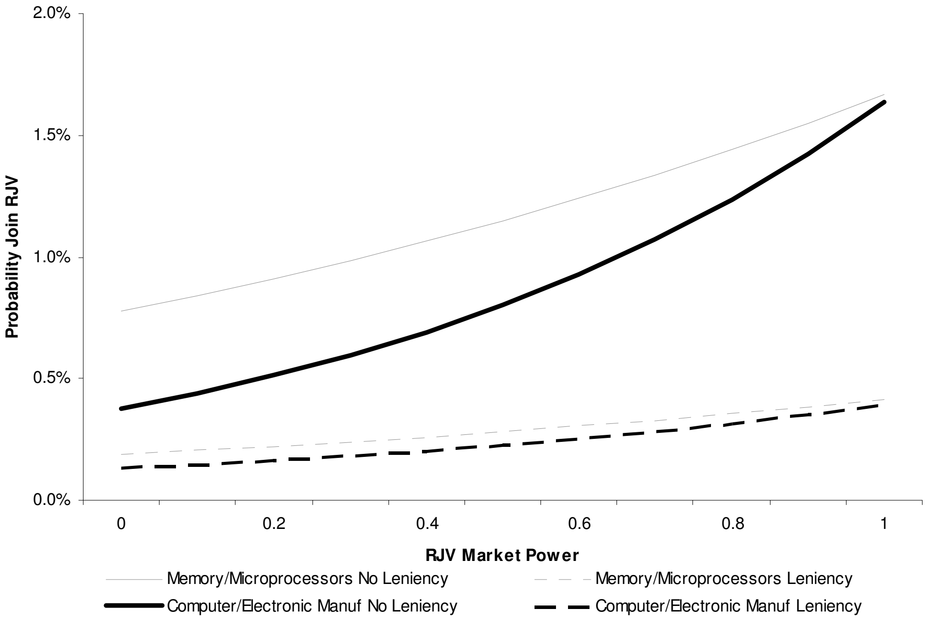


Figure 3: Leniency Policy Effects on Probability Join RJV in Computer Markets

## 6.3 Petroleum Markets

Table 4 presents the estimates for the leniency policy and RJV market power variables for the petroleum markets. The results indicate that the total effect of the increase in leniency policy fines is negative (when significant) for all definitions. Columns (1)-(3) present the results for the Coal and Crude Extraction firms. The total effect of the leniency policy is significant at the 1% level for the Without R&D Effects specifications, where the estimates imply the revision resulted in a 24 to 35% reduction in the 1% observed probability of joining a RJV in the firm's choice set. The impact is of the same magnitude when we control for R&D endogeneity among firms that enter RJVs with other rivals (column (3)) significant at the 10% level. When we consider the other broad market definition, Energy RA, we again find results that are of a similar magnitude, but with differing significance levels across specifications. As columns (4)-(6) show, the total effect of the leniency policy is to reduce the 3.6% observed probability of a firms joining a RJV by about 16%. However, this effect is significant at the 1% level for the With R&D effects specification. The narrowest definition is firms in Petroleum Refining, where the leniency policy has a negative effect, although it is significant at the 1% level only in one specification.

Our results are consistent in sign and are of similar magnitude across all relevant markets. On average the leniency policy revision resulted in a drop in the probability of joining a RJV of 27%. However, the leniency policy effects are not significant at the 1% level in the majority of the specifications. This may be attributable to the data limitations that we mentioned earlier, namely we do not have data on the major market players in the petroleum industries and so our market definition does not capture all relevant competitors. Nonetheless, the results are suggestive, although not as robust at those for the other two markets.

| Level of Aggregation: | 3 Digit NAICS | | | 3 Digit NAICS | | | 6 Digit NAICS | | |
|---|---|---|---|---|---|---|---|---|---|
| Relevant Market Definition: | Coal Manuf and Crude Extraction | | | Energy Research Area | | | Petroleum Refining | | |
| Sample: | All | All | Treatment | All | All | Treatment | All | All | Treatment |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| **Without R&D Effects** | | | | | | | | | |
| Post Leniency Policy Dummy | -1.494*** | 1.496 | -1.054*** | -0.663** | 0.283 | -0.621* | -0.952* | 0.244 | -0.826 |
| | (0.335) | (1.170) | (0.404) | (0.319) | (1.093) | (0.324) | (0.535) | (1.123) | (0.556) |
| RJV HHI | -0.28 | | 1.297 | 1.378* | | 1.872** | 6.102*** | | 6.312*** |
| | (0.649) | | (0.984) | (0.747) | | (0.755) | (2.127) | | (2.190) |
| RJV HHI*Post Leniency | -0.0447 | | -1.628 | -0.0589 | | -0.776 | -3.043 | | -3.632 |
| | (2.958) | | (2.881) | (0.660) | | (0.661) | (3.693) | | (3.601) |
| RJV HHI Fragmentation | | 2.060*** | | | 2.087** | | | 2.275*** | |
| | | (0.562) | | | (0.831) | | | (0.560) | |
| RJV HHI Fragmentation*Post Leniency | | -2.797*** | | | -0.929 | | | -1.960** | |
| | | (1.025) | | | (1.012) | | | (0.946) | |
| Total Effect of Leniency Policy | -0.034*** | -0.029*** | -0.029*** | -0.006* | -0.007 | -0.007** | -0.040* | -0.065*** | -0.043 |
| Wald Test Statistic | 31.614 | 56.840 | 14.443 | 4.930 | 3.470 | 8.049 | 4.654 | 6.010 | 2.550 |
| P-Value | 0.000 | 0.000 | 0.001 | 0.085 | 0.184 | 0.018 | 0.091 | 0.039 | 0.232 |
| **With R&D Effects** | | | | | | | | | |
| Post Leniency Policy Dummy | -1.449 | 0.145 | -1.041* | -0.636*** | 0.285 | -0.514*** | -0.889 | 0.349 | -0.802 |
| | (1.409) | (158.60) | (0.574) | (0.203) | (1.112) | (0.199) | (0.892) | (1.459) | (1.374) |
| RJV HHI | -0.202 | | 1.315 | 1.458* | | 2.074*** | 6.331*** | | 6.434** |
| | (1.293) | | (0.954) | (0.765) | | (0.779) | (2.250) | | (2.542) |
| RJV HHI*Post Leniency Policy | 0.0641 | | -1.585 | -0.0571 | | -0.928 | -3.029 | | -3.544 |
| | (5.607) | | (3.224) | (0.573) | | (0.623) | (4.297) | | (4.794) |
| RJV HHI Fragmentation | | 0.077 | | | 2.150** | | | 2.308*** | |
| | | (72.24) | | | (0.955) | | | (0.619) | |
| RJV HHI Fragmentation*Post Leniency | | -0.174 | | | -0.873 | | | -2.043* | |
| | | (211.90) | | | (0.998) | | | (1.049) | |
| Total Effect of Leniency Policy | -0.032 | 0.042 | -0.029* | -0.006*** | -0.003 | -0.006*** | -0.038* | 0.012 | -0.039 |
| Wald Test Statistic | 1.164 | 0.037 | 5.250 | 15.032 | 2.655 | 20.138 | 5.807 | 3.838 | 4.276 |
| P-Value | 0.424 | 0.982 | 0.072 | 0.001 | 0.265 | 0.000 | 0.055 | 0.147 | 0.118 |
| Number of Observations | | | | | | | | | |
| Without R&D Effects | 5142 | 5142 | 4232 | 20268 | 20268 | 18597 | 3766 | 3766 | 3204 |
| With R&D Effects | 15727 | 15727 | 11893 | 27168 | 27168 | 25423 | 7105 | 7105 | 5987 |

Notes: Robust standard errors clustered by firm are in parentheses. * indicates significant at the 10% level; ** at 5% and *** at 1%. The total effect is computed at the mean of the independent variables. We include the following controls in all regressions: constant, firm assets, firm capacity constraints, number of RJVs the firm is a member of and its square, number of RJV members, relative assets, relative capital constraints, industry fixed effects (for research areas), and year fixed effects. An observation is a firm-year-RJV combination.

Table 4: Estimates for Join a RJV in Petroleum Markets

Figure 4 illustrates the total effect of the leniency policy revision on the probability of joining a RJV for all values of RJV market power. We present the results for one broadly defined 3-digit market, Energy RA (light line), and one narrowly defined market, Petroleum Refining (dark line), both for the With-R&D-Effects specification. As the other figures, we find that the higher the market power of the RJV, the more an impact the leniency policy has on the decision to join a RJV. The RJV market power increases the probability of joining a RJV when there is no leniency policy (both solid lines). When there is a revised leniency policy, the probability of joining a RJV is lower (both dashed lines) and is not impacted by the market power of the RJV.

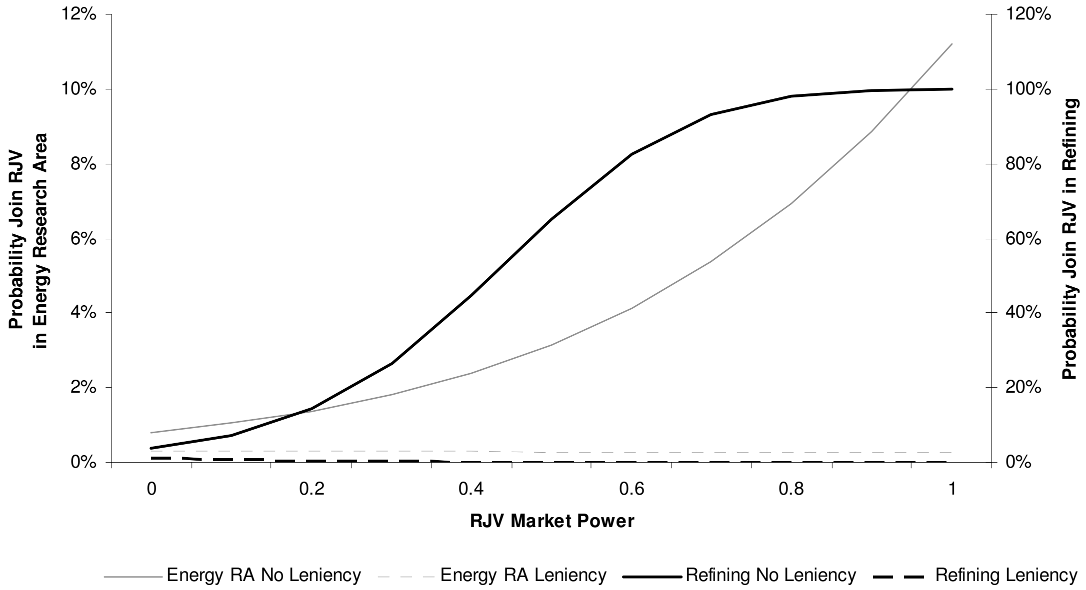


Figure 4: Leniency Policy Effects on Probability Join RJV in Petroleum Markets

## 6.4 Implications

The economic damage caused by cartels is significant. Connor (2003) estimates that modern international cartels resulted in 28% higher prices. The graphite electrode cartel, for instance, caused more than a 60% price increase. Small increases also have the potential to cause substantial harm. For example, the lysine cartel resulted in 17% higher: an overcharge of more than \$75 million in the U.S. and \$200 million worldwide (Connor, 2003). Secondly, cartels may cause dynamic inefficiencies if firms have fewer incentives to innovate to improve their market position.[59] Finally, cartels may generate "X-inefficiencies" in that efficient operation is not as necessary because collusive profits are sufficient to compensate for higher costs.

To the extent that firms in alliances and trade associations (i.e., non-research focused ventures) are registered, and hence protected, under the NCRPA, the welfare implications of collusion are clear. Alliances and trade associations are not engaged in R&D and hence realize no efficiency gains to offset the welfare losses due to collusion.[60] Therefore, welfare is unambiguously lower under collusion. Alliances are prevalent in many industries. For example, in the airline industry a number of antitrust concerns over code-sharing has raised collusive concerns. A study by Oum and Park (1997) found that the 30 largest airlines were involved in over 300 various types of alliances in 1996 alone. In the early 1980s antitrust authorities voiced concern over the cartel-inducing properties of alliances formed in the movie industry. Specifically, major movie companies created a RJV where members would provide movies exclusively to a pay network for a limited time before making them available to other networks.[61]

On the other hand, there are many potential benefits to R&D collaboration as discussed in section 1. Whether overall welfare is reduced as a result of collusion among RJV members depends on the magnitude of the welfare loss due to product market collusion relative to the welfare gain due to R&D collaboration. The welfare implications depend both on the nature of competition in the industry, the characteristics of the RJV, and the extent to which RJVs help to overcome inefficiencies associated with R&D (such as high levels of spillovers). Notice that antitrust authorities are faced with a similar dilemma when considering whether to approve a proposed merger. Mergers can generate efficiencies (e.g., by decreasing costs) but lead to increased market concentration that may overcompensate for the welfare gains.

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[59] However, the conclusion could be to the contrary, as mentioned in Bos (2009), if due to higher profits the colluding firms have more means to innovate. Moreover, a firm may benefit more from its innovation when it is not under competitive pressure.

[60] We thank an anonymous referee for this point.

[61] United States v. Columbia Pictures Indus 507 F. Supp. 412 n. 47 (S.D.N.Y 1980).

In deciding whether to permit a merger, antitrust authorities consider each case individually while applying a "rule of thumb" based on industry concentration.[62] Our results suggest a parallel approach be taken with a subset of RJV applications. First, the conventional wisdom that cartels are most easily established in concentrated industries leads to the suggestion that RJVs formed in concentrated industries should be more closely examined. Second, every partial cartel leads to prices above the competitive level. However the overcharge, and thus the damage caused, increases in the size of the cartel relative to the market. Therefore, the combined market share of the cartel relative to industry concentration (i.e., the RJV market power index) might provide an indication of the welfare implications of collusion. A RJV "rule-of-thumb" could be formulated based on the market power of the RJV. Finally, the results suggest it could be worthwhile to consider the coordination role of RJVs in industries where firms are more fragmented.

# 7 Specification and Robustness Checks

We conducted a number of goodness-of-fit, specification and robustness checks, which we detail below.[63] Overall our results are robust to alternative specifications, controls for potential serial correlation, and the inclusion of unobserved firm and RJV effects.

Table 5 presents tests of the fit of the model. We find that the empirical model has strong explanatory power before the policy change, but that it fits well over the whole time period only when we include the policy dummy and interaction terms. The relevant pre-leniency sample is prior to the leniency policy revision for the Telecom markets and prior to the increase in fines for the Computer and Petroleum markets. The restricted (full) model is the model without (with) the leniency policy indicators and interactions. The first column presents the pseudo R-squared measure of fit of the restricted model over the pre-leniency period. The results of the second column show that the restricted model does not fit as

[62] According to the US Merger guidelines mergers are generally not challenged when the HHI is smaller than 1000, when the HHI is between 1000 and 1800 and the merger will increase the HHI by less than 100 points or when the HHI is larger than 1800 and the merger will increase the HHI by less than 50 points. All other mergers might be challenged.

[63] Due to space constraints we discuss some results for which we do not present parameter estimates. To avoid many repetitions we note here that details for all results are available upon request.

well in the post-leniency period for any market definition. The final two columns report the results of a likelihood ratio test of the null hypothesis that the restricted model fits as well as the full model over the entire sample period. As the P-value shows we can reject the null hypothesis for most markets at the 1% level. We can reject the null at the 5% level for Telecom RA, Wired, and the Long Distance firms under the period of regulation; and at the 10% level for Computer Manufacturing. There are only two markets where the restricted model does not give a worse fit than the full model: the Energy RA (in the petroleum industry) and Long Distance Firms over all years (in the telecom industry).

| | | Restricted Model Psuedo R-Squared | | Likelihood Ratio Test: Null Hypothesis Restricted Model Fits as Good as Full Model | |
|---|---|---|---|---|---|
| | | Pre-Leniency Sample | Post-Leniency Sample | Test Statistic | P-Value |
| Telecom | Research Area | 0.217 | 0.146 | 9.17 | 0.010 |
| | Broadcast | 0.329 | 0.240 | 17.83 | 0.000 |
| | Wired | 0.344 | 0.226 | 8.88 | 0.012 |
| | Long Distance All Years | 0.445 | 0.375 | 1.65 | 0.439 |
| | Long Distance Regulated | 0.445 | 0.398 | 7.46 | 0.024 |
| Computer | Computer/Electronic | 0.305 | 0.232 | 32.22 | 0.000 |
| | Software Research Area | 0.308 | 0.234 | 24.31 | 0.000 |
| | Computer Manufacturing | 0.289 | 0.212 | 5.51 | 0.064 |
| | Semiconductors | 0.283 | 0.197 | 9.60 | 0.008 |
| | Memory/Microproc | 0.303 | 0.228 | 10.78 | 0.005 |
| Petroleum | Coal/Crude Extraction | 0.486 | 0.445 | 29.56 | 0.000 |
| | Energy Research Area | 0.467 | 0.354 | 3.85 | 0.146 |
| | Petroleum Refining | 0.444 | 0.351 | 13.84 | 0.001 |

Results are reported for the "Without R&D Effects" specifications using the primary measure of the RJV measure of market power. All regressions include same controls as in main specification. The likelihood ratio test statistic assumes no heteroskedasticity in standard errors. The Wald statistic for the significance of the leniency policy variables is presented in the estimates tables. The restricted (full) model is the model without (with) the leniency policy indicators. The relevant pre-leniency sample is prior to revision for telecom and prior to increase in fines for computer and petroleum.

Table 5: Goodness of Fit Results

## 7.1 Market Shares and Multi-market Contact

Gugler and Siebert (2007) study the effect of mergers and RJV participation on firms' market shares in the semiconductor industry. They show that efficiency gains realized from a RJV overcompensate for increased market power when combined post-RJV market shares of members are higher than combined pre-RJV shares. We note that if a firm joins a RJV to collude they expect no efficiency gains. Hence, Gugler and Siebert (2007) provide a firm-level specification check.[64] Specifically, we consider whether various measures of RJV contact result in lower post-RJV market shares, which would be consistent with increased market power and suggestive of product market collusion. We estimate four specifications for each market in the telecommunications, computer, and petroleum industries.

The first specification (1) estimates current market share ($s_{it}$) as a function of lagged market share, an indicator variable that is equal to one if firm $i$ participated in a RJV in period $t$, $1(\text{in } RJV)_{it}$, and year fixed effects, $\mu_t$ :

$$s_{it} = \rho_0 + \rho_1 s_{i,t-1} + \tau 1(\text{in } RJV)_{it} + \mu_t + \varepsilon_{it}. \tag{10}$$

Following Gugler and Siebert (2007) we correct for the endogeneity of lagged market share using lagged patent stock (the number of accumulated patents of firm $i$ until period $t-1$) as an instrument and estimate the parameters by two-stage least squares (2SLS).[65] Lagged patent stock captures efficiency differences across firms and so should be correlated with lagged market share. First-stage regressions indicate that patent stock is not a weak instrument: the F-statistic is above 10 for all specifications and market definitions (Stock, Wright, and Yogo, 2002). In specification (2) we include the number of RJVs joined by firm $i$, denoted $\#RJV_{it}$, as an extra regressor. Again, we use lagged patent stock as an IV for lagged market share and estimate by 2SLS. Specification (3) considers the impact of multi-market contact (facilitated by joining a RJV with at least one product market rival) on market shares. It may be the case that the more multi-market contact a firm has the higher the collusive value of the RJV as firms can punish competitors in multiple markets (Cooper and Ross (2009). In this specification we incorporate the number of RJVs joined by firm $i$ with product market rivals, denoted $(\#RJV \text{ with rival})_{it}$. We estimate:

$$s_{it} = \varphi_0 + \varphi_1 s_{i,t-1} + \pi_1 1(\text{in } RJV)_{it} + +\pi_3(\#RJV \text{with rival})_{it} + \mu_t + \varepsilon_{it}, \tag{11}$$

[64] Duso, Roller, and Seldeslachts (2010) extend Gugler and Siebert to examine the impact of joining RJVs on market shares across all 3-digit NAICS industries.

[65] Patent stock data were obtained from the NBER U.S. Patent Citations Data File (Hall, et al, 2001). These contain information on almost 3 million U.S. patents starting in 1963 and programs that compute patent stock, which can be matched to firm-identifiers provided in Compustat.

by 2SLS using lagged patent stock as an IV for lagged market share. There may be unobserved firm-specific attributes that impact firm market shares. In specification (4) we control for unobserved firm-effects by first differencing and using the first difference of lagged market shares and lagged patent stocks as instruments for $\Delta s_{it-1}$ (Arellano and Bond, 1991). These instruments will be correlated with $\Delta s_{it-1}$ but uncorrelated with the first difference of the firm fixed effects.

Table 6 gives the parameters estimates for all industries and market definitions. Across all market definitions, the results of specifications (2), (3) or (4) show that the impact of joining more RJVs (column labeled "Number of RJVs") and/or increasing multi-market contact (column labeled "Multimarket Contact") results in a statistically significant decline in post-RJV market shares. These results suggest that joining more RJVs and in particular joining more RJVs with rivals results in an increase in market power. These findings are consistent with those presented in section 6 that RJVs serve a collusive function. Furthermore, these robustness results are more suggestive of collusive behavior in the Petroleum markets than our RJV-firm-specific results.

| | Market Definition and Specification | | Lagged Market Share Coefficient | Std. Error | In at least one RJV Coefficient | Std. Error | Number of RJVs Coefficient | Std. Error | Multimarket Contact Coefficient | Std. Error |
|---|---|---|---|---|---|---|---|---|---|---|
| Telecom Markets | Research Area | (1) | 0.9778*** | (0.0130) | 0.0022*** | (0.0007) | | | | |
| | | (2) | 0.9904*** | (0.0150) | 0.0039*** | (0.0015) | -0.0013* | (0.0007) | | |
| | | (3) | 0.9900*** | (0.0144) | 0.0042*** | (0.0015) | -0.0012* | (0.0007) | -0.0001*** | (0.0000) |
| | | (4) | 0.8570*** | (0.0637) | 0.0005 | (0.0011) | -0.0005 | (0.0009) | -0.0000 | (0.0000) |
| | Broadcast | (1) | 0.9397*** | (0.0136) | 0.0024** | (0.0012) | | | | |
| | | (2) | 0.9580*** | (0.0133) | 0.0032** | (0.0014) | -0.0008** | (0.0004) | | |
| | | (3) | 0.9043*** | (0.0311) | 0.0029** | (0.0013) | -0.0004 | (0.0004) | -0.0019*** | (0.0006) |
| | | (4) | 0.9510*** | (0.0499) | 0.0018 | (0.0011) | -0.0006 | (0.0005) | -0.0001* | (0.0001) |
| | Wired | (1) | 0.9430*** | (0.0169) | 0.0031* | (0.0017) | | | | |
| | | (2) | 0.9681*** | (0.0153) | 0.0044** | (0.0021) | -0.0012** | (0.0006) | | |
| | | (3) | 0.9075*** | (0.0322) | 0.0044** | (0.0019) | -0.0008* | (0.0004) | -0.0027*** | (0.0008) |
| | | (4) | 0.8845*** | (0.0415) | 0.0026 | (0.0016) | -0.0004 | (0.0005) | -0.0001 | (0.0001) |
| | FCC All Years | (1) | 0.9834*** | (0.0112) | 0.0071 | (0.0066) | | | | |
| | | (2) | 0.9924*** | (0.0059) | 0.0140 | (0.0108) | -0.0037 | (0.0023) | | |
| | | (3) | 0.9838*** | (0.0122) | 0.0133 | (0.0102) | -0.0036* | (0.0020) | -0.0042 | (0.0031) |
| | | (4) | 0.9705*** | (0.0344) | 0.0015 | (0.0013) | -0.0006 | (0.0004) | 0.0001 | (0.0001) |
| | FCC Regulated Years | (1) | 1.0261*** | (0.0114) | 0.0079 | (0.0076) | | | | |
| | | (2) | 1.0684*** | (0.0206) | 0.0273 | (0.0202) | -0.0102 | (0.0073) | | |
| | | (3) | 1.0616*** | (0.0166) | 0.0271 | (0.0198) | -0.0102 | (0.0071) | -0.0046 | (0.0032) |
| | | (4) | 0.9300*** | (0.0230) | 0.0043* | (0.0025) | -0.0013* | (0.0008) | 0.0000 | (0.0001) |
| Computer Markets | Computer/Electronic | (1) | 0.9647*** | (0.0072) | 0.0004** | (0.0002) | | | | |
| | | (2) | 0.9650*** | (0.0070) | 0.0004* | (0.0003) | -0.0000 | (0.0002) | | |
| | | (3) | 0.9633*** | (0.0072) | 0.0004* | (0.0003) | -0.0000 | (0.0002) | -0.0001*** | (0.0000) |
| | | (4) | 1.1298*** | (0.0480) | -0.0001 | (0.0001) | -0.0001 | (0.0002) | -0.0000 | (0.0000) |
| | Software Research Area | (1) | 1.0119*** | (0.0285) | 0.0017 | (0.0011) | | | | |
| | | (2) | 1.0176*** | (0.0278) | 0.0043*** | (0.0017) | -0.0020*** | (0.0007) | | |
| | | (3) | 1.0166*** | (0.0280) | 0.0046*** | (0.0017) | -0.0019*** | (0.0007) | -0.0000*** | (0.0000) |
| | | (4) | 0.8095*** | (0.1172) | 0.0002 | (0.0003) | -0.0002 | (0.0003) | -0.0000*** | (0.0000) |
| | Computer Manufacturing | (1) | 0.9786*** | (0.0116) | 0.0028 | (0.0022) | | | | |
| | | (2) | 0.9781*** | (0.0114) | 0.0012 | (0.0055) | 0.0012 | (0.0036) | | |
| | | (3) | 0.9772*** | (0.0127) | 0.0017 | (0.0055) | 0.0012 | (0.0036) | -0.0008*** | (0.0002) |
| | | (4) | 1.0962*** | (0.1455) | -0.0059 | (0.0046) | 0.0028 | (0.0033) | -0.0001 | (0.0001) |
| | Semiconductors | (1) | 0.9841*** | (0.0426) | 0.0021 | (0.0034) | | | | |
| | | (2) | 1.0214*** | (0.0229) | 0.0157** | (0.0064) | -0.0108*** | (0.0031) | | |
| | | (3) | 1.0209*** | (0.0218) | 0.0158** | (0.0063) | -0.0104*** | (0.0031) | -0.0004 | (0.0003) |
| | | (4) | 0.5819*** | (0.1452) | 0.0060 | (0.0039) | -0.0038** | (0.0018) | 0.0002 | (0.0001) |
| | Memory/Microproc | (1) | 0.9119*** | (0.0232) | 0.0064 | (0.0042) | | | | |
| | | (2) | 0.9528*** | (0.0153) | 0.0130* | (0.0076) | -0.0057* | (0.0035) | | |
| | | (3) | 0.9352*** | (0.0175) | 0.0122* | (0.0070) | -0.0049* | (0.0028) | -0.0013*** | (0.0004) |
| | | (4) | 1.0858*** | (0.1337) | 0.0025** | (0.0010) | -0.0028*** | (0.0009) | 0.0001 | (0.0000) |
| Petroleum Markets | Coal/Crude Extraction | (1) | 1.0160*** | (0.0145) | 0.0040 | (0.0028) | | | | |
| | | (2) | 1.0215*** | (0.0121) | 0.0075 | (0.0046) | -0.0014** | (0.0007) | | |
| | | (3) | 1.0255*** | (0.0125) | 0.0077* | (0.0046) | -0.0013** | (0.0006) | -0.0001** | (0.0000) |
| | | (4) | 0.7739*** | (0.2350) | 0.0007 | (0.0010) | 0.0004 | (0.0004) | 0.0001* | (0.0000) |
| | Energy Research Area | (1) | 0.9471*** | (0.0651) | 0.0057** | (0.0024) | | | | |
| | | (2) | 0.9479*** | (0.0654) | 0.0083*** | (0.0031) | -0.0013** | (0.0005) | | |
| | | (3) | 0.9512*** | (0.0669) | 0.0086*** | (0.0030) | -0.0011** | (0.0005) | -0.0002*** | (0.0000) |
| | | (4) | 0.6599** | (0.2977) | 0.0004 | (0.0005) | -0.0001 | (0.0001) | 0.0000*** | (0.0000) |
| | Petroleum Refining | (1) | 1.0111*** | (0.0112) | 0.0014 | (0.0018) | | | | |
| | | (2) | 1.0143*** | (0.0104) | 0.0041 | (0.0032) | -0.0009** | (0.0005) | | |
| | | (3) | 1.0137*** | (0.0100) | 0.0038 | (0.0030) | -0.0007* | (0.0004) | -0.0009*** | (0.0002) |
| | | (4) | 0.7043*** | (0.2035) | 0.0006 | (0.0007) | -0.0002* | (0.0001) | 0.0000 | (0.0000) |

Regressions include year fixed effects. Lagged patent stock is used as an IV for lagged market share in specifications (1)-(3). Specification (4) controls for firm fixed effects following Arellano and Bond (1991). Robust standard errors clustered at the firm-level are in parenthesis. *** indicates signficant at the 1% level; ** at the 5% level; and * at the 10% level.

Table 6: 2SLS Market Share Regressions

## 7.2 Robustness Checks

Our first robustness check considers that, in our descriptive framework including controls for observable industry, RJV, and firm characteristics may not be sufficient as there may be unobserved firm- or RJV-specific factors that affect the value of entering a RJV. To determine if this impacts our results, we estimate a number of fixed effects logit models of the decision to enter a RJV.[66] We present the results for the "Without R&D" specification for the primary measure of market power (i.e., the counterpart to the results reported in the top panel first column of each market definition in Tables (2) - (4)). Table 7 includes the total effect of the leniency policy across market definitions for a logit regression without fixed effects (for comparison), with RJV fixed effects, and with firm fixed effects. The total effect of the revised leniency policy does not change when firm and RJV fixed effects are included, where the effect is significant and negative across almost all specifications. Furthermore, for most specifications, the magnitude of the total effect does not change significantly, although in some instances the total effect is higher when fixed effects are included. These results indicate that our findings are robust to inclusion of firm and RJV fixed effects.

Second, we conducted a "placebo" test of whether we would conclude that the leniency policy revisions had a significant negative effect on RJV formation if we incorrectly assigned the year of the policy change. For all market definitions we assigned placebo leniency years for the three years surrounding the correct leniency policy revision. For the telecommunications industry there was no effect of the placebo policy during any year or market definition with the exception of the broadly defined 3-digit telecommunications RA. The placebo policy change had a very small effect (on average a 2% drop in RJV formation over the placebo years) for the telecom RA, although the effect was statistically significant. This result suggests the telecom RA is not an appropriate market definition, but it is one of many and is the least preferred for other reasons as mentioned in previous sections. For the computer industry, there was no negative effect of the placebo policy for any years or market definitions.[67] For the petroleum industry there was no effect of the incorrect leniency policy change for any market definitions or years.

[66] Due to the "incidental parameters problem," a fixed effects probit regression will not give consistent estimates of the parameters. The logit does not suffer from this problem. See Greene (2000) for a discussion.

[67] A couple of years generated a positive effect for some broadly defined market definitions via the RJV-market-power and placebo-leniency interaction parameter.

| Industry | Market Definition | Included Fixed Effects | Total Effect of Leniency Policy | Wald Statistic | P-Value |
|---|---|---|---|---|---|
| Telecom | Research Area | None | -0.001** | 8.784 | 0.012 |
| | | RJV | -0.009*** | 38.020 | 0.000 |
| | | Firm | -0.024* | 5.488 | 0.064 |
| | Broadcast | None | -0.011*** | 13.420 | 0.001 |
| | | RJV | -0.019** | 9.233 | 0.010 |
| | | Firm | -0.039 | 3.088 | 0.213 |
| | Wired | None | -0.018** | 7.505 | 0.024 |
| | | RJV | -0.026 | 4.140 | 0.126 |
| | | Firm | -0.036 | 1.342 | 0.511 |
| | Long Distance All Years | None | -0.038 | 1.852 | 0.396 |
| | | RJV | -0.593 | 4.171 | 0.124 |
| | | Firm | -0.076 | 0.722 | 0.697 |
| | Long Distance Regulated | None | -0.001*** | 16.060 | 0.000 |
| | | RJV | -0.370*** | 144.700 | 0.000 |
| | | Firm | -0.032*** | 36.980 | 0.000 |
| Computer | Computer/Electronic | None | -0.001*** | 26.790 | 0.000 |
| | | RJV | -0.034*** | 36.360 | 0.000 |
| | | Firm | -0.017** | 19.520 | 0.000 |
| | Software Research Area | None | -0.001*** | 23.480 | 0.000 |
| | | RJV | -0.080*** | 95.790 | 0.000 |
| | | Firm | -0.167*** | 16.690 | 0.000 |
| | Computer Manufacturing | None | -0.003** | 9.225 | 0.010 |
| | | RJV | -0.547*** | 391.000 | 0.000 |
| | | Firm | -0.040*** | 17.050 | 0.000 |
| | Semiconductors | None | -0.001*** | 12.330 | 0.002 |
| | | RJV | 0.000 | 0.112 | 0.946 |
| | | Firm | -0.005*** | 10.300 | 0.006 |
| | Memory/Microproc | None | -0.002*** | 9.751 | 0.008 |
| | | RJV | -0.016 | 2.287 | 0.319 |
| | | Firm | -0.009** | 8.416 | 0.015 |
| Petroleum | Coal/Crude Extraction | None | -0.023*** | 27.130 | 0.000 |
| | | RJV | 0.473 | 2.014 | 0.156 |
| | | Firm | -0.011* | 5.719 | 0.057 |
| | Energy Research Area | None | -0.003* | 5.238 | 0.073 |
| | | RJV | -0.004 | 0.065 | 0.968 |
| | | Firm | -0.574*** | 49.000 | 0.000 |
| | Petroleum Refining | None | -0.028** | 7.976 | 0.019 |
| | | RJV | -0.144*** | 9815.000 | 0.000 |
| | | Firm | -0.084*** | 14.740 | 0.001 |

Results are reported for the "Without R&D Effects" specifications using the primary measure of the RJV measure of mark
All regressions include same controls as in main specification including year dummies (and industry dummies for researc

Table 7: Fixed Effect Logit Results

Third, the estimates presented in the results section address potential serial correlation in the errors by clustering. An alternative way to limit the effects of potential serial correlation is to run the regressions in a tighter window around the leniency policy. We estimated the regressions using only data from 1991 to 1997. The results from this robustness check do not change in sign or significance, although the total effect of the leniency policy revision is smaller in magnitude for the 3-digit Computer market definitions and the Computer Manufacturing market definition. Not surprisingly, given the restricted sample, the significance values are lower. The results suggest that the negative impact of the leniency policy on RJV formation is not an artifact of the sample period.

Finally, to examine if our results are sensitive to limiting the set of RJVs which firms can enter (by considering specific markets), we estimated our model using a pooled sample of firms across all industries. Constructing a sample that consists of all possible firm-year-RJV combinations in all industries yields a dataset of unmanageable size. Therefore, we restricted our analysis to firms with complete Compustat data that joined a RJV (in a given year) and a random sample of firms that did not join (in a given year).[68] Our pooled sample consists of 1,651 firms yielding 13,399 firm years and 133,654 firm-year-RJV observations. Firms in the pooled sample undertake more R&D and have more assets, free cash, and sales than an average Compustat firm. Market concentration at the 6-digit NAICs is higher (0.280) than at the 3-digit level (0.082).

Table 8 presents the results for the pooled sample across all 3-digit industries for both R&D effects specifications. Columns (1) and (4) include the post leniency policy revision and its interaction with the RJV market power as regressors, for the Without R&D and With R&D Effects, respectively. The results suggest that, holding industry, firm, and RJV characteristics constant, the revision of the leniency policy resulted in a significant reduction of the probability a firm joins a RJV in the set of available RJVs open to the firm regardless of industry. The total effect of the leniency policy is to reduce the probability of joining by 1.5 to 4%, although the reduction is larger for RJVs among rivals (Columns (3) and (6)) where it is 2 to 5.5%. The total effects are all significantly negative at the 1% level. When the leniency policy indicator is interacted with the fragmentation measure of RJV market power, in columns (2) and (5), the results indicate the leniency policy level effect is significant and negative, but the interaction is significant and positive resulting in an overall positive effect of the leniency policy. The impact is not significant at the 1% level and the magnitude is also small $(1 - 2\%)$. One potential problem in interpreting the across all industries results is that the RJV measure of market power differs across industries and is of a similar magnitude within industries. Hence, while industry fixed effects are included as

[68] As our selection criteria is whether a firm joined a RJV there may be concern about sample selection bias. However, selection bias is mitigated due to the panel aspect of our data. That is, since the data are a firm-RJV-year panel, a firm will potentially have a number of years in which it does not join a RJV, and a number of years during which it could potentially join (i.e., other members of its industry have joined) but it does not. Hence this firm is included among joiners in some years and non-joiners in others. In many ways the estimation strategy is to estimate a panel of the probability of joining but to include those firms that never join to allow for systematic differences between the two groups.

control variables, it may still be that the RJV market power effects are reflecting differences across industries in RJV market power. Furthermore, differences across industries (such as the degree of product homogeneity, the presence of many dispersed customers, etc.) may influence the feasibility or the optimal structure of the partial cartel. These points further motivate the necessity to examine firm behaviors within more narrowly defined markets. However, the exercise is useful as it presents an overall picture which is consistent with our industry-specific results in that the effect on average is negative and significant, which suggest our industry-specific findings are not due to a limiting of the potential choice set of firms.

| Specification: | Without R&D Effects | | | With R&D Effects | | |
|---|---|---|---|---|---|---|
| Sample: | All | All | Treatment | All | All | Treatment |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Post Leniency Policy Dummy | -0.178*** | -0.247** | -0.171*** | -0.113* | -0.195* | -0.108* |
| | (0.0645) | (0.126) | (0.0655) | (0.0580) | (0.115) | (0.0591) |
| RJV HHI | 0.717*** | | 0.655*** | 0.645*** | | 0.582*** |
| | (0.0726) | | (0.0759) | (0.0711) | | (0.0719) |
| RJV HHI*Post Leniency | 0.331*** | | 0.292*** | 0.301*** | | 0.266*** |
| | (0.0774) | | (0.0781) | (0.0716) | | (0.0704) |
| RJV HHI Fragmentation | | -0.716*** | | | -0.629*** | |
| | | (0.0872) | | | (0.0795) | |
| RJV HHI Fragmentation*Post Leniency | | 0.296** | | | 0.276** | |
| | | (0.128) | | | (0.114) | |
| Total Effect of Leniency Policy | -0.0008*** | 0.0002* | -0.0011*** | -0.0003*** | 0.0004** | -0.0004*** |
| Wald Test Statistic | 19.57 | 5.450 | 15.54 | 17.84 | 6.960 | 14.50 |
| P-Value | 0.0001 | 0.0655 | 0.000422 | 0.0001 | 0.0308 | 0.0007 |
| Observations | 222059 | 222059 | 146458 | 166916 | 166916 | 112747 |

Notes: Robust standard errors clustered by firm are in parenthesis. An observation is a firm-rjv-year combination. All specifications include the usual controls plus industry dummies. Total effect is computed at the mean of the regressors. * indicates significant at 10%; ** at 5%; *** at 1%.

Table 8: Estimates for Join a RJV for Pooled 3-Digit Industries

# 8 Conclusion

This paper examines an important and relatively unexplored issue: Do research joint ventures serve as a collusive device? RJVs allow for easy communication among partners, and members are granted antitrust protection. It is possible that permitting firms to legally collude in R&D may facilitate illegal collusion in the final goods market. If this is the case, firms may undertake RJVs for anticompetitive reasons with possible negative social welfare repercussions. The question of whether collusive intensions may be facilitated by RJVs has not been addressed in the empirical literature, and this paper fills this gap.

To separately identify the intention to collude from other (legal) reasons to form a RJV we take advantage of a shift in antitrust policy which made product market collusion more difficult to sustain. We exploit the variation in RJV formation generated by a revision to the leniency policy that effects the collusive benefits of a RJV but not the research synergies associated with that venture.

We examine RJVs in three industries with a history of antitrust litigation that are characterized by high multi-market contact via RJVs: telecommunications, computer manufacturing, and petroleum refining. We find that the leniency policy revision has a significant negative effect on the probability of joining a RJV in telecommunications and computer industries across market definitions. The results are robust to a variety of modifications and specifications. Our findings are consistent with collusive behavior on the part of telecommunications firms (particularly over the years of telecom regulation) and computer manufacturers. We also find support for collusive behavior among petroleum refiners. Our results indicate the revised leniency policy reduces the average probability that telecom firms join a given RJV by 34%; the reduction among computer and semiconductor manufacturers is 33%; and among petroleum refiners the probability decreases by 27%. Furthermore, our findings show that the higher the market power of the RJV the more collusive potential it has, which generates a differential effect of the leniency policy on the probability of joining a RJV. To the extent that antitrust authorities wish to detect and prohibit collusion brought about through RJV formation, our results suggest they should be more concerned when RJVs have a high joint market share relative to industry concentration.

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